Dry Agriculture

1. Introduction

The objective of the following analysis is to identify critical determinants that may contribute to promote desertification under dry agriculture and to define strategies that may efficiently counteract this process. Agronomical aspects will mainly refer to land and water conservation with a particular focus on typical non-irrigated crops of the Mediterranean environment, which generally rely on seasonal rainfall. In this context, environmental, political and economic issues related to sustainability of dry agriculture will be also addressed.

Although dry climates can be identified quite easily, water-limited environments are more difficult to define. A widely used system to classify water-limited environments is based on mean precipitation. Arid lands have less than 250 mm of annual rainfall and semi-arid lands have a mean annual precipitation between 250-500 mm. Extremely dry environments, desert and semiarid regions allow plant growth to some extent. Therefore, cropping systems established in these areas have evolved through a gradual merging of suitable cultivation practices and plant selection programs. These systems will be examined in order to highlight agriculture-associated desertification problems and possible mitigation strategies. Standard measures to combat desertification and *novel* approaches, including the reintroduction of *traditional knowledge* and the potential of biotechnologies will also be considered.

2. Water conservation

Dry agriculture is strictly dependent on precipitation and its variability and it is implicitly based on water-saving agriculture systems, which must address: 1) a rational exploitation and utilization of water resources, 2) agronomic water-saving practices; 3) water saving management measures (Sarno, 1998). Therefore, soil and water management are critical determinants of conservation and sustainability in dry agriculture. Soil conservation is fundamental to guarantee optimal conditions in the root zone, including sufficient water availability for plant growth. If we consider that the soil water balance can be expressed by the relationship

$$P+I= R+ET+\Delta S+D$$

[where P and I are precipitation and irrigation water respectively; R=the runoff water; T=evapotranspiration, ΔS= variations in the root zone water; D = the seepage below the root zone].

it is quite evident that 1. Minimizing water loss through evaporation, runoff and drainage beyond the root zone and 2. Enhancing the use of rainfall are the fundamental objectives that we need to pursuit to improve crop establishment and yield under water shortage.

2.1. Increasing soil water storage capability

The soil water retention depends on *a*) the soil structure; *b*) the soil particles size distribution; *c*) the soil depth in which roots will expand. It is quite difficult to modify *b*) on large surfaces, therefore the soil water content can be efficiently increased by improving the soil structure and increasing the *active* soil in the root zone. The soil structure affects chemical, physical, and biological determinants of soil fertility, which will all contribute to increase the available soil water for plant growth. Organic matter also plays a fundamental role in improving both soil structure and structure stability since this will promote the formation of soil aggregates (the basic component of soil structure). According to Jastrow et al. (1995), 70% of soil organic matter is immobilized in soil aggregates where it forms complexes with clay minerals, which are essential to guarantee a stable soil structure. Break down of soil aggregates, as a consequence of poor soil management, or low organic matter content, will also facilitate soil erosion, which in turn will lead to reduce the amount of soil available for proper root development. The addition of crop residues, manure and/or other forms of organic matter is important to improve the formation of soil aggregates and is critically associated to crop rotation, a practice that has been gradually abandoned as a consequence of crop specialization. Details on the role of soil organic matter for a sustainable land management can be found in Raman (2006).

Tillage generally increases the active (chemically and biologically) soil that can be explored by the root system (Pala et al., 2000). This effect is particularly important in clay and compact soils, where tillage will increase the soil volume easily accessible to roots, it will improve soil porosity and gas/water exchanges between different soil layers, and ultimately enhance the soil water storage. In hot and dry regions, traditional ploughing that will expose deeper soil layers to air and high temperatures should be discouraged since these will speed-up the organic matter mineralization, which will eventually negatively affect both soil structure and aggregate stability. In contrast, rippering and/or subsoil ploughing will improve water infiltration while preserving soil structure from chemical and mechanical damages. The role of an intense tillage with respect to soil water conservation in dry environments has been recently questioned. In some environments, deep tillage during the dry season, followed by a medium seasonal rainfall, will increase soil water accumulation of 50mm and 100mm compared to minimum and zero-tillage, respectively. This situation seems to be reversed with low rainfall. In this case, minimum tillage results in an improved soil water content and higher yield respect to deep tillage. A comparison of different tillage techniques in Southern Italy has indicated that no-tillage was superior below 300 mm rainfall, whereas higher rainfall enhanced yield under conventional tillage. When no-tillage has performed better than conventional tillage during the durum wheat growing season, this was associated to a reduced water evaporation from the soil combined with an enhanced soil water availability. In addition, it should be considered that long-term effects of mechanical disturbance of the soil by conventional tillage will destabilize soil aggregates, which in turn will both facilitate soil particles displacement (erosion) and reduce soil depth.

2.2. Reducing runoff

When the rainfall intensity is higher than the infiltration velocity, stagnation or runoff may occur, both of which will lead to an irreversible water loss. In plain lands, stagnation will expose water to evaporation loss and it will also cause anoxia in the root zone. In hilly areas, slow infiltration of the rain water will cause water loss through runoff, which will eventually cause displacement of soil particles and erosion. Actions aimed at improving the soil infiltration properties should be focused on introducing those measures that will ameliorate the soil structure, including addition of organic matter, reintroducing crop rotations, and minimizing mechanical damages associated to an intensive tillage. In presence of steep slopes, conservative measures should include modifications of the soil profile through simple actions such as contour tillage and construction of ridges that will slow-down the runoff water, or introduction of more complex structures such as terraces.

2.3. Improving water infiltration

Higher water infiltration rates into the soil can be achieved by improving the soil structure and the permeability of different soil layers. Mulching with crop residues may counteract mechanical damage of rain drops on soil aggregates and may reduce, up to 50%, water loss through runoff. Traditional practices like leaving the bare soil for a year to improve water storage for the following crop (fallow), although gradually abandoned, may still have some value. This technique aims at 1) improving water infiltration through deep tillage before the rain season and 2) reducing evapotranspirative water loss through both superficial tillage (hoeing) and mechanical weeding, after the rain season. Based on analyses of experimental results, we can provide the following guideline relative to fallow practiced in different environments:

- It provides better results in cold-dry climates;
- It may be important when yearly rainfall is around 250-300 mm;
- If > 450 mm $year^{-1}$ it may not be necessary;
- If < 400 mm $year^{-1}$ it is beneficial on soil water storage;
- In very arid regions (250-300 mm $year^{-1}$) it is necessary to guarantee sufficient water for the following crop.
- In most cases, the use of legumes as cover crops or pastures can be suggested as a more effective alternative. It must be pointed out that, compared to fallow, cover crops do not

specifically improve the soil water content, but they can ameliorate soil fertility, the aggregate stability and the general soil physicochemical properties.

2.4. Reducing soil water evaporation

This goal can be practically achieved through 1. Use of wind barriers, 2. Mulching, 3. Tillage of superficial soil layers (10-15 cm). Among the environmental factors that will affect evaporation, wind plays a critical role since it enhances evaporation by increasing the vapour pressure deficit (VPD) in proximity of the soil. Wind barriers counteract evaporative water loss from the soil. For relatively small surfaces, wind barriers can be walls, plastic screens or wooden palisades. Most common are tree or bush barriers. Mulching also improves the soil water balance by reducing evaporative loss in addition to fulfil other functions like minimizing weed development, increasing the soil temperature and reducing runoff and soil erosion. For most field crops of rain-fed environments, organic residues from different crops are left on the soil for mulching purposes. The amount of mulching residues covering the ground, however, is critical for a complete protection. For cereal residues (wheat) 10t ha^{-1} are recommended. Tillage of superficial soil layers is also a multipurpose practice in dry environments. For example, hoeing is effective in both controlling weed development and reducing water loss through evaporation. In addition, it will enhance in some circumstances water infiltration by breaking superficial crusts. The main effect of hoeing is the interruption of the soil capillary water movement. This can reduce up to 50% the evaporative water loss. Sandy and heavy soils may both benefit of this practice that will effectively minimize evaporative surfaces by closing either macro-pores (sandy soils) or deep cracks (which in clay soils are responsible of 20-30% of the evaporative water loss).

2.5. Reducing transpirational water loss

Reducing the water loss via transpiration is most critical in dry climates. Traditionally this is accomplished by using wind barriers, weed control and possibly using anti-transpirants. Wind may have an effect on leaf surfaces similar to that described for the soil. Dry wind will cause intensive transpirational fluxes that in some cases can determine physiological unbalances (quite common in wheat grown in semi-arid environments). Although the available strategies to counteract this phenomenon are quite limited, the above mentioned wind barriers will accomplish the same function with respect to the control of transpirational water loss (Sarno, 1998).

Weeds massively compete with the crop for most resources, including water. In water limiting environments competition between wheat and the associated weed *Avena fatua* L. can reduce yield up to 60%. Weeds generally possess adaptive/tolerance traits that make them very competitive in resource limited environments. An effective weed control is sometimes difficult to accomplish due to technical and/or cost limitations. Burning of crop residues is an old practice that eliminates seeds and propagation organs of most weeds. This practice in some circumstances may have opposite effects by stimulating germination of some seeds or vegetation of subterranean organs that were not devitalized by the high temperature. Although mechanical weed control is generally limited by the type of crop, cost, effectiveness and possibility of accessing the field with an established crop, it still remains the preferred control system in many contexts. Mechanical weeding (harrowing) often provides better control compared to chemical weeding since it has positive effects on soil water retention properties and the reduction of water loss by soil evaporation. In dry-hot environment mechanical weed control, before autumn seeding, should be recommended when possible. Chemical control generally overcomes problems associated to the accessibility of clay soils during the rain season. It should be pointed out that problems associated to phytotoxic compounds accumulation into the soil are particularly important in dry environments. The sustainability of this practice should therefore be considered in the specific environmental context. Results of multiple experiments in different locations have demonstrated that the soil water loss from August to June respect to different weed control practices can be summarized by the following ranking: no weed control (highest water loss)> chemical control> hoeing > mulching with crop residues (lowest water loss).

3. Improving water use efficiency in dry environments

In addition to the above mentioned techniques, improving plant water use efficiency (WUE, the ratio of water applied to crop yield) and harvest index [HI, the ratio of grain (or commercial product) to above-ground dry matter] are major challenges in dry environments. A rapid establishment of the crop will increase WUE since this will reduce the amount of solar radiation that reaches the soil and causes evaporative water loss. Anticipated sowing, fertilization, and rapidly growing varieties (*early vigor*) will all contribute to reduce soil water loss. Technical strategies to improve a more efficient water use should aim at obtaining the best match between water sensitive phenological stages and water availability. For a typical cereal crop (wheat) of rain-fed Mediterranean environments, an excessively long vegetative stage due to over-fertilization (N excess) or delay in the sowing time, will result in high water requirements during the reproductive phase and possible water shortage during grain filling (a very sensitive physiological stage in dry environments). A poor crop management in these conditions will lead to a dramatic reduction of the Harvest Index. Plant water use efficiency can also be critically affected by an optimal nutritional environment. Resource-extractive low-input cultivation systems such as those practicable in marginal rain-fed areas can gradually deplete soil fertility (Raman, 2006) and enhance other penomena such as soil erosion, drought and eventually desertification. In extreme cases this process has led to agricultural stagnation. An important role in sustainable cropping systems for these environments is played by legume crops that, in addition to provide forage for livestock rations, significantly contribute to the biological and chemical soil fertility. The improved soil physical and chemical properties associated to the presence of legume crops will result in a reduced erosion in hilly areas and an increased accumulation of soil organic matter. The re-introduction of legumes should also be considered in terms of crop diversification, which may counteract insects, disease and weed specialization (Sheaffer and Seguin, 2003).

Plant breeding and genetic engineering are powerful tools to transfer tolerance traits to low-input environments (Maggio et al., 2002a; 2002b)). Water use efficiency (WUE) has been considered for long time a genetic trait not easy to transfer. Breeding programs aimed at improving the production per unit volume of water have actually improved the Harvest Index rather than WUE, either by introducing dwarf and short-cycle varieties or by selecting for tolerance to closer planting (higher density). Margins to further improve the HI are rather limited, however (Raman, 2006). Recent advancement in molecular genetics has opened new avenues in this field since genes that may control plant water use efficiency have been identified (Bennet et al., 2002; Masle et al., 2005) and represent an important genetic resource to improve plant WUE.

4. Social and economic implications: strategy to counteract desertification in dry agriculture areas: merging agronomic and socio-political options

The social economic aspects associated to desertification in dry agriculture are particularly important since the economic sustainability of cropping systems that can be practiced in these environments is quite often a limiting factor. Social and economic crises in traditional agriculture in recent years have caused migration of people from less favourable rural to urban areas, which in turn resulted in land abandonment and exposure of marginal land to degradation. Additional complexities that may exacerbate desertification problems associated to dry agriculture of Mediterranean regions are: the presence of diversified landscapes; overlapping of various cultures; climatic conditions characterized by seasonal droughts with high rainfall variability or sudden/intense rain. In this respect, demographic shortfall and depopulation are a serious issue for a large part of semi-arid land regions, especially because the migration from these areas is mainly of the younger and more literate part of the population. This process is partially due to the increasing problem of isolation, both physical and cultural, which is considered as a main constraint. Despite the abovementioned complexities, the agricultural sector plays a significant role in both land use and socio-economic terms in the Mediterranean basin. Therefore the assessment of the effects of current practices in terms of resource conservation and use efficiency could be helpful to identify weaknesses and correction measures to improve farm organization and the sustainability of the overall performances.

Dry agriculture of Mediterranean regions often involves a large number of small-scale entrepreneurs who make individual decisions on the management of their natural resources and on the investment of their capital. Although the land use decisions of any individual farmer may seem irrelevant, these decisions are repeated over and over again the countryside, and jointly can achieve major regional and even global consequence. Therefore it is widely recognized that agricultural land use systems are significant contributors to soil and environmental degradation. Many studies have been conducted to evaluate this contribution and to produce worldwide soil risk maps, mainly based on the environmental issues, except the case where some management factors have been taken in account, like in the case of the Environmental Sensitive Areas (ESAs) index (Kostas *et al.,* 1999). An articulated examination of the cultivation practices and livestock production management associated to land degradation risk has been recently performed for the Agri Basin (Kostas *et al.,* 1999). Results for two representative crops, wheat and olive, which in this region are typically cultivated in absence of irrigation, are briefly described.

4.1. Wheat

The technology generally used for wheat cultivation in most hilly and dry areas of Southern Italy, plays a very important role as regards both to land degradation and land mitigation. The study carried out in the pilot area of the Agri basin (Desertlinks, 2002) found 59 different techniques for wheat cultivation that can be summarized according to their impact on land degradation as follows:

Very good practices. These techniques are mainly based on the *direct sowing* (direct drilling, no tillage) with crop rotation. Their percentage is very low, less than 4%, on the total techniques inquired. The results both from the environmental point of view and from the economic one are extremely remarkable, in relative and absolute terms. All these techniques are only used since few years, the oldest has been applied for four consecutive sowing season, and it is particularly interesting to follow this experience for the next years to verify the continuity of its excellent performance.

Good practices. The inquire found also a small percentage, about 11%, that according to their overall impact on soil degradation, can be defined as a good ones for the area. These practices allow either *direct sowing* without crop rotation or *minimum tillage* with crop rotation. In these circumstances the light tillage operation are considered as compensated by crop rotations, that ensure both chemical and physical benefits, reducing soil erosion and increasing its organic matter content.

Bad practices. The practices that make a large use of ploughing activity and other soil operations, together with the absence of any crop rotation since decades, are considered totally unsustainable for the area (Bove et al., 1996), (Quaranta, 1999). Among these, the ones that allow the conventional parallel contour tillage, counts for about 13% on the total techniques gathered. Where the slope conditions permit the farmers to operate their machinery following the contour lines, some of them prefer this method, but in any case the reasons almost never seems derived by agronomic considerations.

formal education among the Agri farmers. There is no progeny to continue their parents' activity, whereas they are usually involved in off farm activities, very often outside this region.

4.2. Olive

Current practices. Olive orchards are also quite represented in the Agri basin. Tillage practices for olive production in this area include a winter rippering (20 cm depth) and a spring superficial ploughing, using harrowing and/or rotary cultivators. In traditional intensive systems, fertilization is generally both mineral and organic, whereas in traditional extensive systems is mostly organic (green manure or pasture). Winter pruning (February) is usually carried out on alternate years. Pruning residues are rarely ploughed into the soil, more generally they are collected and burned. The use of cover crops is not common. Spontaneous growth between ploughings period may occur. The weed control in olive orchards is mostly mechanical and in a few circumstances also chemical (glyphosate).

Margins for improvements. In dry olive-farming conditions, water intake and storage during the rainy season are the most critical variable that will affect the final yield. Therefore best management practices must aim at preserving and improving the soil structure, minimizing erosion and carbon loss, enhancing water intake during the rain season, reducing water loss during the dry season. Soil management measures that will reduce soil erosion include contour ploughing, strip cropping and/or terracing, minimum tillage or no-tillage with chemical weed control. No-tillage with full vegetation cover or with some vegetative bands appears to further reduce erosion rates, although competition effects between cover crops and olive trees should be considered. In this case, temporary cover crop or natural vegetation during the wettest period of the year, followed by a cut during the dry period, could significantly limit the competition for water. Use of terraces and/or ridges to slow-down the run off water in hilly lands in addition to legumes intercropping, minimum tillage and minimum pruning would also improve the long-term sustainability of olive production in most susceptible areas.

5. Conclusive remarks

Based on all the above, we may conclude that improving technical control measures for water and soil conservation is most critical in dry agriculture. This is not new in resource-limited environments. Specifically to susceptible areas, these measures should be envisioned in terms of both *production enhancement* and *environmental implications*. In this respect, typical farms and cropping systems should be re-designed to guarantee the sustainability of the production process with respect to environmental conservation. When this complex equilibrium is unbalanced towards maximizing yield, a gradual degradation of soil, water and environment occurs (Prihar et al., 2000) (Quaranta et al., 1999), which will eventually lead to an environmental cost.

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