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Comparison of conservation technologies and identification of best practices

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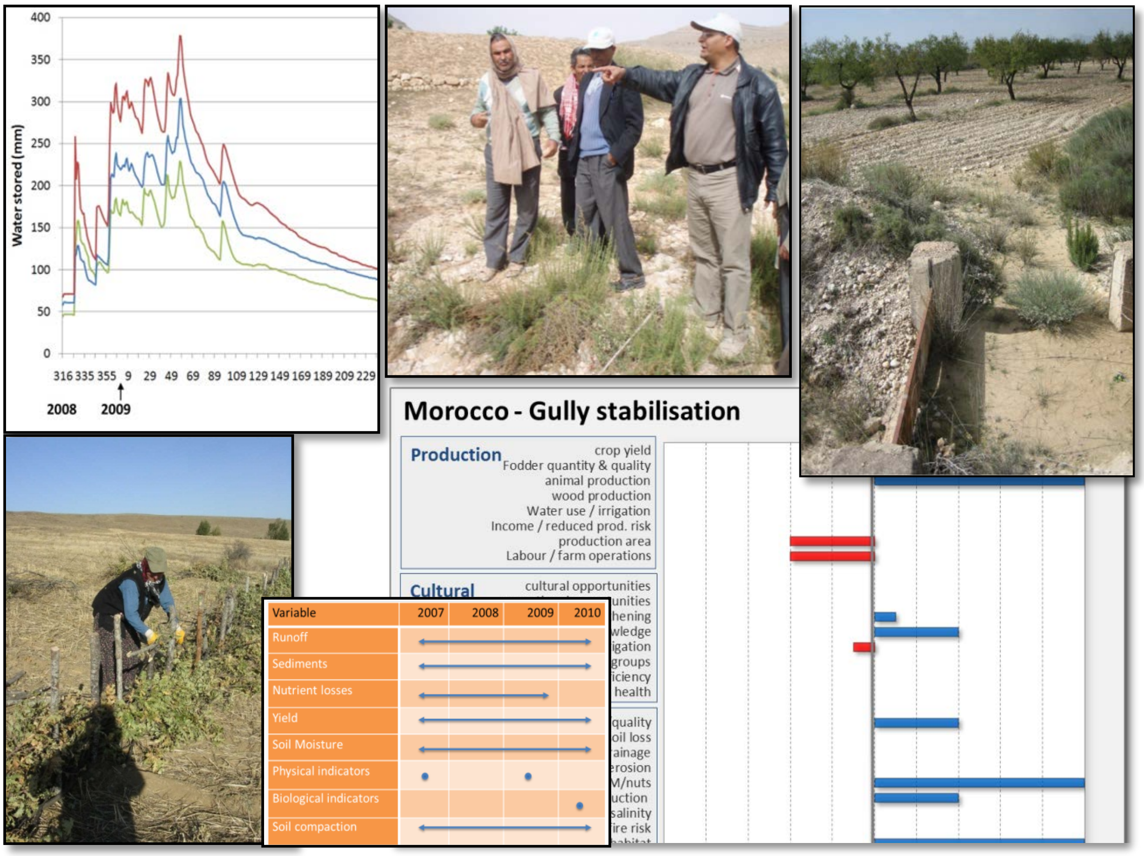
WB4 – Comparison of conservation technologies and identification of best practices



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1 COMPARISON OF SLM TECHNOLOGIES AND IDENTIFICATION OF BEST PRACTICES

This report is the deliverable 4.5.1 of Work Package 4.5 of the DESIRE project: a comparison of conservation technologies across sites and possible identification of best practices. This document is based on the results as described in deliverable 4.3.1 (report and annex) which describes the site results in detail[1].

1.1 MAIN OBJECTIVES

The objective of this part of the project (Work Block 4) is to test the effectiveness of the conservation and mitigation measures selected by the stakeholders in an interactive series of meetings following the WOCAT system (Work Block 3). While this report compares the results between sites and draws more general conclusions, it is, strictly speaking, not an exercise in upscaling. Work Block 4 analyzes and discusses results at a “stakeholder scale”, i.e. the level of a field or a farm. The upscaling to the entire site is done in Work Block 5. However, implications for a wider application of a technology will be discussed on the basis of stakeholder input and discussions where available. In a way, the comparison of field results in different sites that is done in WB4 is also upscaling, but not in the sense of applying measures in larger areas. Rather, general lessons are drawn from field tests under different circumstances.

The technologies implemented in WB4 have two main goals: mitigate the biophysical problems from desertification processes, and at the same time improving the situation/livelihood for the stakeholders. While the first goal is needed to avoid further environmental degradation, the second is imperative to make a technology acceptable. One cannot do without the other. This immediately results in the following ‘boundary conditions’:

- The experiments must be directly visible and executed on a stakeholder level (field scale);
- The results, good or bad, must be made clear both as scientific analysis, and also translated for non-experts;
- Stakeholders will not gamble with their income, so the technologies selected by them are ‘proven’ technologies and while mostly new to the site itself, they are in most cases not innovative.

Based on their personal situations and the available experience and knowledge of themselves and the scientific terms, stakeholders selected between 1 and 3 conservation technologies to implement in their area. One or more farmers were willing to host a series of field trials. These trials were designed as much as possible as a comparative study: two or more adjacent fields or plots where usual farm practices are compared to a conservation technology. There are variations on the theme: for some desertification situations some situations do not warrant such a setup, such as forest fires, testing a biogass installation, or rangeland resting for instance.

The experiments were done according to Site Implementation Plans (SIP), which are described in deliverable 4.1.1 of this project. The SIPs were made to ensure a homogenation of the trials so that results are comparable as much as possible. This was followed by a period of 2 – 3 years of monitoring on each site. The *effectiveness* of the experiments can be approached from two viewpoints:

[1] In order to make this report readable as a stand alone document, some of the methodology described in deliverable 4.3.1 is repeated here.

1) A bio-physical scientific viewpoint: how are desertification processes altered by the experiment and what does that imply for desertification as an environmental problem. Conclusions of this are based on the experimental measurements, monitoring activities and (in part) on the experience of the scientific teams.

2) A stakeholder viewpoint: how are the technology *evaluated* by the stakeholders in terms of their personal and local context. Conclusions are based on an extensive questionnaire where changes brought about by these experiments are evaluated from an economical, socio-cultural and also bio-physical viewpoint. Also pertinent remarks about the results are taken into consideration.

The experiments are categorized related to the WOCAT system: World Overview of Conservation Approaches and Technologies (http://www.wocat.net). In this context, Workblock 4 focusses on the monitoring and evaluation of SLM *technologies*, defined as "agronomic, vegetative, structural and management measures that prevent, mitigate or rehabilitate land degradation and enhance productivity in the field". Technologies are embedded in wider strategies of implementation called *approaches,* defined as "ways and means of support that help to introduce, implement, adapt and apply soil and water conservation technologies on the ground". The emphasis in this report is on the technology level, although where possible important factors to be taken into consideration on an approach level are mentioned where possible. WB5 deals with an integrated site approach through modeling.

1.2 BRIEF OVERVIEW OF DESERTIFICATION PROBLEMS

The three major desertification processes in the sites are soil erosion by water, water stress/drought and overgrazing. While erosion is more a long term problem, which a farmer might experience as a slow decline of fertility or a process that renders fields unusable because of gullying, drought is a much more acute problem. Thus soil erosion is not often directly experienced as a problem, while water shortage leads immediately to yield loss/failure or a decline of grazing capacity. Overgrazing is also a long term problem with strong social and economic drivers but in the project rangeland appeared to be quite resilient in terms of restoration when left alone. Thus the term long term or short term is difficult to apply here. Soil erosion, however, has added consequences downstream (or off-site) such as siltation of channels and ponds/dams. Another group of technologies that was also investigated in this project are conventional technical solutions such as furrow and sprinkler irrigation systems; these do not always work or are applied wrongly (Nestos basin, Russian sites), causing water logging, salinization and even erosion my excessive surface irrigation leading to runoff. Lastly a group of technologies are investigated that indirectly combat desertification: a biogas installation to conserve fuel wood in Botswana, and solutions to combat forest fire and a direct loss of biomass/biodiversity and long term problems of soil erosion.

Table 1 gives an overview of the desertification problems and the locations that are investigated, summarized in one sentence. More detailed information about the sites can be found on the HIS (www.desire-his.eu).

Nr	Site	Desertification processes
1	Spain - Guadalentin Basin, Murcia	Drought, Soil erosion by water
2a,b	Portugal –Mação & Gois	Forest fires, vegetation degradation, soil erosion
3	Italy - Rendina Basin(*, Basilicata	Soil erosion by water, dam siltation
4a,b	Greece - Crete	Soil erosion by water, overgrazing
5	Greece - Nestos Basin, Maggana	Salinisation, irrigation problems
6	Turkey - Konya Karapinar Plain	Soil erosion by wind, drought, grazing problems
7	Turkey - Eskisehir Plain	Soil erosion by water
8a,b	Morocco - Mamora/Sehoul	Soil erosion by water, gullying, drought
9	Tunesia - Zeuss-Koutine	Drought, competition for scarce water resources, rangeland degradation
10	Russia - Djanybek	Water logging caused by over irrigation, salinization in depressions
11	Russia - Novij, Saratov	Water logging and leaching of chemicals, caused by over irrigation, erosion caused by flow irrigation
12	China - Loess Plateau	Soil erosion by water
13	Botswana - Boteti Area	Fuelwood depletion causing envir. degradation
14	Mexico - Cointzio catchment	Soil erosion by water, dam siltation.
15	Chili - Secano Interior	Fertility and mono culture leqading to envir. Degradation, soil erosion by water, gullying
16	Cape Verde - Santiago Island	Soil erosion, drought, flash floods, dam siltation.

Table 1. Brief descriptions of the bio-physical aspects of desertification on the sites. For more information see: www.desire-his.eu. Note that the numbering is not logical, but in line with the original project Description of Work, and maintained throughout the project.) site 3 (Italy) did not contribute directly to WB4 because the stakeholders did not cooperate and technology trials were not done, instead this site contributed to WB2 (designing new indicators) and WB5 (large scale analysis).*

1.3 WB4 STRATEGY AND IMPLEMENTATION

The implementation of work block 4 follows a strategy that aims to create some unity in a wide range of bio-physical and socio-economic settings, which consists of 5 phases:

1) Selection of suitable SLM technologies in work block 3, and collection of background data, information from previous experiments and general site information.

2) Design phase (W 4.1): each study site makes a detailed *Site Implementation Plan* (SIP) according to a general blueprint provided by the WB coordinator (partner 21). The SIP provides a summary of the situation on the monitoring locations, followed by a practical implementation of the SLM technologies, a detailed monitoring activity plan divided in several categories. The compiled SIPs are the subject of this report, deliverable 4.1.1.

3) Implementation phase (WP 4.2): each study site collects background data and implements the SLM technologies. During the implementation practical adaptations were sometimes made by the site coordination team in discussion with the stakeholders, to better fit the circumstances. This happened in site 6 (Turkey, Eskisehir area) where sloping terraces with vegetation barriers were created, instead of fully constructed level terraces. Also in site 8, Morocco, olive plantations were not realized because the long term investment could not be met. Instead gully stabilisation with planting of natural vegetation was done.

4) Monitoring phase (WP 4.3): each site reports regularly based on the variables and situations described in the SIP. To help in deciding which monitoring techniques to apply, a document was compiled called "Guidelines for field assessment" (deliverable 4.2.1). The monitoring can be categorized into several types of monitoring: meteo data, one time measurements, regular observations and photos, regular measurements with equipment or sampling, stakeholder activities and yield analysis. An overview of measurement and monitoring equipment is given in deliverable 4.1.1.

5) Analysis (WP 4.4/4.5): the analysis is done on various levels. The experimental setup provides for a "non-treated" field or plot against which the effect of the technologies is compared. *Bio-physical analysis* is done by direct data analysis and statistics. Socio-economic analysis is done by means of an extensive questionnaire from the WOCAT system (explained below). These results are published as deliverable 4.3.1.

1.4 Overview and grouping of SLM technologies in DESIRE

Table 3 gives an overview of the experiments, organized according to similarity and intended function. In total there are in 33 experiments, on 16 locations. Some of these are directly comparable because the same technology is done on more than one site, others are grouped based on a similarity of what they aim to achieve. This leads to 7 groups for which the experiments are compared (see table 2).

#	Functional group	Description	Sites
1	Minimum Tillage	Minimum and no tillage experiments with and without additional agronomic operations such as herbicide control and deep ploughing	Spain, Chile, Morocco, Greece (Crete), Turkey (Karapinar)
2	Soil cover management	Mulch and stubble mulch, Green cover and green manure, crop rotation and intercropping to promote cover and have additional production	Greece (Crete), Spain, Turkey (Karapinar), Chile, Mexico
3	Runoff control	Contour ploughing and runoff barriers (wicker fences), gabions in gullies. Terracing also controls runoff but these are grouped under water harvesting,	Turkey (Eskesehir), Cape Verde, Spain
4	Water harvesting	Runoff water harvesting systems with and without terraces, bench terraces and check dams	Spain, Tunisia, China, Cape Verde
5	Irrigation management	Fresh water irrigation and drip irrigation for salinity control	Greece (Nestos), Russia (Dzhanybek, Novy)
6	Rangeland management	Fencing and set aside of rangeland, also gully control with fodder species, also biogas to conserve fuelwood.	Morocco, Tunisia, Botswana
7	Forest fire management	Techniques to combat forest fire	Portugal

Table 2. Experiments organized in functional groups, according to their intended effect on desertification processes.

Many experiments serve a dual purpose, such as runoff control that increases infiltration and therefore increases water availability, gully planting with fodder type species, or crop rotation to promote fertility and soil cover. Often one of these purposes has a more agronomic context (promoting a higher yield) while the other combats a desertification process.

		1	2			3		4			5		6			7
Site number		Minimum tillage	Mulch / residue /stubble	Green cover	Rotation/crop type	Contour ploughing	Woven fences/runoff control	Water harvesting	Terrace (bench)	Check dams	Fresh water irrigation	Drip irrigation	Gully control/Fodder	Rangeland management	Biogas	Fire break/prescribed burning
1	Spain	X	X	X		X		X								
2	Portugal															XX
4	Greece Crete	X1		X1										X		
5	Greece Nestos										X					
6	Turkey Karapinar	X	X													
7	Turkey-Eskisehir					X	X									
8	Morocco	X1	X1										X			
9	Tunisia							XX						X		
10	Russia Dzhanybek											X				
11	Russia-Novy											X				
12	China								X	X						
13	Botswana														X	
14	Mexico	X			X								X			
17	Chile	X			X	X	X									
18	Cape Verde						X1		X1							

Table 3. (1) Minimum tillage; (2) Soil cover management; (3) Runoff control; (4) Water harvesting; (5) Irrigation management; (6) Rangeland management and fodder production; (7) Forest fire management.

1.5 EVALUATION METHODOLOGY

Bio-physical analysis

The monitoring strategy in WB4 allows a direct comparison with (normalized) time series of for instance soil moisture or sediment loss. Variables are generally soil physics related (moisture related) or chemistry related (fertility and salinity). Crop yields are measured for arable farming and vegetation density and quality are measured for rangeland type environments. Also the sites that focus on a catchment level (such as the forest fire analysis in Portugal) will use catchment results to draw conclusions. More extensive reports about the experiments are given in the annex of Deliverable 4.3.1.

Socio-economic analysis

Bio-physical effects only make sense within the context of a site. An increase of 30 mm of soil moisture per year may be significant in one setting where for instance the grazing capacity and fodder quality is increased, but not enough in another setting which depends on certain crops. This depends on many specific details, environmental, economic and socio-cultural.

The WOCAT system provides the users with a questionnaire to evaluate a technology (QT): http://www.wocat.net/en/methods/case-study-assessment-qtqa/questionnaires.html. QT addresses the following questions: what are the specifications of the Technology, where is it used (natural and human environment), and what impact does it have. The last section (QT chapter 3 - impact), is used in WB4 to evaluate the experiments. The WOCAT QT follows the logic that a technology is compared to an untreated reference situation. By means of a large series of questions the benefits and disadvantages with respect to the 0-situation are appraised. These effects are evaluated in 4 levels of change: 0-5%; 5-20%; 20-50% and >50% (decrease or increase). This is done in 4 classes for positive and 4 categories for negative effects: production & socio-economic, socio-cultural ecological and off-site effects. In total there are therefore 8 tables. Figure 2 shows a fraction of such a table.

These lists were used to create 59 questions that can be scored as positive or negative (for instance: ‘increase in crop yield’ and ‘decrease in crop yield’ becomes ‘crop yield’ that can be scored with +20 or for instance – 5. The questionnaires were filled in by the site coordination themes, as many of the questions are very specific and require a specialist background, especially to quantify the level of change. However the teams had many discussions with the stakeholders during and after the experiments so we feel the evaluation is not biased towards one or the other experiment. In several cases the results of the experiments were counterintuitive or disappointing, and this was noted objectively.

In order to generalize the evaluation results further, the questions were grouped so that for each of the 4 category 3 factors remained (12 in total, see table 4). The scores given by the sites (-50, -20, -5, 0, 5, 20, 50) were summed for each of the 12 factors. Table 4 also shows the questions that contribute to each of the factors. Although some factors have many more questions than others, in practice often no more than 4 questions were really judged because a single technology does not influence all of the questions. It was therefore assumed that the maximum effect that could be scored by a factor was 50% increase or 50% decrease for 4 questions. It was furthermore assumed that the answers to the different questions can be added up, which might not be true. However, such an assumption is needed to be able to evaluate the technologies. In other words a technology could have a theoretical effect of -200% (disadvantage) or +200% (benefit) relative to the unmitigated situation. This allows us to calculate an average success rate for each factor: if e.g. yield is +50% and production risk is +20%, the average effect would be calculated as (50+20)/200 = +35%.

Production and socio-economic	
Production	*crop yield*
	fodder production
	fodder quality
	animal production
	wood production
	risk of production failure
Irrigation/Domestic Water	*household water*
	livestock water
	irrigation water
	irrigation demand
Income/labour/maintenance	*agricultural expenses*
	farm income
	diversification income sources
	product diversification
	production area
	labour constraints
	work load
	simplified farm operations
	(bio) energy generation

Socio-cultural	
Opportunities	Cultural opportunities
	recreational opportunities
Comm. Strengthening	institutional strengthening
	conservation knowledge
	conflict mitigation
	situation disadvantaged groups
Situation/health	food security/self sufficiency
	health

Ecological	
Water Quan/Qual	*available water/ soil moisture*
	watr quality
	evaporation
	drainage
	groundwater
Erosion/degradation/salinity	*surface runoff*
	hazard susceptibility
	wind erosion
	soil loss
	crusting/sealing
	compaction
	salinity
Biomass/Org.Mat./Cover	*soil cover*
	biomass
	nutrient cycling
	soil org. mat.
	reduced competition (water, sunlight, nutrients)
	fire risk
	biodiversity
	invasive species
	Increased competition (water etc)
	beneficial species
	biological pest control

Off-site benefits	
Water	*increased water availability*
	reduced flooding
	increased streamflow
Siltation/polution	*reduced downstream siltation*
	reduced groundwater / river pollution
	buffering capacity
	reduced wind transported sediments
Border conflicts	*reduced damage fields*
	reduced damage infrastructure
	reduced grazing other areas

Table 4. WOCAT-QT questionnaire to judge the effect of a technology. The left hand column are the main factors (three for each of the 4 categories), the right hand column are the original questions.

2 RESULTS PER TECHNOLOGY GROUP

2.1 Minimum Tillage

Theory

In conventional cultivation practice soil is tilled to manage crop residues or kill weeds in order to provide a good environment for seeds and roots and also to facilitate the infiltration of water (Encyclopaedia Britannica Online). But intensive tillage tends to break down soil structure to such an extent that it becomes susceptible to crusting and impeding water intake thus making the soil vulnerable to erosion. Conventional tillage can also cause compaction below the plough zone because of the repeated use of heavy machinery. Occasionally 'deep ploughing' with a non-turning plough is needed to break this layer, but compacted pieces of soil remain in the soil for a long time.

Because of this reason the concept of minimum tillage has received much attention. In minimum tillage the soil surface is broken to seed the crops without further tillage operations. In this system crop residues from previous harvest are left in the fields to minimize soil erosion. In no tillage the soil is left relatively undisturbed, only a narrow seedbed is prepared or holes are drilled for planting the seeds (direct drilling). The idea is to minimize disturbances to soil through cultivation practices and restore a natural soil structure.

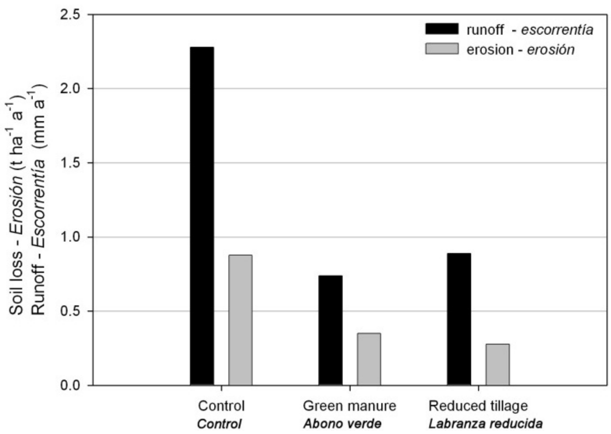
Thus minimum tillage or no tillage is primarily used as a means to protect soils from erosion and compaction, to conserve moisture through reduced evaporation and reduce production costs (Lampurlanés, Angás et al. 2002; Holland 2004). Minimum tillage can be considered very important in cultivation practices especially in semi-arid areas of the world where evapotranspiration often exceeds precipitation. Minimum tillage practice is reported to minimize erosion because of enhanced vegetative cover as compared to traditional cultivation practices in which the tilled soil is often bare during the first months of the rainy period (Astatke, Jabbar et al. 2003). No tillage or minimum tillage is also reported to be effective in carbon sequestration in the semi-arid environment (Hernanz, Sánchez-Girón et al. 2009). The increase of soil organic matter due to reduced tillage is also reported to improve soil structure due to reduced soil bulk density and increased proportion of larger aggregates (Daraghmeh, Jensen et al. 2009). Positive effects of conservation tillage on soil physical, chemical, macro and microbial conditions have been researched and reported extensively as shown by various research results (Titi 2002; Imaz, Virto et al. 2010).

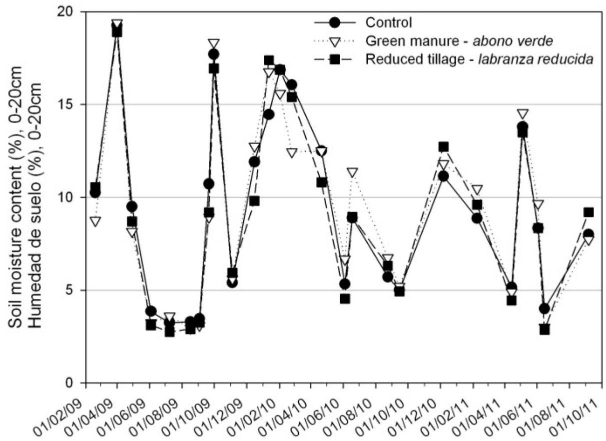
The method also has negative effects: in order to control weeds the method still requires herbicides, sometimes more than conventional tillage. Also it is used only for cereals as an irregular soil structure does not give easily harvestable root crops.

Implementation and results

Minimum tillage was applied in Spain with Wheat and in Almond orchards, in Crete under Olive trees (with and without herbicide application), in Chile with and without contour ploughing, barrier hedges and deep ploughing, and in Morocco and Turkey (Karapinar) as a single experiment. The results show that in Spain, Crete and Chile it works well, while in Morocco and Turkey the expected effects on runoff and soil moisture are negligible.

Figure 2.1.1 shows a summary of the results of Spain on sloping Almond fields. There is a clear effect on runoff and erosion, which is more than halved compared to the reference plot with conventional tillage in the 3rd year of the experiment (a total of 18 rainfall events). A stable soil structure seems to be established after a few years. There is no significant difference in soil moisture of the top 20 cm, which seems contradictory to a difference in runoff, but the soil moisture content may not reflect the incidental rainfall that caused runoff. The yields of 2009 indicate a slightly lower yield compared to the conventional plot. However the harvest of 2010 was destroyed by frost, and the inter-annual variation in yield is high, so these results should be treated with care.





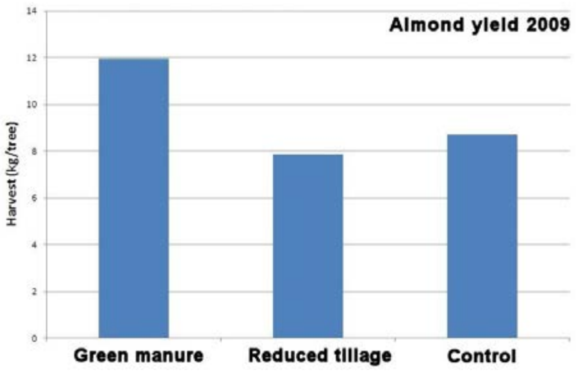


Figure 2.1.1. Spain, minimum tillage in Almond orchards: (top left) runoff and soil loss on sloping almond field with and without minimum tillage; (top right) soil moisture content in the topsoil; (left) 2009 Almond yields.

In Chile minimum tillage was combined with other expeirments described elsewhere in this report. Figure 2.1.2 shows the soil moisture contents of two of the no tillage (Nt) experiments (Nt+Sb = no tillage with sub-soiling)) compare to conventional tillage (Ct). After an initial moisture content at the same level, the entire profile is remains considerably wetter in the No Tillage experiment. Sub-soiling, i.e. deep ploughing to break the compacted layer below the plough zone, causes a decrease in soil moisture in the deepest layers but the topsoil water availability remains higher. Also here a considerable runoff decrease is visible after several years, although there is strong inter-annual variation (figure 2.1.3). Sub soiling is needed to alleviate the compaction and its effect shows in the yield: in the first year of the study (2007), oat grain yield and biomass production of Nt+Sb was significant (p<0.01) higher than the rest of the treatments, while Nt+Cp and Nt obtained the lowest productivity. In 2008, (more humid year) the highest wheat productivity was observed in the Nt+Sb and Ct treatments, and the lowest in Nt. Finally, in the third year oat crop production was higher in the Nt+Sb, Ct and Nt+Bh treatments compared to Nt.

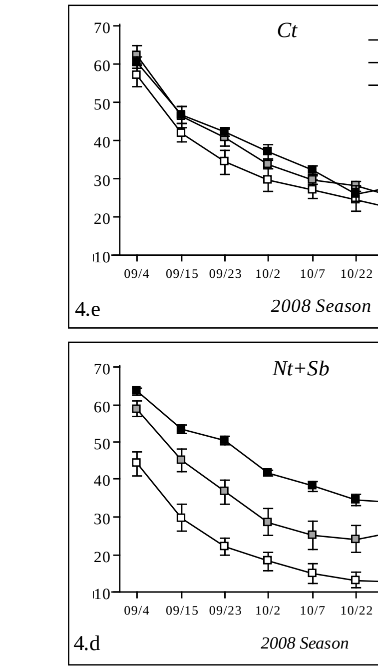


Figure 2.1.2. Chile Soil water content (SWC) at 10-30, 30-50, and 50-70 cm layer, during 2008 season. (top left) conventional tillage; (top right) No tillage; (left) No tillage and sub-soiling.

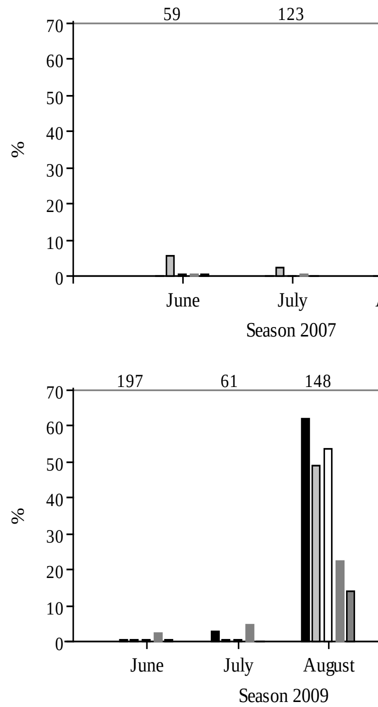


Figure 2.1.3. Chile: Runoff percentage in wet seasons of 3 years. Top axis values are rainfall amounts.
Ct = conventional tillage;
Nt = no tillage;
Nt+Sb = Nt+sub soiling;
Nt+Bh=Nt+runoff barriers;
Nt+Cp=Nt+contour ploughing

Minimum tillage in Crete was applied under Olive groves to induce soil cover and minimize runoff. The experiment was executed as minimum tillage with application of herbicides and without. The results are very similar: Total runoff amounts decreased in the first year from 44.7 mm in conventional tillage to 16.1mm for minimum tillage with herbicides and 8.8 mm without herbicides, while in the second year the values were respectively 9mm, 8mm and < 1 mm for the treatments. This means that both the improved soil structure and increased soil cover, that are both a result of minimum tillage, have strong effect.

Not all physical implications are well understood yet: farmers believe that an additional cover under Olives or Almonds may give competition for water, and this question was not satisfactorily answered.

However, in the two sites of Morocco and Turkey (Karapinar) minimum tillage with cereals has a less pronounced effect. In Morocco the experiment was on a slope but on a very stony soil (a river terrace). The stoniness prevents the seeds from entering in the soil and they get blown away by wind or eaten by birds. Direct seeding or even direct drilling is not an option under these circumstances and the topsoil has to be opened up and a seedbed must be prepared. The area was fenced to avoid grazing by roaming animals, which induced a grass/herb cover that explains the increase in biomass (see figure 2.1.4). The production was slightly higher but not sufficient to compensate for the cost of fencing. The moisture content was higher for the minimum tillage treatment but the effect cannot be separated from the grass cover and there is a strong inter-annual variation. The yield was very similar: 545 kg/ha Barley for minimum tillage, against 505 kg/ha for conventional tillage.

In Turkey the minimum tillage was tried on a flat area which is very dry and normally irrigated. Only crop related parameters were obtained here and there is no information on soil moisture unfortunately. Although there were differences in crop parameters (number of shoots, density and weight of grains) the final yield was about 500 kg/ha for both normal tillage and minimum tillage.

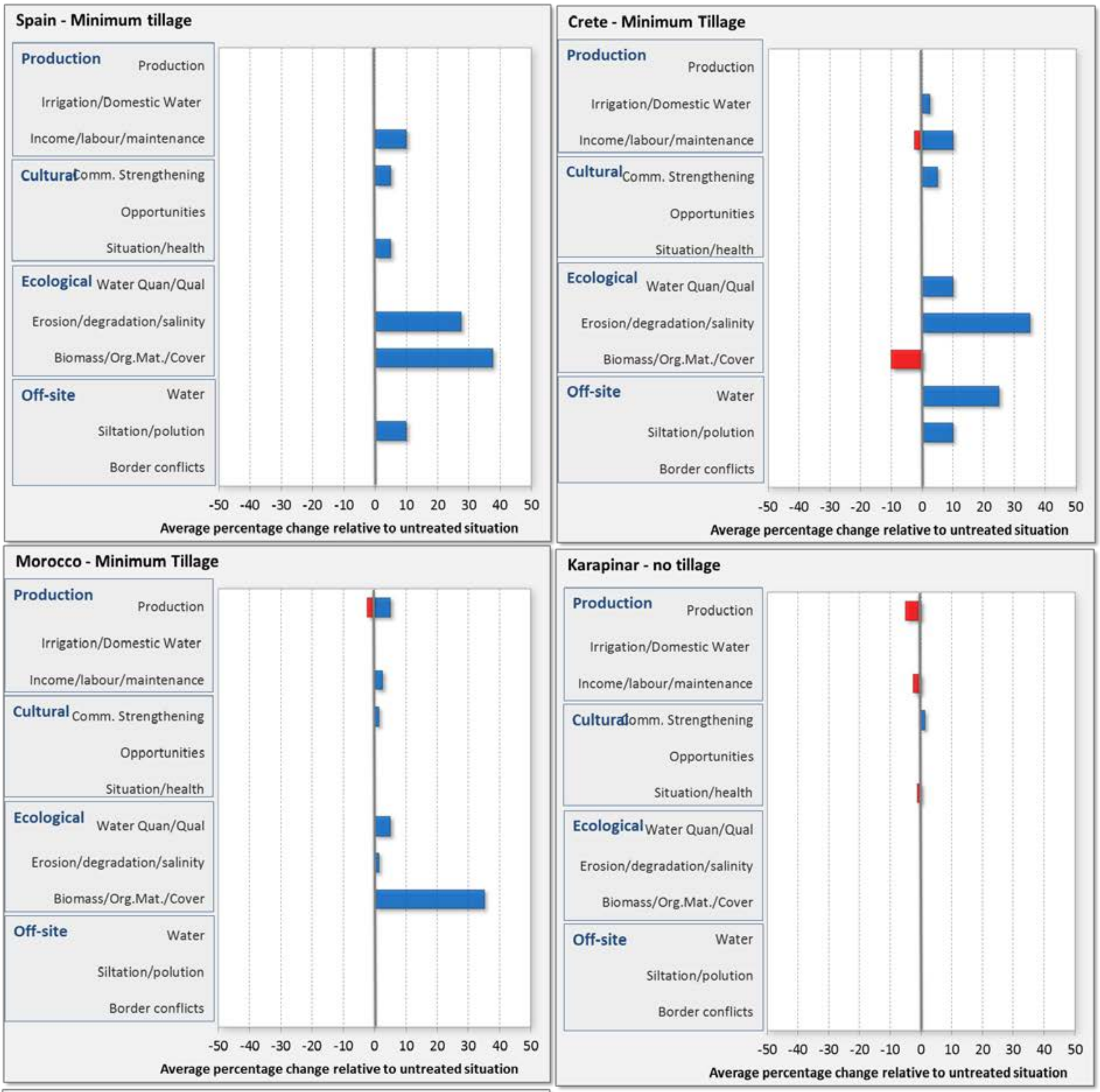
Evaluation

In figure 2.1.4 the results of the WOCAT evaluation method are summarized. The length of the bars is an indication of the performance compared to the conventional situation (in % difference). These are averages and should not be taken too literally.

In all experiments there was a slightly lower to similar yield compared to conventional tillage. The strong effects in moisture content and runoff do not directly translate to a direct benefit for the stakeholder. In view of the total farm management there are benefits and disadvantages: a drop in yield and income is experienced as strongly negative, no tillage or minimum tillage generally means lower production costs in fuel and labour, and maybe higher costs in herbicide application (depending on the situation). Whether labour is really counted depends on the social system in a country: is family involved in labour or are wages involved? In Spain the costs of minimum tillage were not much lower than the conventional system, the net profit of the Almond harvest under minimum tillage was 1208 Euro and 1284 Euro (+5%) under conventional tillage. Socially there may be constraints because a minimum tillage fields do not look clean (herb cover) and farmers may be regarded as “lazy” by the community.

The offsite effects are estimated and show the expected decrease in runoff and erosion. In how far this has a direct off site effects depends on the catchment structure position of the fields, relative to major stream channels.

These conclusions also can be seen from the evaluations: strong ecological effects, minor production effects with a negative effect in the sense of yield and a positive effect in the sense of other expenses. Community strengthening and knowledge of conservation of the community can be linked to the project and the promotion of discussion among the stakeholders.



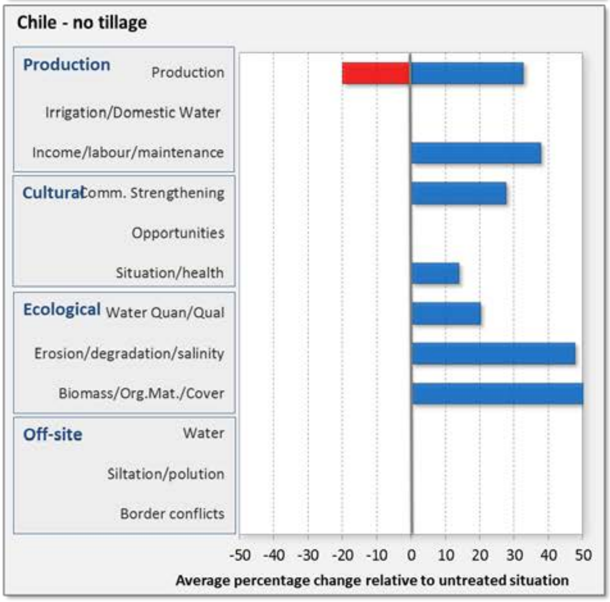


Figure 2.1.4. Summary of the WOCAT based evaluation for 5 sites on the effects of minimum tillage. Percentages are average indications of change in % compared to conventional tillage.

Conclusions

The results from the experiments show that under the right circumstances desertification mitigation processes are actually achieved: runoff is decreased and moisture content increases. In Morocco the soil is very stony and has to be ploughed to make any type of sowing feasible. The method works well in combination with other conservation practices such as increasing soil cover. Environmental effects from using more herbicides were not included in the study and unfortunately no conclusions can be drawn in that respect. The improvement of soil structure seems to become apparent already in the second year.

Figure 2.1.5. Crete: no-tillage under Olive trees, (top) no-tillage and no herbicide; (middle) no-tillage and herbicide; (bottom) conventional tillage. The difference in soil cover is clearly visible.

In spite of the relatively positive bio-physical effects, this technology is not well accepted by the farmers for several reasons:

Crop yield is usually slightly lower, although still on comparable levels with the conventional tillage methods. Thus there is a (slight) drop in income which is only positive because the expenses are less. In these expenses, however, labour is also included as a cost factor (besides lower fuel costs), but labour may not always be expressed in cash, where it concerns family labour. With this in mind the reason for doing minimum tillage would be to control erosion. The increased water availability is generally considered moderately positive but does not appear to increase yields, perhaps due to competition for water. Erosion control however also does not translate directly in yield increase and the offsite effects are not the responsibility of farmers alone. Erosion is therefore not seen as an immediate problem and that benefit does not outweigh the trouble of implementing minimum tillage. Lastly minimum tillage field look different form conventional fields, often less “clean”. The social implication is that you are a “bad” or “lazy” farmer, which is a strong negative incentive.

It is sometimes difficult to separate the costs of an experiment, for instance by fencing a plot, from real cost that would be incurred if minimum tillage was done at a larger scale, which would not involve large scale fencing. However, the wider implication is that in an area with free roaming cattle some sort of management must take place to protect minimum tillage plots from trampling.

2.2 SOIL COVER MANAGEMENT

Introduction

Soil is subjected to degradation when it is bare. Cover management practices are mainly aimed for protecting the soil against erosion, increasing fertility status and for controlling pests. Mulching and crop rotation were selected as effective technologies.

Mulching is a practice to cover the soil by plant residues, straw or leaves in order to retain soil moisture (Moitra, Ghosh et al. 1996; Sharma, Singh et al. 1998; Huang, Chen et al. 2005), to suppress weed growth and to reduce soil erosion (Li, Zhang et al. 2011). Since it retains soil moisture, it also helps in seed germination. Moreover conservation tillage in combination with crop residue mulch can play an important role in restoring soil organic carbon (Lal 2004). Of all the materials used for mulching crop residue and straw seem to be common although materials such as gravel (Nachtergaele, Poesen et al. 1998; Li 2003) and volcanic material (Tejedor, Jiménez et al. 2003) are also used.

Crop rotation is the practice of growing crops in sequence which are dissimilar in nature e.g. deep rooted crop followed by shallow rooted crop, cereals followed by tubers or legumes, etc. It helps improve soil structure and fertility(Shah, Shah et al. 2003; Blair, Faulkner et al. 2006), and in the mitigation of pests that often occurs when one type of crop is grown continuously (Govaerts, Mezzalama et al. 2006). Crop rotation also helps conserve soil and water resources as compared to traditional continuous cropping, this is shown in the research done in the Loess plateau area in China (Li, Gao et al. 2002).

Implementation and results

Mulching was applied in Spain with reduced tillage and green manure and also with mulching in almond field (Fig 2.2.1), in Greece with no tillage experiment without application of herbicide in olive field, in Turkey with minimum tillage and stubble mulch in wheat field and in Chile with crop rotation of wheat with leguminous species.

Figure 2.2.1: Experiment combining green manure and minimum tillage in Spain.

The result shows that mulching helps in reducing surface runoff and minimizing soil erosion. It also helps in increasing soil moisture and reducing evaporation loss from the surface. If mulching is applied in combination with minimum tillage it seems to be very effective. In Spain 60% reduction in soil losses is reported when mulching is applied together with no tillage (Figure 2.2.2). In Greece surface runoff is reduced by 25% and substantial reduction of soil losses is reported in the field with minimum tillage and no herbicide use (green mulch)(Figure 2.2.3 and Figure 2.2.4). In Turkey crop yield is reported to be increased by 40% in no tillage and stubble mulch experiment.

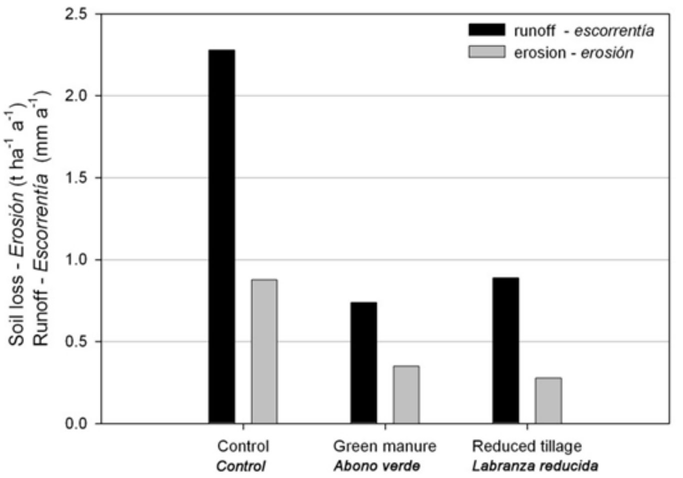


Figure 2.2.2: Mulching in combination with reduced tillage lowers surface runoff and soil losses in Spain

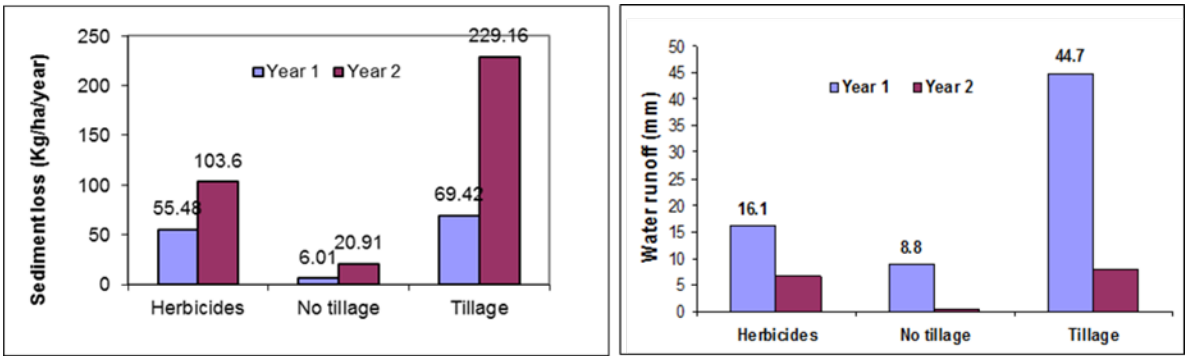


Figure 2.2.3: Minimum tillage and no herbicide application reduces substantially runoff and soil loss in Crete

Table 2.2.1: In the experiment in Mexico on Crop rotation wheat yield is decreased by almost half if no fertilizer is used, with crop rotation with leguminous species yield is reduced by about 20-40 %. The decrease of crop yield is compensated by low production costs and additional second crop (legume).

Treatments (Crop rotation)	*Phonological stage*				*Grain yield*
	Tillering	*Advanced tillering*	*Shooting*	*Grain filling*	
	------------------------------ *k ha-1* ----------------------------				
Cereal monoculture + inorganic N	*488 a*[1]	*2.469 a*	*4.177 a*	*12.970 a*	*3.328 a (100%)*
Cereal monoculture + Without inorganic N	*274 b*	*908 c*	*2.158 b*	*8.735 c*	*1.533 c (46%)*
L. luteus - Wheat	*437 a*	*1.933 ab*	*3.674 a*	*9.947 b*	*2.483 b (75%)*
L. angustifolius - Wheat	*470 a*	*2.145 ab*	*4.734 a*	*9.334 b*	*2.623 b (79%)*
P. sativum – Wheat	*463 a*	*1.470 bc*	*4.146 a*	*9.965 b*	*2.398 b (72%)*
Avena sativa – Vicia faba (green manure) - Wheat	*285 b*	*1.071 c*	*2.081 b*	*8.275 c*	*1.950 c (59%)*

Total fertilizer in cereal monoculture + inorganic N, was 350 k Urea ha^{-1}. [1]Values with different letter in columns present differences among themselves ($P \leq 0.05$) according to minimal significant difference.

Crop rotation increases diversification of farm income. Crop rotation with leguminous species and without application of fertilizers decreases wheat yield by about 20-40 % in the experiment in Mexico but the production costs is also decreased since fertilizer is not applied (Table 2.2.1). Crop rotation with leguminous species helps carbon sequestration and thus minimises greenhouse effects. It also helps improve soil conditions by increased surface cover and soil organic matter.

Evaluation

Figure 2.2.4 shows the results of the evaluation of the WOCAT questionnaire on soil cover management. Mulching helps protect soil by increasing vegetation cover and reducing soil loss. It does not increase farm income directly, but lowers production cost if green manure with leguminous species is applied since the cost of fertilizer application is saved. In case of stubble mulch it is not profitable since the stubble have to be transported from other farms, which involves transportation costs. Mulching is also evaluated to increase fire risk.

Community strengthening and knowledge of conservation of the community can be linked to the project and the promotion of discussion among the stakeholders.

Green manure is effective and feasible although it doesn't give a direct economic benefit so the acceptance is not yet very high. Stakeholders generally approve the effectiveness of the technologies tested. However the treatment includes a fallow period and the land is taken out of production which is considered very negative. In Spain the mulch would have to be purchased or collected from surrounding natural vegetation, which would mean increased labour. Moreover it does not increase the crop yield. In addition the farmers also consider the land not tidy when mulching is applied. The end result is therefore that the technology is not readily accepted because the benefits are not sufficiently clear cut. In case of crop rotation despite all the positive effects, it will still not be accepted easily by the farmers because of the main crop yield will decrease in case of no fertilizer application and due to the problem of marketing new products (legumes).

Conclusions

The effects of these measures are a protection of the soil, obstruction to runoff control and protection against direct surface evaporation, conserving water. Green cover/green manure can be used between annual crops to cover the soil during a bare period in the growing season (such as with alfalfa or mustard seed). Nitrogen rich species are used that are ploughed into the soil as extra nutrient supply and structure improvement. In a different fashion green cover can also be introduced in orchards to cover bare area between the trees, as is the case for Almonds (Spain) or Olives (Crete). On the down side the mulch may actually also intercept rainfall, while green cover can in certain situations be in competiion for water with the first crop (Almonds, Olives). The overall results of these experiments are unclear. In the first place in semi-arid environments it is not easy to get mulch, biomass is in short supply and it may even be expensive to obtain, while (at least in Spain) the results were not at all convincing. So mulch was not accepted by the farmers at all in this one case. Green manure between Almonds had some clear positive effects but this may not outweigh the extra trouble, this depends on the price you get for the harvest of this second crop. So it is market driven. Green cover in Olive groves has a clear effect in runoff and erosion mitigation, but farmers generally feared too much water competition, which could not really be disproven in DESIRE, and erosion conservation is not their first concern.

Figure 2.2.4. Evaluation of stakeholder response to WOCAT questionnaire

2.3 RUNOFF CONTROL

Introduction

In soil erosion the detached soil particles are transported by surface runoff and the runoff itself also detaches particles. The amount of soil losses is thus controlled by detachment and by the transport capacity of runoff. The SLM technologies were applied to control runoff in order to minimize soil erosion. For this purpose the selected technologies were contour ploughing and vegetative barriers (both in Turkey (Eskesehir) and Chile). The technologies involving check dams and terracing have a double function: water harvesting and runoff control.

Contour ploughing is the farming practice of ploughing across slope following the contour lines instead of ploughing up- and down the slope. This reduces the velocity of runoff while infiltration is enhanced. The technique is reported to have positive effect in soil and water conservation (Thapa, Cassel et al. 1999; Gebreegziabher, Nyssen et al. 2009).

Vegetative barriers and wicker fences places a small dyke with a wicker fence on top (from woven branches), following contour lines at given distances along the slope. These fences are easy to build and maintain and their distance should not hamper tillage practices while providing sufficient obstruction for the runoff water and sediment. The steeper the slope, the closer these barriers should be (see fig 2.3.1).

Figure 2.3.1: Turkey: contour ploughing and fencing making on small dykes following contour lines

Check dams and terracing help in controlling runoff. Terracing decreases soil loss and increases soil moisture due to increased infiltration (Schiettecatte, Ouessar et al. 2005). In the level terraces which are constructed mainly for growing rice in south and south-east Asia, the rate of percolation seems to equal average infiltration rates making the subsurface flow more prominent (Huang, Liu et al. 2003). Because of cutting and filling during construction, the outer edge of the terrace is made up of filling material making the terrace riser weak and susceptible to movement. Slope instability is common in rice fields due to increased soil moisture in the contact zone with the underlying material (parent material or bedrock) and excess weight of the level terraces (Gerrard and Gardner 2000; Shrestha, Zinck et al. 2004). The sloping inwards terraces are more effective in heavy rainfall areas whereas the outwards terraces are commonly used for rain-fed agriculture.

Implementation and results

Contour ploughing and terracing by means of making bunds is applied in Turkey (Figure 2.3.1)and does not cost so much. The experiment was carried out in order to investigate water retention and crop growth against the conventional cultivation practice. Soil moisture is reported to increase in both the technologies. Seed germination rate is also high and crop yield is increased by 3 times.

In Cape Verde vegetative barriers are used to control runoff, for this purpose pigeon peas are planted along contours (Figure 2.3.2a). The result shows that pigeon pea plantation lowers the surface area having high erosion rates (more than 10 $t.ha^{-1}.yr^{-1}$).

In China and in Mexico check dams are constructed to control runoff (Figure 2.3.2b). The result shows that the most upstream check dams capture the most sediment and help controlling runoff and gully formation. Thus selecting the suitable location for constructing the check dam is very crucial.

Figure 2.3.2. (left) Vegetative barrier helps make terraces in Cape Verde; (right) Construction of check dams in Mexico

Evaluation

Figure 2.3.3 shows the results of the evaluation of the WOCAT questionnaire on runoff control.

The result shows that contour tillage reduces runoff and increases soil moisture. Crop yield in the terrace and contour tillage plots is increased by 2-3 times probably because of high soil moisture content, also seed germination rate is better (Experiment result in Turkey). In Cape Verde the contour barrier plantation of pigeon pea helps improve vegetation cover which reduces surface runoff and soil erosion.

In China, soil moisture is reported to increase because runoff from the up-stream area is detained by the check dams. In the terraced fields, there is no erosion. In Mexico, the check dams located in the upper parts of the streams are reported to capture most of the sediments meaning that one check dam, if constructed at the right location, can control runoff and gully formation.

Terracing involves additional costs and possible loss of some land whereas contour ploughing can be widely applied without much effort. The field however has to be wide enough because contour ploughing might create many short tracks and turns of a tractor resulting in possible loss of land resulting in lower crop yield. Some training would be necessary for implementing terrace cultivation in steeper slopes. Also smaller tractors with more maneuvering capability will have to be selected for cultivating terraced land. If these are not available yet, this adds considerable cost.

The construction of check dams needs good studies especially to identify the critical locations. Check dams should be constructed starting from the upper part of the stream since they capture most of the sediments (experiment in Mexico).

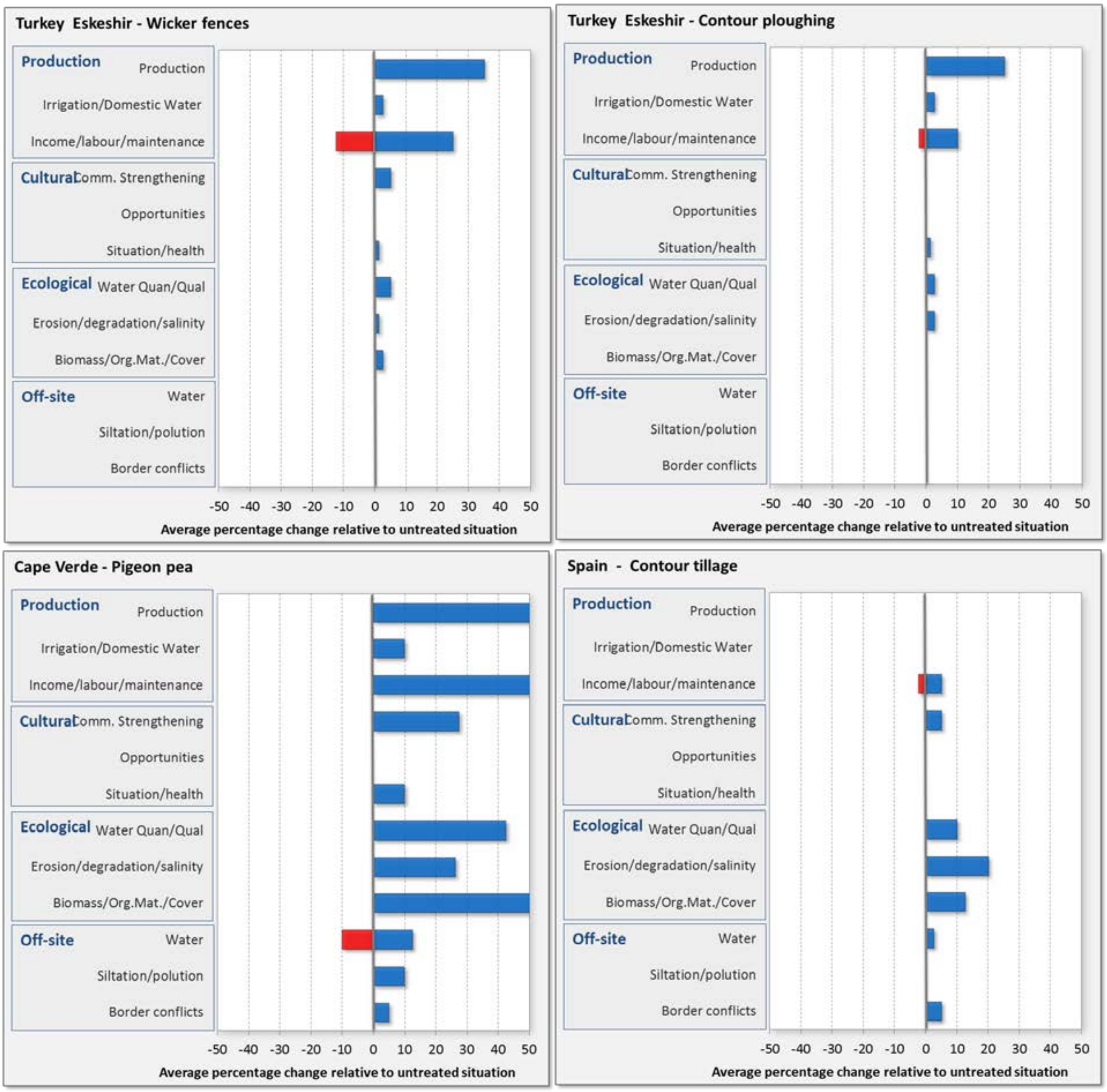


Figure 2.3.3: Evaluation of stakeholder response to WOCAT questionnaire

Conclusions

The purpose of these measures is always twofold: reduce runoff and erosion, and increase water availability through increased infiltration. This is a mixed group of various techniques, from actual terracing subsidized by the government (China, Cape Verde) to a stakeholder approach in Turkey (Eskeshir) where farmers made fences woven from branches that capture sediment and runoff that will gradually form terraces. In general the results are good if the terraces are established with outside help and people are used to it. This experience is confirmed form many parts in the world (Nepal, Peru, South East Asia). Water availability is higher, crop yield is also higher in all cases. However from a point of view of local stakeholders, soil erosion is seen as a wider problem where it concerns offsite effects, and it is therefore considered the responsibility of the government. Also, terracing is very expensive, needs a great deal of technical experience to avoid erosion and landslides, and generally destroys the soil structure when they are created, which takes long to restore. The project results confirm that it is almost never a local stakeholder solution that can be carried by the community.

The experience of Turkey however shows that good results can be obtained with a much less rigorous intervention: woven fences are easy to establish and restore and combined with contour plouging work well to increase moisture and prevent runoff. However, again there is a downside that might prevent farmers from using this technique: depending on the field shape and orientation towards the slope direction, the technique may result in very short and wavy tillage lines with many tractor turns needed. The tractor is also hampered by the fences. Thus operational costs may be higher, while the yield may be lower. In Turkey this was not the case: yield was actually higher but the reasons were not quite clear

2.4 WATER HARVESTING

Introduction

The term "water harvesting" is used in this report for all techniques in dryland agriculture that increase the amount of water in the soil directly. Generally this can be large scale and more related to a catchment in which the field is located, or small scale on a plant or field level. Large scale are often techniques that promote agriculture in wetter places, such as valleys or streambeds with shallow groundwater in an otherwise dry environment, or runoff capturing techniques where intermittent discharge in natural channels is captured and led to fields (a kind of surface irrigation). In these cases the agricultural fields and also the surrounding natural areas are part of the system and a watershed management plan or at least protection of these areas must be present. Small scale water harvesting is at crop level: furrows and stone lines lead local runoff water to pits and half-moon dykes in which the crop is planted. Runoff as well as sediment is captured. Runoff also sometimes comes from higher terraces, especially if they are at an angle. Many variations on the theme exist as can be found in the WOCAT book "where the land is greener" and later versions (Liniger et al., 2007).

In the DESIRE project the water harvesting techniques are of the large scale kind: irrigation by runoff water in Spain (Boquera system), water harvesting on terraces from surrounding valleys in Tunisia (Tabias and Yessour systems) and terracing of steep slopes in China. The first two (Spain and Tunisia) are known traditional systems, where in the case of Spain the system is not often used anymore because of groundwater irrigation. However on non-irrigated Almond fields on terraced lands it can be a worthwhile addition of water. In Tunisia the Yessour and Tabias system is already in use for a long time, applied on Olive groves. These Olive trees can only exist here because of the system, as the annual rainfall is between 200 and 280 mm. The system includes check dams across river beds to replenish groundwater and terraces with dams to grow Olive trees.

In China the terraces have a double function. Terracing helps in decreasing soil loss and increasing soil moisture storage due to reduced runoff and increased infiltration (Schiettecatte, Ouessar et al. 2005). They have been created in some parts of the Loess plateau in China with government and Worldbank funds. Similarly check dams are created in valleys and fill up with sediment rapidly and form terrace type structures. They are used for Maize production.

There are also disadvantages apart from the high level of cost and technology input in their construction. In the level terraces which are constructed mainly for growing rice in south and south-east Asia, the rate of percolation seems to equal average infiltration rates making the subsurface flow more prominent (Huang, Liu et al. 2003). Because of cutting and filling during construction, the outer edge of the terrace is made up of filling material making the terrace riser weak and susceptible to movement. Slope instability is common in rice fields due to increased soil moisture in the contact zone with the underlying material (parent material or bedrock) and excess weight of the level terraces (Gerrard and Gardner 2000; Shrestha, Zinck et al. 2004). The sloping inwards terraces are more effective in heavy rainfall areas whereas the outwards terraces are commonly used for rain-fed agriculture.

Implementation and results

In the Spain area, Almonds are sometimes planted on a cascading system of flat terraces. Originally all of these terraces were irrigated from a traditional water harvesting system, called *boquera* in Spanish. A *boquera* is a system where during rainfall events that result in flow through a nearby ephemeral stream

(Rambla), this water is (partly) diverted to the nearby terraced fields through a series of man-made gateways and corresponding channels (i.e. *acequia*s). Nowadays, because of lack of maintenance of these channels, only a few of the monitored terraces can still benefit from the inflow of water. The system was revived to monitor how well it might function. In another terrace, without additional inflow of water from the *boquera*, a straw mulch (~15cm thick) was applied under the canopy of the almond trees after the spring rainfall since spring 2009 (discussed in the soil cover section). In a third terrace, also without additional water inflow, normal production scheme was used as a control plot. Figure 2.4.1 shows that the topsoil water content was highest for the Boquera system and that there was a regular supply of runoff water in the 2009 season. In the soil layer below the topsoil the situation was reversed: the control system was wetter for unknown reasons. The yield was clearly higher in the Boquera system, but could only be measured for one season because of hail and frost destroying the crop in 2010. In 2009 the Boquera Almonds had 9.5 kg/tree as opposed to the control plots that had 5 kg/tree on average. The cost of maintenance of the Boquera system was about 350 Euro but even with that included the net profit was 1898 Euro as opposed to 1248 Euro. Not all fields are connected to a Boquera channel, but the effect is clearly positive.

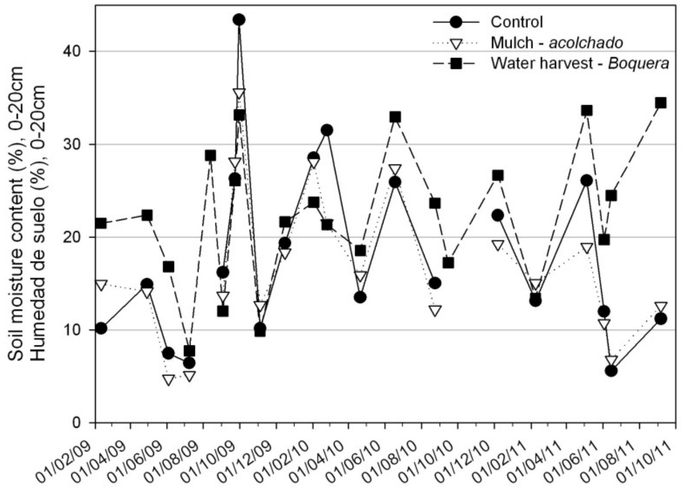


Figure 2.4.1. Top Soil moisture content in a water harvesting system in Spain.

The Tunisian systems were tested in extremely dry circumstances (annual rainfall 132mm), dryer than even the system could cope with. Additional water was supplied to save the Olive crop. The efficiency of the system could not be tested under these circumstances. However a steady decline of groundwater was measured and the system appears very fragile.

In China the results indicated an increase of soil moisture because the runoff from the up-stream area is detained by the check dams. Soil loss on the terraces was negligible(figure 2.4.2). The orchard with a bare soil shows twice as much soil erosion as the experiments under forest and on grass land. Terraces and check dams have of course no runoff because of the flat slope.

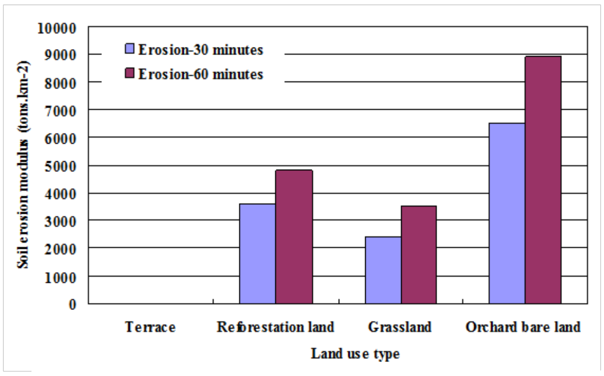


Figure 2.4.2. Soil loss from rainfall simulator experiments (55 mm/h) for different land use types.

Total cost involved in the cultivation in check dam land and on terraces is higher because there is simply more surface to plant (see Table below). But the net income is also higher on the flatter areas because of better yields in all the 3 land use types: the yield of check-dam land, terrace, slope crop land is 7800, 4500, 2400 kg per hectare respectively (table 2.4.1).

Table 2.4.1. Cost in Yuan for cropland on check dams, terraces and the control situation (sloping land)

Land use	Seeds	Chemical Materials*	Tillage And planting	Direct input	Labor	Labor cost	Total Input Including Labor	Yield	Value	Net income without labor	Net income with labor
	Yuan	Yuan	Yuan	Yuan	Day	Yuan	Yuan	kg	Yuan	Yuan	Yuan
	a	b	c	d=a+b+c	e	f=e*50**	g=d+f	h	v=h*1.85***	v-d	v-g
Check-dam land	525	4575	525	**5625**	105	5250	**10875**	7800	14430	**8805**	**3555**
Terrace	420	2700	525	**3645**	90	4500	**8145**	4500	8325	**4680**	**180**
Slope Crop land	300	1800	525	**2625**	75	3750	**6375**	2400	4440	**1815**	**-1935**

** Chemical Materials: fertilizer, pesticides and herbicide; ** Price of corn: 1.85 Yuan RMB per kg; *** Price of labor days: 50 Yuan*

Evaluation

In figure 2.1.3 the results of the WOCAT evaluation method are summarized. The length of the bars is an indication of the performance compared to the conventional situation (in % difference). These are averages and should not be taken too literally.

Spain: Boquera system inlet gate on Almond terrace

The evaluation of the Spanish water harvesting system reflects the findings: slightly more expensive but this is outweighed positively by both production and ecological parmeters. There might be an estimated negative downstream effect because of a lower water availability. Reliance on a natural system, if it is secure enough, is also positively evaluated. The Tunisia evaluations are also very positive, more based on experience of the stakehodlers than the results of the expriments in the extremely dry years. The Olive production is not very high but only possible through this system, it is not possible without (there is no control plot). There is some maintenence involved (the red production bars) and occasional groundwater irrigation with pumps. A positive offsite aspect is the recharge of groundwater by infiltration while in a negative sense capturing runoff reduces the water availability downstream for consumption. This leads sometimes to conflicts. In general the system provides little future prospects for young Tunesians who migrate to the city. So it is questionable whether the system is sustainable form a social point of view.

In China one of the main interests of te government is to combat erosion in order to mitigate problems downstream. Measures that drastically improve the onsite circumstances, such as terracces and checkdams are interesting because they create flat land with favourable conditions. This is shown by substantially increased yields. In fact rainfed agriculture with staple food crops on slopes is hardly profitable because of the low yields. However constructing and maintaining check dams and terraces is expensive. Since Cropland is in short supply (0.1 ha per capita) it is impossible for most people to do this themselves. Therefore they are interested but also regard is as something unobtainable. Many farmers find an income in other types of work such as road and building construction. This gives the wrong impression that in the evaluation initial costs are not counted, they are not part of the “perception” of the farmer.

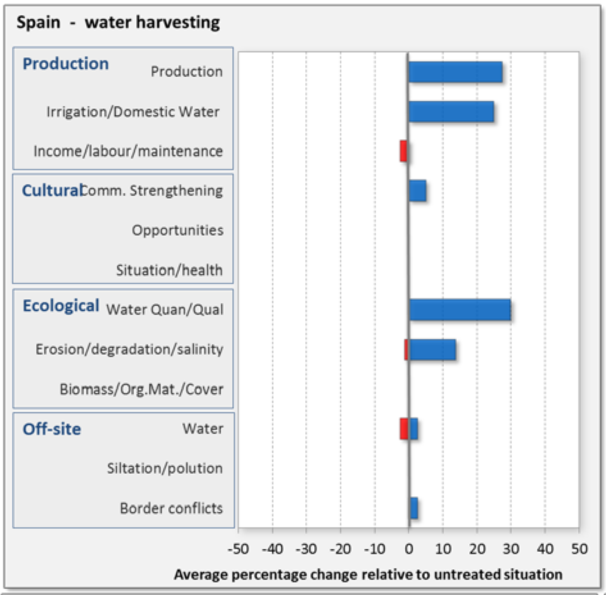
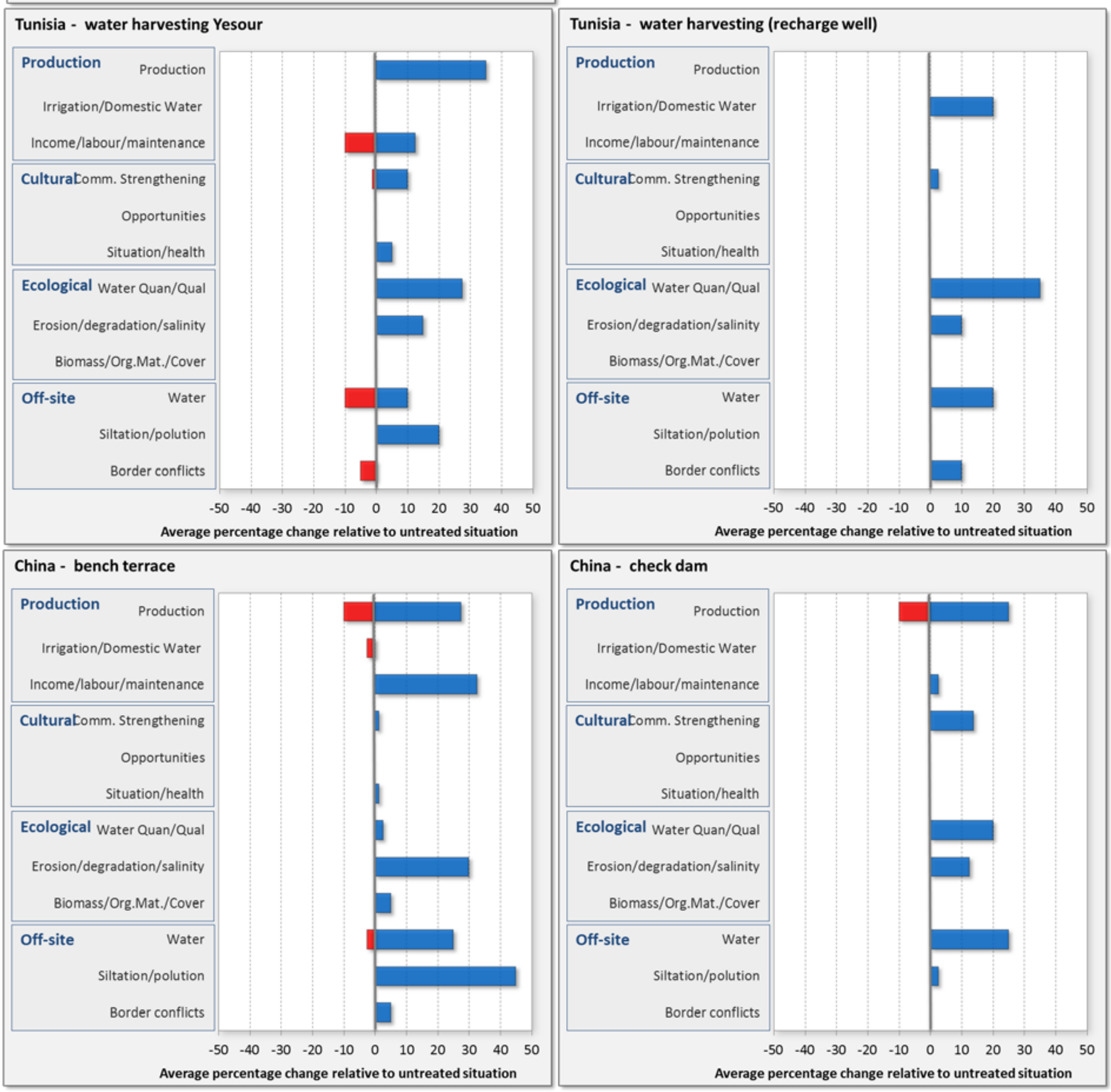


Figure 2.4.3. Summary of the WOCAT based evaluation for 5 sites on the effects of runoff water harvesting. Percentages are average indications of change in % compared to unmitigated situations.



Conclusions

The water harvesting techniques tested are all related to capturing natural runoff and leading this to terrace like, flat pieces of land. In Tunisia this system has been used for many decades and people are used to it and know exactly what they can expect. Water of the surrounding area is captured to have a (subsistence) Olive harvest. Since this is in a true arid area with very low rainfall, there would be no agricultural activity without this system. Thus here is not really an unmitigated system to test. It can be said however that the groundwater is sometimes also for additional watering and this causes overexploitation. The system functions if it is combined with groundwater infiltration zones. There is complete acceptance of this technique as it is the only low-cost solution available. However, it may not give a secure future for younger generations.

In Spain, a similar traditional water harvesting system exists, using natural runoff water (traditional *Boquera* system), is combined with Almond orchards. It is being revived after having been neglected for a period of time, due to economic fluctuations and because groundwater was used for irrigation. It works well in terms of increased water availability, increasing yield. It will not be available to everybody because your fields need to be downstream of a water delivering system. An added benefit might be that the natural surrounding area increases in value.
In China bench terraces and check dams are being built by the government that also serve as water harvesting systems, simply because the steep slope and fast runoff is now being captured on the flat terrace surfaces. The construction is expensive and can only be done by the government, who is interested in decreasing downstream sediment problems (because of hydroelectric power installations and domestic and industrial use of river water). Once established, the terraces work well and show increased yields and decrease of soil loss. Currently farmers in the area find work outside agriculture and the interest is less.

Summarizing, water harvesting by capturing runoff is an old and established technique. If the terrace structures exist there are only limited maintenance costs. The increased soil moisture directly increases crop yields and income. If the initial costs can be overcome or done by outside subsidy there is a strong positive effect. Runoff collection in combination with terraces also may have considerable downstream implications: the soil loss is strongly reduced (positive) but also the runoff leading to river discharge is reduced which may lead to water shortages downstream and potential conflicts. Catchment management is needed here, both to safeguard the natural areas that supply water upstream as well as ensuring water availability downstream.

China: (top) Check-dam land and (bottom) bench terraces

2.5 IRRIGATION MANAGEMENT

Introduction

Irrigation is obviously used in conditions with insufficient rainfall combined with intensive agriculture. There are many different irrigation technologies, which can be grouped in the way water is transported to the fields: by gravity or pumps through a system of channels and furrows, through pumps and a Sprinkler system that simulates rainfall, or through an on-the surface or subsurface system of perforated tubes: drip irrigation. Salinity from irrigation can occur over time wherever irrigation occurs, since almost all water (even natural rainfall) contains some dissolved salts. When the plants use the water, the salts are left behind in the soil and eventually begin to accumulate. Salinization (also called salination) from irrigation water is also greatly increased by poor drainage and use of saline water for irrigating agricultural crops. Once salts are accumulated in the topsoil, they are very difficult to remove.

Apart from the chemical problems for crop growth, salinization affects the permeability of soil and causes infiltration problems, because sodium in the groundwater replaces calcium and magnesium adsorbed on the soil clays and causes dispersion of soil particles: a breakdown of aggregates and natural soil structure. Also deeper in the soil this has caused compacted layers to form.

Large scale irrigation systems are not always very efficient: flow irrigation along the surface must be timed correctly and the system transporting water to the fields must be efficient. This is rarely the case. Water losses along the way are large. Sprinkler irrigation has a more natural application of water but suffers from direct evaporation and wind effects that increase water losses. Large systems need considerable maintenance and also operational costs can be high (fuel costs for pumping for instance).

Sprinkler system in the Novy study site.

Irrigation is applied in three sites in the project: in Greece in the Nestos river basin, in Russia in the Dzhanybek region and the Novy region. The first two have salinity problems for different reasons, the latter has soil erosion and soil degradation because of mismanaged irrigation systems. The solutions applied in these three sites are flushing with fresh river water to counteract salinity in the Nestos area, and drip irrigation on the Russian sites.

Implementation and results

The experiment in Greece focused on counteracting the effects of salinization by irrigation with fresh river water. The coastal region of the East Nestos River Delta (Maggana, northern Greece) has limited freshwater supplies although irrigation is exceptionally intensive. Studies show that there is intrusion of seawater into the coastal aquifer. The shallow brackish groundwater is in use for irrigation since the last 40-50 years, which has caused severe salinization of the soil. A corn field which has been irrigated with freshwater from a local stream for the last 10 years was selected for the study. A second field which is traditionally irrigated with saline groundwater was also selected. In both fields, the data on soil physical and chemical properties and crop production was collected. The freshwater field serves as reference for the evaluation. For the experiment, the saline field was irrigated with relatively fresh groundwater from a well further inland (the river was too far). Before the experiment more saline water was used on this field. In addition, different amelioration strategies (deep ploughing to break deeper compacted layers, addition of gypsum) were tested. The chemical analysis results of the irrigation water used in 2009 and that used in 2010 shows that the latter has lower EC, pH, Ca^{+2}, Mg^{+2} and Cl^{-} anion concentrations but a slightly higher SAR (Sodium Adsorption Ratio, a measure for suitability of water for irrigation, higher means less suitable). These values make the fresh well irrigation water acceptable for irrigation according to international standards.

Analysis of the soil samples shows that the EC, SAR and Cl^{-} content in the soil in 2009 is clearly higher than in 2010, indicating a positive effect of using fresh groundwater even after one season. This depends on the general moisture content: the values all increase towards the driest month of August when the difference is less pronounced. The differences in the subsoil are less clear because of fluctuations in 2010 The SAR is even higher at soil depth 60-70 cm in 2010.

The overall result shows that the improved irrigation water seems to have positive impact on almost all the parameters. The Wheat yield improved: 3.4 ton/ha in 2009 versus 4.2 ton/ha in 2010.

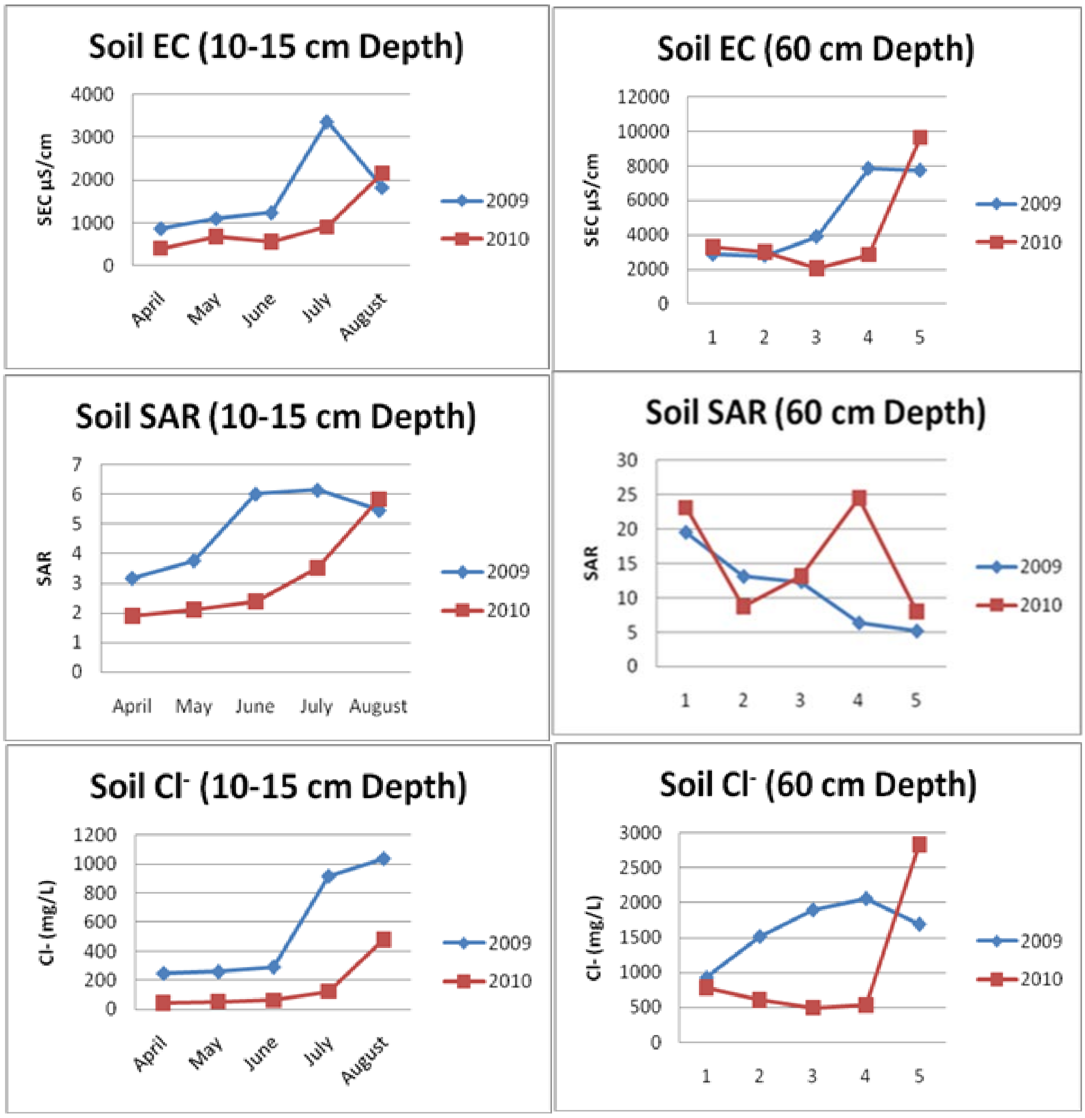


Figure 2.5.1. Nestos: change of soil chemical properties in two years after irrigation with fresh water.

A similar problem occurs in The Russian site of Dzhanybek, where high evaporation gradually causes salinity of the groundwater in depressions. The groundwater in this region is recharged generally after snow melt and the depth and concentration is determined by the micro-relief. Under micro-depressions the surface of groundwater is convex with depth about 2 - 5 m and mineralization about 0,3-1,4 g/l. Under micro-elevations the surface of ground water is concave with depth about 3 - 9 m and mineralization about 4-17 g/l. It has to be used with care. Fresh water is available after snowmelt but in limited amounts and good management is necessary. People also depend on this water for domestic purposes. The experiment use sdrip irrigation in home gardens to demonstrate its use and the possibility of growing cash crops such as tomatoes. The setup was to have (1) experimental plots at micro depressions within agricultural fields with the use a fresh ground water stored in between soil surface and salty ground waters, (2) experimental plots at garden of householders at villages with the use of municipal water delivery system and (3) experimental plots within natural pasture near location of temporary summer habitation of shepherds with water transported in tank or cistern.

Installing drip irrigation lines in Tomato plots, Dzhanybek

The results were very positive. The actual use of irrigation water by drip irrigation was estimated at 2000 m^3/ha while normal furrow irrigation uses 3600-4050 m^3/ha. At the same time this increases the water available for other uses (by roughly 30-50%). Effect on salinity was too early to tell. Also the amount of labour and fuel costs for pumping decreased considerably. Consequently the drip irrigation has a very large effect because of the more precise application, shorter supply lines and decrease in evaporation. Vegetable yield increased from 4 to 6 ton/ha while the workload decreased from 2 hours to 1 hour per day.

Finally the experience in the Novy site in Russia is very similar from the Dzhanybek site. It is closer to the Volga river so fresh irrigation water is available. However through lack of maintenance and mismanagement the large irrigation systems perform badly. The traditional furrow irrigation of vegetables is a technology with high and inefficient water use: about 20-30% of water is absorbed by roots of growing plants and about 70-80% is lost, causing runoff and even soil erosion. Drip irrigation technology improves the moisture regime and water availability in soil root zone by a permanent slow input that can be adjusted to seasonal and diurnal variation of water consumption of plants during growing season. Yields under both techniques are very similar.

Evaluation

In spite of the differences between the sites, the evaluation is actually very similar. The ecological effects are positive: a better management of irrigation systems can reverse the negative effects of salinization and soil erosion. Also in areas with limited water supply (Dzhanybek) a careful management of available water can increase water for other uses (domestic, animals). In the case of Nestos, all groups of stakeholders were interested in the results of freshwater transport technology, especially the farmers. The evaluation indicates a medium positive effect overall: there is an increase in crop yield, but at the same time there are also increased costs because of installing an irrigation system that brings water from the streams or wells further inland to the coastal zone. While such groundwater wells further inland have relatively fresh water, there are still elevated salt contents. There are also clear improvements in soil structure and organic matter, from observations on the fresh water field. The yield and crop quality of these fields is a lot better. The evaluation results confirm this. The Nestos farmers rate installation and maintenance costs as a main bottleneck because they would have to pay this themselves, this is weighted against a better harvest security in the future. The Russian farmers see strong benefits because their current situation is poor and growing of high quality tomatoes appeals to them, but this is under the assumption that the initial costs are subsidized, which is not shown in the graphs.

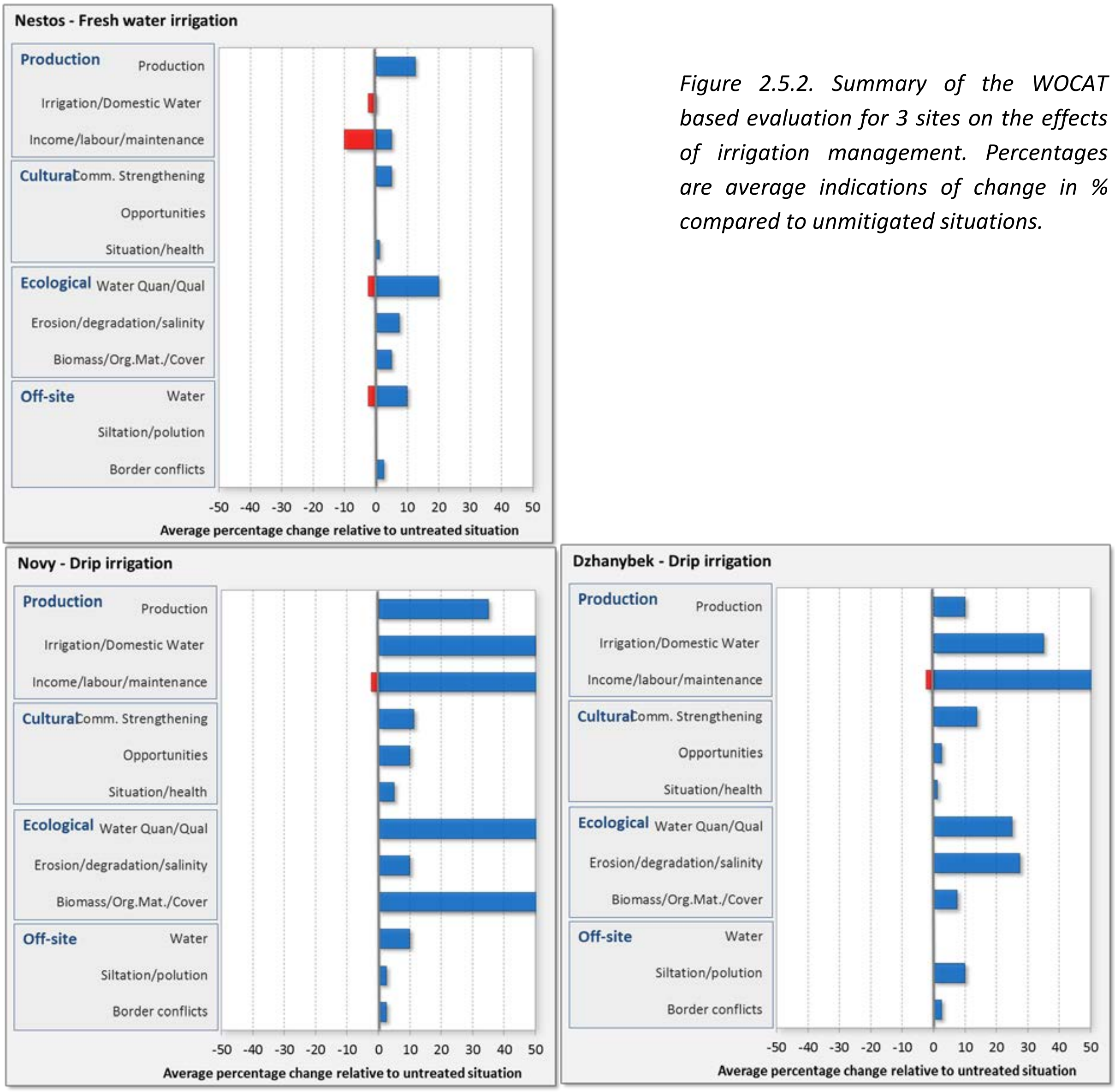


Figure 2.5.2. Summary of the WOCAT based evaluation for 3 sites on the effects of irrigation management. Percentages are average indications of change in % compared to unmitigated situations.

Conclusions

The total cost of this technology must be taken under consideration before implementation. The reactions of stakeholders were very positive and they were keen on implementing the technology if financial aid is given. All stakeholders expecting the transport of fresh water from the nearby river Nestos, but not all may be in a geographical position to benefit against reasonable costs. Also the effect on the ecology of the river system of such a major water extraction has not been studied yet.

Also in the Russian sites the interest of farmers is large: drip irrigation offers them alternative crops with good returns, with generally less production costs, and also more independence. In this case there is some technology transfer necessary, although drip irrigation technology is not complicated, just new in the area. However, the main bottleneck is the initial costs of drip irrigation systems. Not all farmers have access to a functioning system so for a large scale application considerable investments would be needed. A special regional drip irrigation supporting program is needed as well as an environmental protection program. Furrow irrigation systems could be taxed and excluding from the list of subsidy of energy needed for water transportation. This subsidy could instead be used for installation of drip irrigation systems.

2.6 RANGELAND MANAGEMENT AND FODDER PRODUCTION

Introduction

The farmers in the semi-arid areas in the project do not depend on a single type of farming for their subsistence. Apart from the rainfed agriculture or Olive production, many farmers own lifestock. In Morocco, Greece (Crete) and Tunisia, this lifestock roams more or less freely in the areas. There are no fences and grazing is managed extensively by herders that take care that crops are not grazed and trampled. Often when the rainfall is not enough for a crop to mature or produce a grain yield, livestock is allowed to graze on the crop and/or residue. Outside these moments the natural vegetation, grass and bushes, are used as fodder. All areas show signs of severe overgrazing: few species remain and these are unpalatable or have poor nutritious value, plant cover and biomass is low, and the surface shows signs of severe degradation (shallow and stony soils, a lack of organic matter and water and wind erosion).

Morocco: gully stabilization with Atriplex

A way to mitigate the effects of overgrazing is to allow rangeland restoration. In areas without fencing, this can only be achieved by good agreements between communities that control the communal grazing grounds. The application of so called set-aside areas, areas that are rested for 1 or 2 years and make up a substantial part of the total areal (such as 25% or more), could cause the area to slowly restore if the biomass and biodiversity sufficiently regenerates. The experiments on Crete and in Tunisia were designed to investigate the restoration capacity by fencing of a plot and monitoring the vegetation.

A second major strategy to combat overgrazing is to plant fodder species. Certain species exist that can survive dry circumstances and are rich in nitrogen. This is applied in Morocco by stabilizing gullied areas by planting *Atriplex halimus* (also known as Saltbush or Orache), This serves a dual purpose of combatting erosion and providing a valuable return as fodder.

Finally in this category is the Botswana site where fuel wood is conserved by testing a biogas installation. Fuel wood is a major fuel for domestic use, not only for households but also community services such as schools and hospitals in rural areas. The amount of fuel used daily is large and a biogas installation would cut down on degradation of the surrounding shrubland.

Implementation and results

The Zeuss Koutine area in Tunisia area suffers from over-exploitation of pastoral land. Ever since the ground water has been exploited by means of drilling a lot of pastoral land was converted into irrigated cropland or orchard. This has increased the pressure on the remaining land causing over grazing and associated soil erosion. An experiment was carried out to improve plant cover and biodiversity in the grazing areas aiming at minimizing land degradation. The resting technique was carried out on three sites (Alamet Mechlouch, Beni Ghezaiel and Sidi Makhlouf) within four management modes: RK3: rested rangeland, RK2: moderately degraded rangeland, RK1: overgrazed rangeland, rk: abandoned cultivated rangeland. Monitoring was done on several transects, and included global plant cover, specific frequencies, flora richness, the plant density and the range biomass production as well as the grazing capacity. The experiment was conducted during four years: spring 2007 (initial state), spring 2008, spring 2009 and spring 2010. The experiment shows that there is an increase of plant species when the plots are rested for several years. The number of species already doubles from 10 to >20 in the first year of resting, but fluctuates in relation to local circumstances. The degraded plots (RK2) have the lowest species number (see figure 2.6.1). The cover percentage initially increases but fluctuates because of climatic differences between the years. The other sites show similar effects. In rainy seasons, annual species are very abundant also in degraded sites.

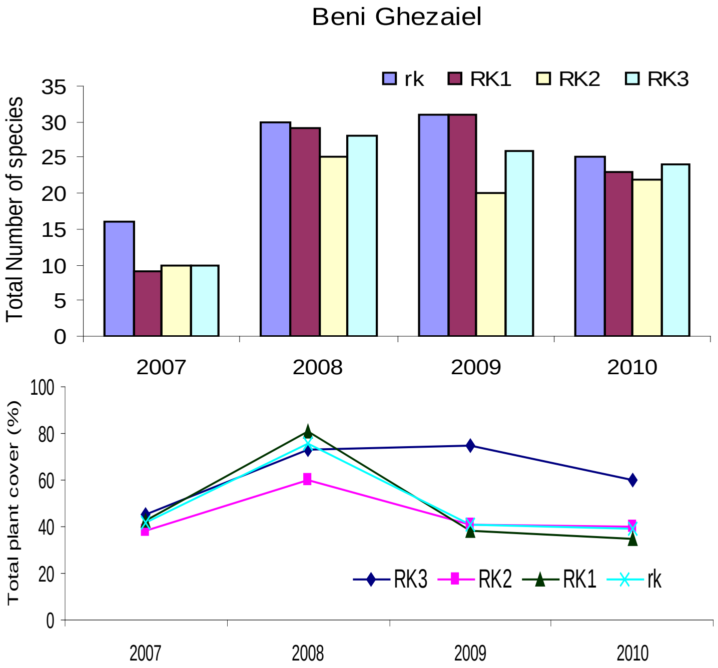


Figure 2.6.1.Tunisia: (top) species increase during rangeland resting in one of three sites. (bottom) Cover percentage change. RK3: rested rangeland, RK2: moderately degraded rangeland, RK1: overgrazed rangeland, rk: abandoned cultivated rangeland

On Crete an added effect is measured as the overgrazed areas are in hilly terrain. In the sustainable grazing plots the annual as well as the perennial vegetation and the plant residues covers about 85% of the soil surface, protecting the soil from splash detachment, formation of surface crusting, and minimizing surface runoff. The sustainable grazing management practice reduces surface runoff by more than half in both the study years. In year 1, surface runoff from overgrazed plot was 43.7 mm and that of sustainable plot was 28 mm. In year 2, the difference was even more (19 mm verses 7 mm). Sediment loss was similarly affected by grazing intensity. As shown by figure 2.6.2 sediment losses in the overgrazed plots in year 1 is 352 kg ha-1 yr-1 whereas it is 143 kg ha-1 yr-1 in the sustainable grazing plot. Similar result is shown in year 2. The result shows that soil losses can be minimized by about 2.5 times by employing sustainable grazing.

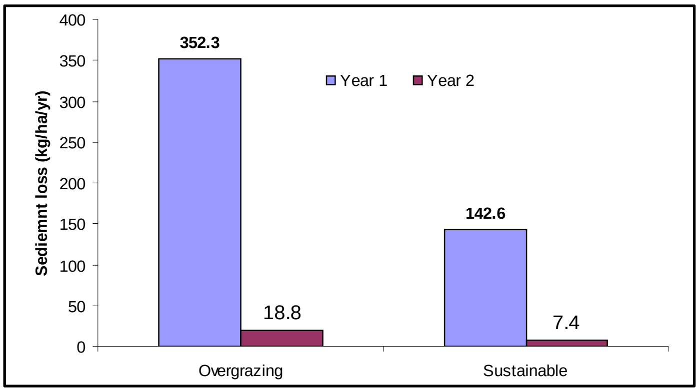


Figure 2.6.2. Sediment loss on over4grazed and sustainably grazed plots in Crete.

In Morocco the surface cover of degraded gully area was increased by planting *Atriplex halimus*. This species can survive dry years, was planted in 2009 in a regular pattern across the gullies (see photo above). *Atriplex* is a Mediterranean species and adapted to the climate, but initially the plants were irrigated to protect them from drought. The gully area is fenced to keep out animals, so this may have influenced the results. The experimental plot has been isolated with one light grazing, for two years after which controlled grazing took place. The experiment has clear effects both on the biomass increase and the gully stabilisation. Biomass of both annual grasses and perennials has increased considerably from 360 kg/ha to over 1200 kg/ha. Also the quality of the vegetation has increased, with good grass species, making this a viable source of fodder. The number of grass species was 20/m^2 on the 'atriplex' plot as opposed to 10/m^2 on the fallow plot. Expressed in cover % the cover was more permanent (see figure below). Experience shows that in a dry year the *Atriplex* survives and provides a minimum biomass, while in a wet year there is a combination of grasses and *Atriplex*. The effect on sediment loss needs longer monitoring at catchment level, but no further gully change has been observed in the plot.

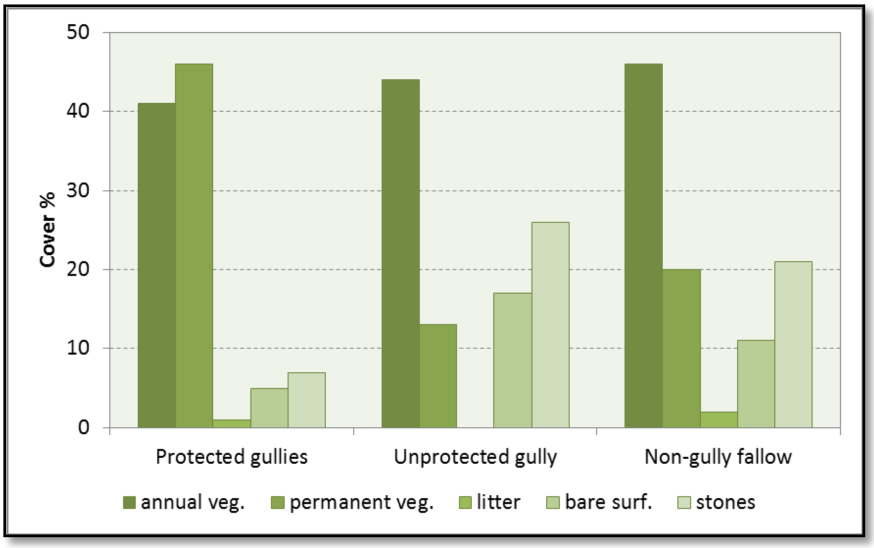


Figure 2.6.3. Morocco. Cover % of the three plots: while the cover of annual grasses is about the same, the perennials give a good all-round cover and protection.

Soil moisture seems to be higher in the Atriplex plot although this may differ from season to season according to rainfall. The soil was less compacted in th plot. Effect on other factors such as soil organic matter need longer monitoring to evaluate.

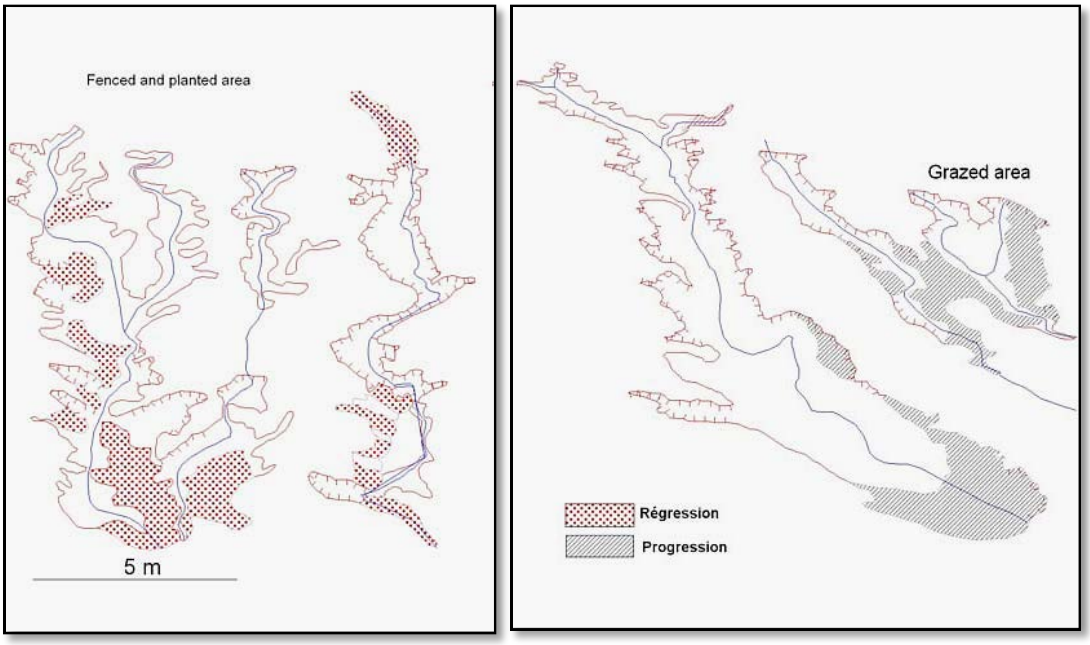


Figure 2.6.4. The effect of 2 years of fencing showing a decrease of the gully area (left) by gradual collapsing and filling in (marked as regression) as opposed to the reference area (right) where the gully area that has increased (marked as progression).

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Evaluation

The stakeholders meetings in Tunisia show the technology as a well adapted technique for the environment. About 10% of the land user families have applied the technology with external support and 1% of the land user families have applied it without external support. This support is needed because resting means land is taken out of production temporarily (first years) and with current animal stocking levels this means either subsidy in the form of fodder or an increased risk of overgrazing the remaining area. Experience in Crete and the other sites shows that while these are ecologically good measures, fencing would be very costly for little return for land owners. Rangeland resting where agreements are made to leave an area as set aside without fencing might be possible. However, the landowners receive EU subsidy based on the number of animals so this effectively negates any means to protect the fragile soil. Since fencing or set aside would mean a decrease in animal density, this is a further loss of income.

Calculations from Morocco show that it takes a number of years to earn back the investment of establishing the gully protection plot. Without subsidy this is not a viable technique as the restoration of the gullies does not directly benefit the farmers.

Input/ha	Euro	Output/ha	Euro	Euro
Plants	405	**Fodder yield 1rst year**	0	
Holes	810	**Improve in site**	135	
Fence	587	**Improve downstream**	135	
Irrigation	720	**Total outputs 1rst year**	270	
			0	-2252
		Fodder + ecosystem services	405	-1442
		Fodder + ecosystem services	405	-1307
		Fodder + ecosystem services	540	-767

Table 2.6.1. Cost benefit estimate of gully fencing in Morocco.

These findings are confirmed by the evaluation shown in figure 2.6.5. The ecological benefits are clear and also the increase of production (fodder or rangeland) is evident but the costs are too high. Without support the technology will not be accepted. Cape Verde may be an exception because the added crop is valuable in itself and the fodder aspect of pruning is a secondary advantage.

Botswana is a separate case (biogas) which cannot really be compared to the others but has ultimately the same result. The evaluation shows the initial findings: initial costs of installation are very high. Because there is no experience with this technique possibly not the easiest or cheapest design is used. However the people are interested when it would be cheaper. The impact of the biogas is too early to show, but schools, villagers – have all expressed interest, citing the limited energy sources as a major challenge. Interest ranged from using the gas for: cooking, powering a generator to produce electricity, to larger scale like providing energy for cooking i.e. to replace 19 truckloads that are needed every 3 weeks for each secondary school in the area.

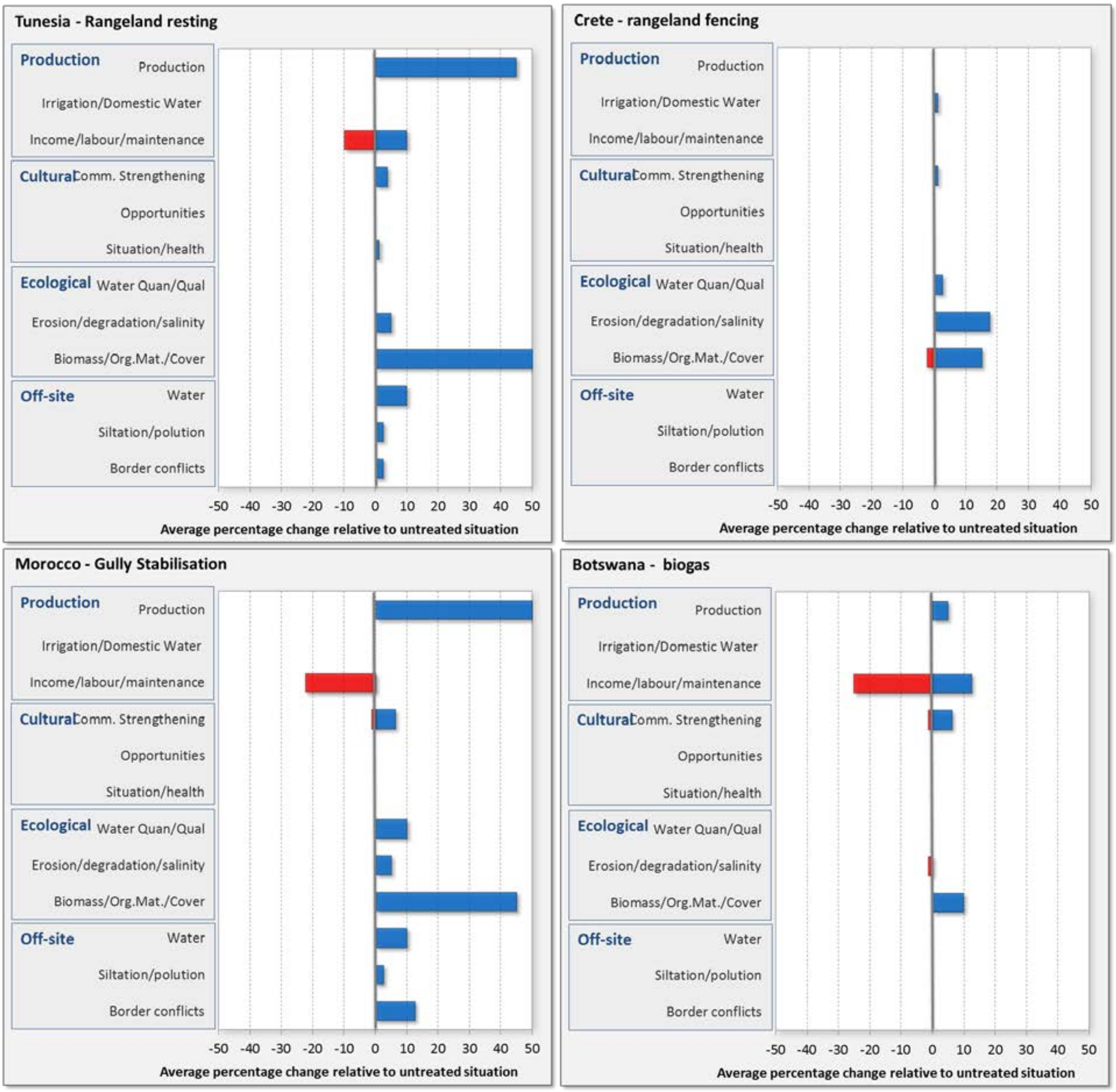


Figure 2.6.5. Summary of the WOCAT based evaluation for 4 sites on the effects of rangeland management. Percentages are average indications of change in % compared to unmitigated situations.

Conclusions

The rangeland resting technology helps increase plant cover and plant biodiversity, especially in dryer years, as compared to conventional grazing land. In wetter years the degradation is less visible, so resting is especially beneficial for resilience: recovery in dry years.

To make the technology successful and sustainable it has to be accepted by the people. It could mean change of grazing culture (planning of resting areas which is agreed upon by the community and adapting to less grazing areas. This needs management of the communal lands and in the beginning possibly extra subsidy for fodder. The experiments show that the sustainable grazing results in minimizing surface runoff and sediment loss by more than half of that in the overgrazed areas on sloping areas.

These results of the experiment are positively regarded by stakeholders. However the farmers point out that a large scale fencing and planting of the degraded lands in the region is impossible for them, without financial compensation for time and subsidized equipment and materials. An initial set aside period of 2-3 years would mean a substantial (temporary) loss of grazing land. The initial investments in Morocco for instance are approx. 2x as high as the combined 3 year returns in this experiment. The farmers are spectators at the moment, until the long term effects are clearer and more convincing.

A large scale adaptation of this measure is impossible, and fencing areas that are otherwise open for grazing may have also social and cultural implications. A viable approach could be to establish several of these experiments in strategic and visible locations both to combat erosion and to promote acceptance and increase understanding. A long term effect of a larger availability of fodder might be that a reduction in pressure on other ecosystems, such as the forested areas that are now overgrazed.

The biogas installation in Botswana is running well, and the results are beginning to show i.e. how much gas is generated from what quantity of cow dung or food waste. This will be the first time in Botswana, where exact performance measurements are done.

2.7 FOREST FIRE MANAGEMENT

Introduction

Like many Mediterranean countries Portugal suffers from forest fire due to its dry and hot climate. The problem is not only degradation of forest and the emission of carbon dioxide to the atmosphere but it also increases soil losses and pollution of water and air. The Mação Region in Portugal suffered massive fires in 2003 and 2005 affecting more than 70% of the municipality area. To protect the forest from wild fire a strip network is constructed. This can have negative impact by increasing surface runoff and soil losses due to the removal of vegetation along the strips.

To compare the effect of prescribed burning with that of wild fire four sites were selected: Camelo catchment (site 1) and Vale Torto (site 2) close to Góis, both having similar conditions with respect to geology (schist and quartzite), relief, vegetation, soil and climate. To study the effect of wild fire and prescribed fire following data were used: Wild fire in Camelo study site (3.3 ha) in early summer 2008 comprising scrub vegetation representing a fuel load of 65 t/ha (Lower photo left); Vale Torto, submitted to an experimental fire (9 ha) with a lower fuel load (23 t/ha) in February 2009 (Upper photo left); Podentes subjected to a prescribed fire in April 2009. In Podentes (site 3), the forestry service burned a smaller area (2 ha) comprising scrub vegetation on calcareous bedrock with fuel load of 70 t/ha. In Moinhos (site 4) an area of 95 ha was burnt in September 2009 where eucalyptus were planted. To study the effect of forest fire, field study was carried out to collect data on soil moisture, infiltration, suspended sediments and nutrient contents. In addition to collecting data on soil, Vegetation recovery monitoring was also carried out using vertical-photography of plots of size 0.25m. In addition, a lysimeter was also used to assess fire impact on soils started during 2010. During the experimental lysimeter fire flame temperature was assessed using an infrared heat sensor, that shows temperatures values of over 700ºC.

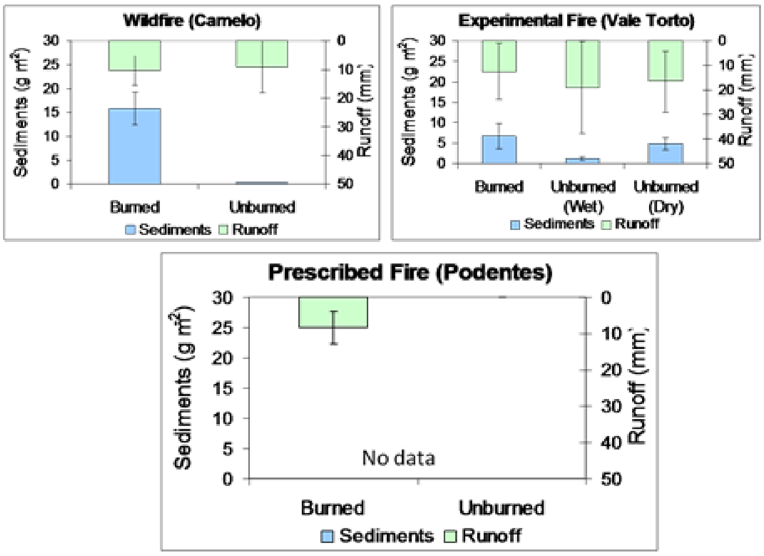
“Other techniques” is a category that contains three trials that cannot be readily compared. There are two tests to combat forest fire: by a network of fire corridors along roads, and by prescribed burning (decreasing the fuel load biomass in spring to avoid heavy fires in summer). These two are not really comparable because it cannot be tested which one works better! Both were in fact researched for their susceptibility to soil erosion after burning.

Implementation and results

	Infiltration rate (mm/h)			Infiltration capacity (mm/h)		
	Burnt	Unburnt	ratio	Burnt	Unburnt	ratio
Bare soil		7.50			13.85	
Q. coccifera S	10.45	13.80	0.76	30.26	30.56	0.99
P. lentiscus S	15.05	22.39	0.67	29.64	31.13	0.95
A. unedo S	7.99	12.09	0.66	11.89	32.45	0.37
Average	**11.16**	**16.09**	**0.69**	**23.93**	**31.38**	**0.76**
Q. coccifera N	25.47	41.03	0.62	26.87	46.13	0.58
P. lentiscus N	28.94	29.42	0.98	30.25	31.76	0.95
A. unedo N	16.23	24.57	0.66	16.62	30.10	0.55
Average	**23.55**	**31.67**	**0.74**	**24.58**	**36.00**	**0.68**
Whole area	**15.81**	**21.14**	**0.75**	**21.94**	**29.14**	**0.76**

The result shows an increase in soil water repellence after burning which is not shown by the unburned area. This is relevant because water repellency influences both runoff and erosion. Burning intensified soil hydrophobicity (compared with the unburned site) probably due to enhanced drying and high temperatures during the fire. Studies carried out in the effects of ash in Podentes study site revealed that water repellence depends on plant species and to some extent also on slope aspect. The ash from *A. Unedo* shows major water repellence behaviour as compared to ash from other shrub species (Quercus coccifera, Pistacia lentiscus).

Fire also influences soil infiltration. The study shows reduction of soil infiltration by about 25 per cent. Highest decline of infiltration capacity was observed in the burnt shrub species, *A. unedo*, which has also high soil water repellence value. This could be related to different surface litter and root systems of plant species. The results also show higher infiltration capacities on limestone area as compared to the area with schist bedrock. On schist sites, the fire had no discernible impact on runoff, and the average runoff coefficients for the burned sites were 24% Camelo, 29% Vale Torto and 8% Podentes.

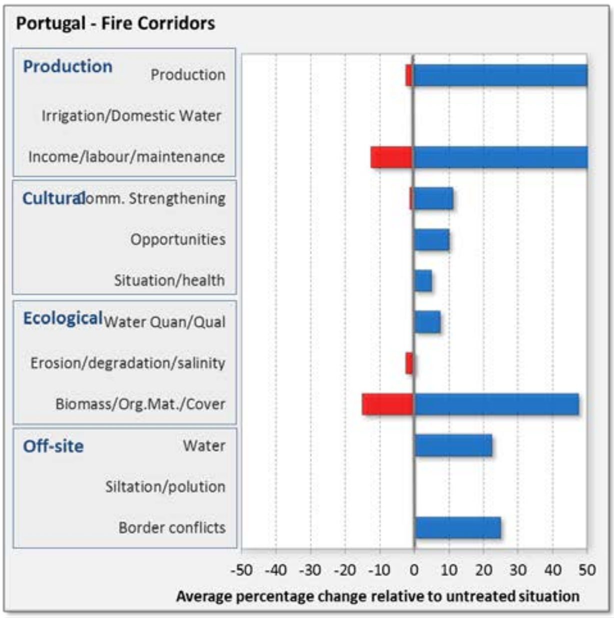


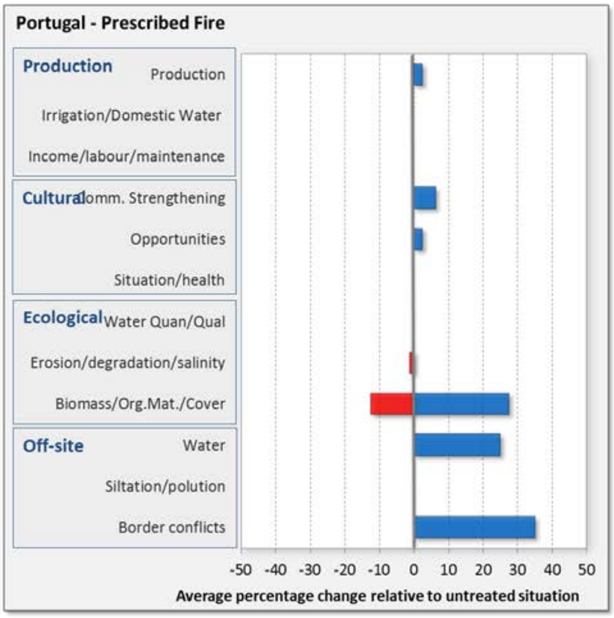
In case of soil losses, the schist study site shows a significant increase of soil loss for both cases: wild fire versus un-burned area (3.8 g m^{-2} vs 0.1 g m^{-2}), and prescribed fire versus un-burned area (1.6 g m^{-2} vs 1.2 g m^{-2}). In case of Vale Torto the increase in soil erosion after the fire was also significant. Soil loss results in Vale Torto site show a distinct increase (upto 8 -15 times) as compared to pre fire periods. In Camelo site, soil losses per unit contributing area are on average 1-2 orders of magnitude higher (2.2 t/ha for the first year after the wildfire, and 3.6 t/ha for the whole 19-month monitoring interval up to March 2010) compared with prescribed fire.

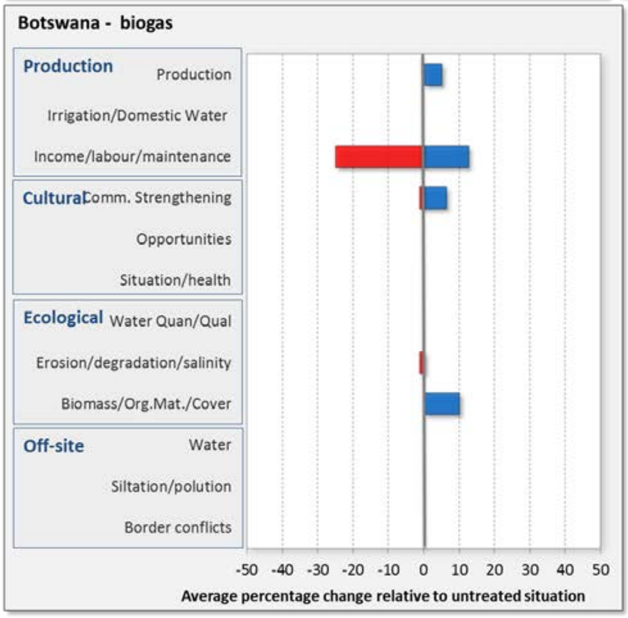
Evaluation

Prescribed burning is increasingly used as a tool for landscape management, in order to increase diversity and reduce forest fire risk. To perform prescribed burning, one has to get approved in a special fire management course, the means to perform it are only possible with the involvement of local authorities, which became involved in the Vale Torto experimental fire. The stakeholders were responsible for getting all the permits and perform the prescribed burning. They followed up the recovery of the burned area. The Benefits are the improvement of pastures for grazing and the reduction of forest fire risk. Prescribed fire is probably the most cost effective technique for landscape management, it is an old practice that was forbidden during 60 years, but it still has the adherence of local stakeholders. We expect a reduction on fire frequency and the diversification of local economy due to an increasing on grazing, bee keeping, cheese production, etc.

Finally a completely different technique was used in Botswana, but also one that potentially conserves natural vegetation: a biogas installation to conserve fire wood for coocking and domestic use.







Conclusions

Forest fire prevention using strip network is a useful technique but it can cause increased runoff and soil losses since the area along the strips will be bare and exposed to erosive rain. Currently the main infrastructure is protected but not the side roads. Possibly the strip network will extend to those as well. Where trees are cut at the strip there is a risk of erosion. Sediment loss from the strip area depends on tree species and terrain slope gradient. The erosion risk appears to be relatively low. Due to the testing activities, the erosion risk is now better integrated into the strip construction.

Prescribed burning, during the wet period seems to have less impacts on the soil and vegetation than the summer wildfires, therefore it is suitable as a land management technique. It has a reduced cost/effect rate, especially when compared with other techniques. It can be used to promote higher landscape diversity and therefore promote biodiversity. The landscape diversity can induce a higher diversity of economic activities, therefore increasing the appeal of mountain areas, by improving the local community's livelihoods.

3 GENERAL CONCLUSIONS

There are no best practices, only local solutions. Each site has its specific set of bio-physical, social and economic circumstances that each plays a role in the success. In general there are clear positive results, especially in terms of ecological benefits. The techniques selected in WB3 have clear effects on most sites. Where they don't, it can be explained why.

Techniques that work well must directly benefit farmers else the investment is too big. If the benefit is not directly experienced (such as for instance for soil erosion) it is even more difficult. There are usually compelling reasons form a farmer's points of view, not to implement a technique that is successful form a desertification point of view. Success based on longer trials and demonstration farms and even education/extension programs could be helpful. Generally desertification addresses a problem that has a much larger scale than can be addressed by the farmers alone, and they correctly claim that help and subsidy is needed. Also the comparison confirms that desertification can only be addressed if there are direct benefits in terms of production and income. If benefits take a few years to establish such as with minimum tillage and grazing management) subsidy is needed to overcome the first few years.

The efficiency of combatting desertification of the 7 functional groups can be summarized as follows:

<u>(1) Minimum tillage</u>. This technology is meant to restore a natural stable soil structure, which is relatively rich in organic matter. A good soil structure will increase infiltration and reduce runoff and erosion, and the surface is stronger in a sense protection against rainfall impact. The increased infiltration promotes water availability. On the down side there has to be some pest control at the moment of crop emergence, which is usually achieved with a combination of herbicides and light tillage. This land use system only works for cereals, not for root crops.

The results from the experiments show that under the right circumstances these mitigation processes are actually achieved, except in Morocco where the soil is very stony and has to be ploughed to make any type of sowing feasible. Generally water availability increases, as well as a reduction in runoff. The method works well in combination with other conservation practices such as increasing soil cover. Environmental effects from using more herbicides were not included in the study and unfortunately no conclusions van be drawn in that respect. In spite of the relatively positive bio-physical effects, this technology is not well accepted by the farmers for several reasons:

Crop yield is usually slightly lower, although still on comparable levels with the conventional tillage methods. Thus there is a drop in income which is only positive because the expenses are less. In these expenses however labour is also included as a cost factor (besides lower fuel costs), but labour may not always be expressible in hard cash, where it concerns family labour. With this in mind the reason for doing minimum tillage would be to control erosion. The increased water availability is generally considered moderately positive. Erosion control however does not translate directly in yield increase and the offsite effects are not the responsibility of farmers alone. Erosion is therefore not seen as an immediate problem and that benefit does not outweigh the trouble of implementing minimum tillage. Lastly minimum tillage field look different form conventional fields, often less "clean". The social implication is that you are a "bad" or "lazy" farmer, which is a strong negative incentive.

<u>(2) Soil cover, mulch and residue management</u>. The effects of these measures are a protection of the soil, obstruction to runoff control and protection against direct surface evaporation, conserving water. Green cover/green manure can be used between annual crops to cover the soil during a bare period in the

growing season (such as with alfalfa or mustard seed). Nitrogen rich species are used that are ploughed into the soil as extra nutrient supply and structure improvement. In a different fashion green cover can also be introduced in orchards to cover bare area between the trees, as is the case for Amonds (Spain) or Olives (Crete). On the down side the mulch may actually also intercept rainfall, while green cover can in certain situations be in competition for water with the first crop (Almonds, Olives). The overall results of these experiments are unclear. In the first place in semi-arid environments it is not easy to get mulch, biomass is in short supply and it may even be expensive to obtain, while (at least in Spain) the results were not at all convincing. So mulch was not accepted by the farmers at all in this one case. Green manure between Almonds had some clear positive effects but this may not outweigh the extra trouble, this depends on the price you get for the harvest of this second crop. So it is market driven. Green cover in Olives groves has a clear effect in runoff and erosion mitigation, but farmers generally feared too much water competition, which could not really be disproven, and erosion conservation is not their first concern.

(3) Runoff control. The purpose of these measures is always twofold: reduce runoff and erosion, and increase water availability through increased infiltration. This is a mixed group of various techniques, from actual terracing subsidized by the government (China, Cape Verde) to a stakeholder approach in Turkey (Eskeshir) where farmers made fences woven from branches that capture sediment and runoff that will gradually form terraces. In general the results are good if the terraces are established with outside help and people are used to it. This experience is confirmed form many parts in the world (Nepal, Peru, South East Asia). Water availability is higher, crop yield is also higher in all cases. However from a point of view of local stakeholders, soil erosion is seen as a wider problem where it concerns offside effects, and the responsibility of the government. Also, teraccing is very expensive, needs a great deal of technical experience to avoid erosion and landslides, and generally destroys the soil structure when they are created, which takes long to restore. The project results confirm that it is almost never a local stakeholder solution that can be carried by the community.

The experience of Turkey however shows that good results can be obtained with a much less rigorous intervention: woven fences are easy to establish and restore and combined with contour plouging work well to increase moisture and prevent runoff. However, again there is a downside that might prevent farmers from using this technique: depending on the field shape and orientation towards the slope direction, the technique may result in very short and wavy tillage lines with many tractor turns needed. The tractor is also hampered by the fences. Thus operational costs may be higher, while the yield may be lower. In Turkey this was not the case: yield was actually higher but the reasons were not quite clear.

(4) Water harvesting. The water harvesting techniques tested are all related to capturing natural runoff and leading this to terrace like, flat pieces of land. In Tunisia this system has been used for many decades and people are used to it and know exactly what they can expect. Water of the surrounding area is captured to have a (sometimes subsistence) Olive harvest. Since this is in a true arid area with very low rainfall, there would be no agricultural activity without this system. Thus here is not really a unmitigated system to test. It can be said however that the groundwater is sometimes also for additional watering and this causes overexploitation. The system functions if it is combined with groundwater infiltration zones. There is complete acceptance of this technique as it is the only low-cost solution available. However, it may not give a secure future for younger generations.

In Spain, a similar traditional water harvesting system exists, using natural runoff water (traditional Boqueras system), combined with Almond orchards. It is being revived after having been neglected for a period of time, due to economic fluctuations. It works well in terms of increased water availability, increasing yield. It will not be available to everybody because your fields need to be downstream of a water delivering system. An added benefit might be that the natural surrounding area increases in value. In China bench terraces and check dams are being built by the government that also serve as water harvesting systems, simply because the steep slope and fast runoff is now being captured on the flat terrace surfaces. The construction is expensive and can only be done by the government, who is interested in decreasing downstream sediment problems (because of hydroelectric power installations and domestic and industrial use of river water). Once established, the terraces work well and show increased yields and decrease of soil loss. Currently farmers in the area find work outside agriculture and the interest is less.

(5) Irrigation management. Irrigation is of course done in areas with water shortage to be able to grow crops. In all areas however there was a risk of salinization, because of brackish groundwater and high evaporation. Salts concentrate in the top soil over time and decrease yields. Salinisation is very difficult to combat. Flushing with fresh water (as is done in Nestos) is usually expensive and the water has to be available. Drip irrigation is very successful: the water use declines improving the overall water availability and reducing the dependence on brackish groundwater. The detrimental effect on the soil surface of excessive furrow irrigation is absent. Yields are high although they were tested for vegetable garden scale tomatoes, and not for large scale cereals. Drip irrigation also promotes much better water management; furrow irrigation system can be very uneconomical with excess water use (as in the Novy site in Russia) and Sprinkler irrigation can also waste water because of direct evaporation and wind action. Drip irrigation might actually also be a solution for the Greek site of Nestos, but this was not tested. The downside is that drip irrigation systems cost some initial investment, so it depends on the local situation of taxes on water use, fuel expenses for pumping large amount s of water in furrow systems etc.

(6) Rangeland management. This technique promotes to set aside a part of a communal grazing area so that there can be a natural reseeding of species and a higher boidiversity. Often overgrazed lands still have vegetation but generally unpalatable for cattle and sheep, even for goats. Bushes are thorny or have chemicals that prevent eating. Set aside of grazing areas gave very positive and immediately visible results in an increase in biomass, cover and species composition. The returning species (possibly dormant in the soils) were of a high quality for grazing. This technique was used directly to increase the rangeland quality (Tunisia, Crete) or it was used in combination with various erosion mitigation measures such as gully control (Morocco). Stakeholders see and recognize the benefits and are generally positive because the implications for their lifestock are immediate. However there are important initial constraints and considerations:

i) Setting aside a part of the land there must be some fencing to keep cattle out, that is often free roaming. Fencing and maintenance are very expensive. Possibly in a larger integrated approach, areas that have natural barriers (valleys) could be assigned as set aside.

ii) In the first few years when restoration is established, there is potentially too much cattle in an area because part is set aside. Thus calls for a decrease in livestock (very sensitive issue) or extra feeding with fodder brought in, and therefore a subsidy would be needed.

iii) When cattle is kept out of restricted areas, care must be taken that not other areas become overgrazed. For instance in Morocco the Mamora forest is already under pressure from overgrazing, and large scale protection of gullies would be detrimental for this forest. An integrated approach is needed.

iv) Land rights are often a sensitive issue so delineating lands means also defining rights of grazing. This on the one hand might promote a democratic and discussion process, but is a very sensitive issue that cannot be done by outside “scientific” teams.

(7) Forest fire management. In Portugal two techniques for forest fire mitigation have been tested: strip networks where vegetation is cut along major roads, and prescribed burning. The latter is a technique to do controlled burning in spring to reduce the fuel load in summer and thus prevent heavy fires. Both have as an added problem that the bare areas might result in increased soil erosion. The soil surface may become water repellent after burning due to the heat of the fire that affects the organic matter in the soil. Soil erosion was not really a problem in case of the strip network. It might become a problem when he network is extended to secondary roads.

Prescribed burning, during the wet period seems to have less impacts on the soil and vegetation than the summer wildfires, therefore it is suitable as a land management technique. It has a reduced cost/effect rate, especially when compared with other techniques. It can be used to promote higher landscape diversity and therefore promote biodiversity. The landscape diversity can induce a higher diversity of economic activities, therefore increasing the appeal of mountain areas, by improving the local community’s livelihoods.