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Sustainable water management in agriculture under climate change

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Abstract

Water is considered as the most critical resource for sustainable agricultural development worldwide. Irrigated areas will increase in forthcoming years, while fresh water supplies will be diverted from agriculture to meet the increasing demand of domestic use and industry. Furthermore, the efficiency of irrigation is very low, since less than 65 % of the applied water is actually used by the crops. The sustainable use of irrigation water is a priority for agriculture in arid areas. So, under scarcity conditions and climate change considerable effort has been devoted over time to introduce policies aiming to increase water efficiency based on the assertion that more can be achieved with less water through better management. Better management usually refers to improvement of water allocation and/or irrigation water efficiency. The former is closely related to adequate pricing, while the latter depends on the type of irrigation technology, environmental conditions and the scheduling of water application. Agricultural practices, such as soil management, irrigation and fertilizer application and disease and pest control are related with the sustainable water management in agriculture and protection of the environment. Socio-economic pressures and climate change impose restrictions to water allocated to agriculture. The adoption of sustainable water management in Mediterranean is not only a technological problem but involves many other considerations relative to social behavior of rural communities, the economic constrains, or the legal and institutional framework that may favor the adoption of some measures and not others. Sustainable water management in agriculture, which has a multi-functional role in Southern Europe, can be achieved by adopting improvements in irrigation application, soil and plant practices, water pricing, reuse of treated wastewater, farmers' participation in water management and capacity building.

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Keywords: Irrigation; Water efficiency; Water reuse; Innovation; Capacity building

1. Introduction

Water is considered as the most critical resource for sustainable development in most Mediterranean countries. It is essential not only for agriculture, industry and economic growth, but also it is the most important component of the environment, with significant impact on health and nature conservation. Currently, the rapid growth of population along with the extension of irrigation agriculture, industrial development and climate change, are

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stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" methodology either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Global irrigated area has increased more than six fold over the last century, from approximately 40 million hectares in 1900 to more than 260 million hectares (Postel, 1999; FAO, 1999). Today 40% of the world's food comes from the 18% of the cropland that is irrigated. Irrigated areas increase almost 1% per year (Jensen, 1993) and the irrigation water demand will increase by 13.6% by 2025 (Rosegrant and Cai, 2002). On the other hand 8-15% of fresh water supplies will be diverted from agriculture to meet the increased demand of domestic use and industry. Furthermore the efficiency of irrigation is very low, since only 55% of the water is used by the crop (Fig. 1). To overcome water shortage for agriculture is essential to increase the water use efficiency and to use marginal waters (reclaimed, saline, drainage) for irrigation.

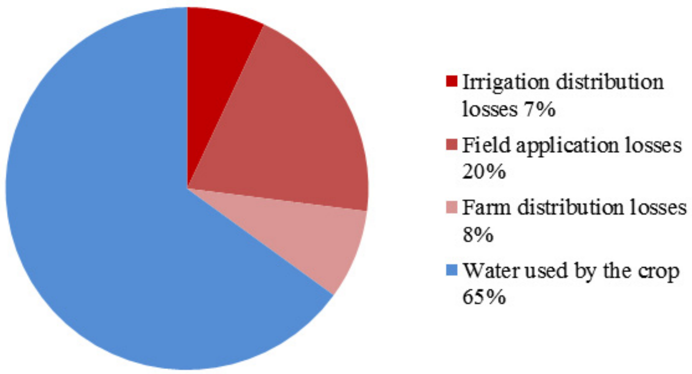

Fig 1 Water losses in agriculture

2. Water and agricultural production

Agriculture currently uses about 70% of the total water withdraw, mainly for irrigation. Although irrigation has been practiced for millennia, most irrigated lands were introduced in the 20th century. The intensive irrigation could provide for the growth of irrigated areas and guarantee increased food production. In the 1980s, the global rate of increase in irrigated areas slowed considerably, mainly due to very high cost of irrigation system construction, soil salinization, the depletion of irrigation water-supplying sources, and the problems of environmental protection. However, as the population is growing at a rapid rate, irrigation is being given an important role in increasing land use and cattle-breeding efficiency. Thus, irrigated farming is expected to expand rapidly in the future with subsequent increase of water use for irrigation.

Irrigation is not sustainable if water supplies are not reliable. Especially in areas of water scarcity the major need for development of irrigation is to minimize water use. Effort is needed to find economic crops using minimal water, to use application methods that minimize loss of water by evaporation from the soil or percolation of water beyond the depth of root zone and to minimize losses of water from storage or delivery systems. Nowadays, during a period of dramatic changes and water resources uncertainty there is a need to provide some support and encouragement to farmers to move from their traditional high-water demand cropping and irrigation practices to modern, reduced demand systems and technologies.

Under scarcity conditions considerable effort has been devoted over time to introduce policies aiming to increase water efficiency based on the assertion that more can be achieved with less water through better management. Better management usually refers to improvement of allocative and/or irrigation water efficiency. The former is closely related to adequate pricing, while the latter depends on the type of irrigation technology, environmental conditions and on scheduling of water application.

It is well known that crop yield increases with water availability in the root zone, until saturation level, above which there is little effect (Hillel, 1997). The yield response curve of specific crops depends on various factors, such as weather conditions and soil type as well as the reduction of the agricultural inputs like fertilizers and pesticides (Fig. 2). Therefore it is difficult for a farmer to tell at any given moment whether there is a water deficit or not. Since overabundant water usually does not cause harm, farmers tend to "play safe" and increase irrigation amount, especially when associated costs are low. Over-irrigation can cause among others temporal water shortage to other farmers, water-logging conditions for the crop, favorable environment for disease development, loss of nutrients due to leaching or deep percolation, contamination of the aquifers from agrochemicals, reduction of crop yield and deterioration of the quality and increase of production cost.

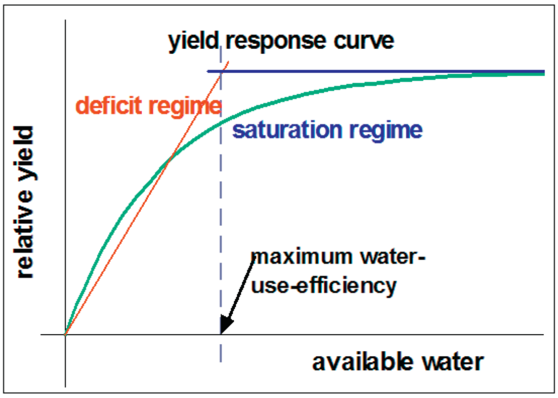

Fig. 2 Plant yield response to water

3. Sustainable water management in agriculture

Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact. Its adoption involves technological problems, social behavior of rural communities, economic constrains, legal and institutional framework and agricultural practices.

Under water demand management most attention has been given to irrigation scheduling (when to irrigate and how much water to apply) giving minor role to irrigation methods (how to apply the water in the field). Many parameters like crop growth stage and its sensitivity to water stress, climatic conditions and water availability in the soil determine when to irrigate or the so-called irrigation frequency. However, this frequency depends upon the irrigation method and therefore, both irrigation scheduling and the irrigation method are inter-related.

3.1. Localized irrigation

Localized irrigation is widely recognized as one of the most efficient methods of watering crops (Keller and Bliesner, 1990). Localized irrigation systems (trickle or drip irrigation, micro-sprayers) apply the water to individual plants by means of plastic pipes, usually laid on the ground surface. With drip irrigation water is slowly applied through small emitter openings from plastic pipes with discharge rate ≤ 12 l/h. With micro-sprayer (micro-sprinkler) irrigation water is sprayed over the part of the soil surface occupied by the plant with a discharge rate of 12 to 200 l/h. The aims of localized irrigation are mainly the application of water directly into the root system under conditions of high availability, the avoidance of water losses during or after water application and the reduction of the water application cost (less labor).

Studies in diverse countries as India, Israel, Spain and United States have consistently shown that drip irrigation reduces water use by 30 to 70% and raises crop yields by 20 to 90% (Postel et al., 2001). Drip irrigation's combination of water savings and higher yields typically increases at least by 50% the water use efficiency, yield per unit water (Tab. 1), and makes it a leading technology in the global challenge of boosting crop production in the face of serious water constrains. Although the area of localized irrigation has expanded 50-fold over the last two decades, it still represents less than 6 percent of the world's irrigated area. The main barriers to its expansion are the high investment cost, ranging from 1,500 to 2,500 € per hectare, and the high sensitivity to clogging.

Table 1. Irrigation water, yield and WUE in kiwi irrigated with different systems (Chartzoulakis et al., 1991)

Irrigation system	Water used* (mm)	Yield (kg/tree)	WUE (kg/mm)
Drip	340	33.2 a	4.00 a
Micro-sprinkler	477	30.9 a	2.65 b
Overhead sprinkler	782	34.6 a	1.81 c

* Average of 10 years

Improvements in localized irrigation systems aiming to reduce the volumes of water applied and increase the water productivity include the use of a single drip line for a double row crop, the use of micro-sprayers in high infiltration soils, the adjustment of duration of water application and timing to soil and crop characteristics, the control of pressure and discharge variations, the use of appropriate filters to the water quality and the emitter characteristics used, the adoption of careful maintenance, automation, fertigation (efficient fertilizer application) and chemigation (easy control of weeds and soil born diseases).

3.2. Irrigation scheduling

Irrigation scheduling is the decision making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crops' water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply (Fig. 3). In most cases, the skill of the farmer determines the effectiveness of the irrigation scheduling at field level. With appropriate irrigation scheduling deep percolation and transport of fertilizers and agro-chemicals out of the root-zone is controlled, water-logging is avoided, less water is used (water and energy saving), optimum soil water conditions are created for plant growth, higher yields and better quality are obtained and rising of saline water table is avoided. In water scarce regions, irrigation scheduling is more important than under conditions of abundant water, since any excess in water use is a potential cause for deficit for other users or uses.

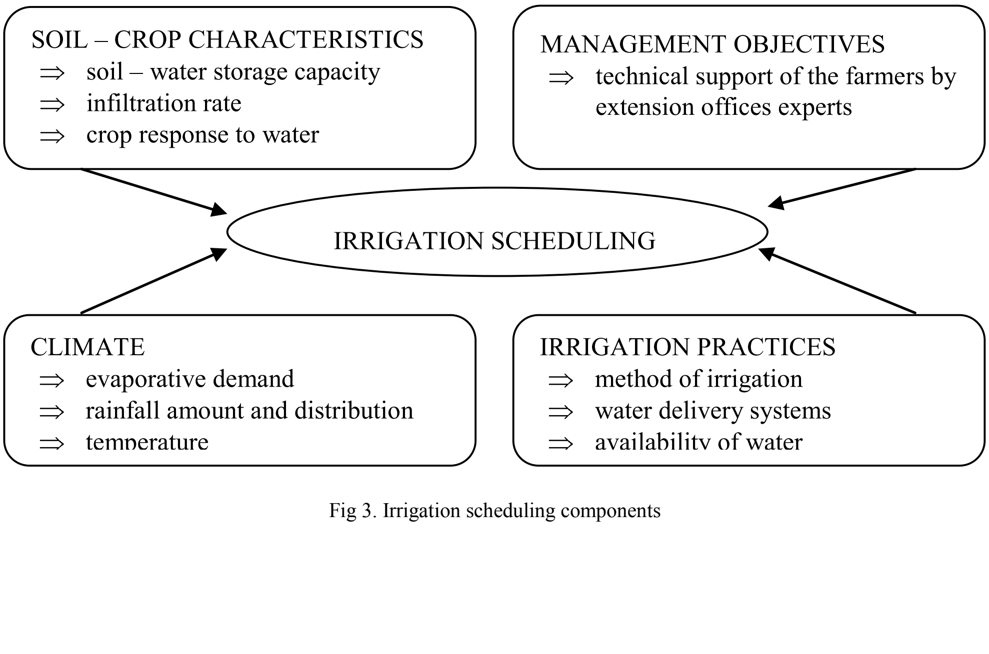

Fig 3. Irrigation scheduling components

Irrigation scheduling techniques and tools varies greatly and has different characteristics relative to their applicability and effectiveness. Timing and depth criteria for irrigation scheduling (Huygen et al., 1995) can be established by using several approaches based on soil water measurements, soil water balance estimates and plant stress indicators, in combination with simple rules or very sophisticated models. Many of them are still applicable in research or need further developments before they can be used in practice. Most of them require technical support by extension officers, extension programmes and/or technological expertise of the farmers. However, in most countries these programmes do not exist because they are expensive, trained extension officers are lacking, farmer's awareness of water saving in irrigation is not enough and the institutional mechanisms developed for irrigation management give low priority to farm systems. Therefore, in general, large limitations occur for their use in the farmers practice. A brief description of irrigation scheduling techniques with reference to their applicability and effectiveness are reported below.

3.2.1 Soil water estimates and measurements

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to assess the availability of soil water for plant growth: by measuring the soil water content and by measuring how strongly that water is retained in the soil (soil water potential). The accuracy of the information relates to the sampling methods adopted and to the selection of locations where point observations are performed due to the soil water variability both in space and depth (Peymorte and Chol, 1992). Soil water estimates and measurements used for irrigation scheduling include: *soil appearance and feel*, *soil water content measurement (TDR), soil water potential measurement* (tensiometers, soil spectrometers and pressure transducers), *remotely sensed soil moisture*.

3.2.2 Crop stress parameters

Instead of measuring or estimating the soil water parameters, it is possible to get a signal from the plant itself indicating the time of irrigation but not defining the irrigation depths. This message can either come from individual plant tissues, where a correct sampling is required, or from the canopy as a whole. Therefore, crop stress parameters are useful when irrigation depths are predefined and kept constant during the irrigation season. Crop water stress parameters include *leaf water content and leaf water potential, changes in stem or fruit diameter, sap flow measurement, canopy temperature, remote sensing of crop stress* (Deumier et al., 1996; Cohen *et al.,* 1981; Idso *et al.,* 1981; Jackson *et al.,* 1981; Itier *et al.,* 1993).

3.2.3 Climatic parameters

Climatic parameters are widely used for local or regional irrigation schemes. Weather data and empirical equations that, once they are locally calibrated, provide accurate estimates of reference evapotranspiration (ETo) for a given area are used. Then, crop evapotranspiration (ETc) is estimated using appropriate crop coefficients. Information may be processed in real time or, more often, using historical data. These techniques include *evaporation measurements* for ETo calculation, *assessment of crop evapotranspiration* using climatic data (air temperature, RH, wind speed, sunshine hours) (Allen et al., 1998) and *remote sensed ET*.

3.2.4 Soil – water balance

The aim of soil water balance approach is to predict the water content in the rooted soil by means of a water conservation equation: Δ (AWC × Root depth) = Balance of entering + outgoing water fluxes, where AWC is the available water content. Soil water holding characteristics, crop and climate data are used by sophisticated models to produce typical irrigation calendars. This approach can be applied from individual farms to large regional irrigation schemes. However, it needs expertise, support by strong extension services or links with information systems. Its effectiveness is very high, but depends on farm technological development and/or support services. Examples of commercial software for irrigation scheduling based on soil-water balance approach are IMS (Hess, 1996), MARKVAND, SALTMED (Ragab, 2002), SIMIS (FAO, 1999b).

3.2.5 Effective irrigation scheduling

It is recognized that appropriate irrigation scheduling should lead to improvements in irrigation management performance, especially at farm level. The farmer should be able to control the timing and the depth or volume of irrigation. However, the practical application of the techniques and methods has been far below expectations. The dependence on a collective system implies social, cultural and policy constraints. The main constrains are the lack of flexibility, either due to rigid schedules or the system limitations, the non-economic pricing of water (price covers less than 30% of the total cost), the high cost of irrigation scheduling (either for technology and/or labor), the lack of education and training of the farmers, the institutional problems, the behavioral adaptation, the lack of interactive communication between research, extension and farmers and finally the lack of demonstration and technology transfer.

The effective application of any irrigation scheduling method and effective implementation of the corresponding delivery schedule are subject to the physical capability of the collective system for delivering water according to this schedule and to the capacity of the management for operating the system properly. One of the major obstacles to effective implementation of crop-based and water-saving irrigation scheduling is the inability of most conveyance and delivery systems to deliver water at the farm gates with the reliability and flexibility required. In modern pressurized irrigation networks water is available on demand, although discharges may be limited due to technical or economic reasons. The farmers are free to select and adopt the irrigation schedules they consider more appropriate to their crops and farming practices. However, in case of drought or limited water supply, managers can enforce restrictions to volumes delivered and/or price penalties for excess water use.

Finally, all agencies involved in efficient irrigation water management should make every effort to disseminate knowledge, upgrade education and training at all levels, transfer technology, incite decision-makers to changes, involve the farmers in the decision process and urge the funding agencies and governments to set up the financial means required

3.3. Fertigation

The application of fertilizers through the irrigation system (fertigation) became a common practice in modern irrigated agriculture. Localized irrigation systems, which could be highly efficient for water application, are also suitable for fertigation. Thus, the soluble fertilizers at concentrations required by crops are applied through the irrigation system to the wetted volume of the soil. Possible disadvantages include the non-uniform chemical distribution when irrigation design or operation are inadequate, the over-fertilization in case that irrigation is not based on actual crop requirements and the excessive use of soluble fertilizers.

3.4. Deficit irrigation practices

In the past, crop irrigation requirements did not consider limitations of the available water supplies. The irrigation scheduling was then based on covering the full crop water requirements. However, in arid and semi-arid regions increasing municipal and industrial demands for water reduce steadily water allocation to agriculture. Thus, water availability is usually limited, and certainly not enough to achieve maximum yields. Then, irrigation strategies not based on full crop water requirements should be adopted for more effective and rational use of water. Such management practices include deficit irrigation, partial root drying and subsurface irrigation.

3.4.1 Regulated deficit irrigation

Regulated deficit irrigation (RDI) is an optimizing strategy under which crops are allowed to sustain some degree of water deficit and yield reduction. During regulated deficit irrigation the crop is exposed to certain level of water stress either during a particular period or throughout the growing season. The main objective of RDI is to increase water use efficiency (WUE) of the crop by eliminating irrigations that have little impact on yield (Tab. 2), and to improve control of vegetative growth (improve fruit size and quality). The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under conventional irrigation practices.

RDI is a sustainable issue to cope with water scarcity since the allowed water deficits favour water saving, control of percolation and runoff return flows and the reduction of losses of fertilizers and agrochemicals; it provides for leaching requirements to cope with salinity and the optimization approach leads to economical viability. The adoption of deficit irrigation implies appropriate knowledge of crop ET, of crop response to water deficits including the identification of critical crop growth stages, and of the economic impact of yield reduction strategies. Therefore, appropriate deficit irrigation requires some degree of technological development to support the application of irrigation scheduling techniques.

Table 2. Effect of irrigation treatments on water use, yield and water utilization efficiency in olive trees (Chartzoulakis et al., 1992)

Treatment	Irrigation water (mm)	Fruit yield	Oil content (% FW)	Ey (kg oil/mmH_2O)
Full irrigation	432	38.3 a*	21.3 a	0.49 a
Deficit irrigation	321	34.1 a	22.8 b	0.73 b
Rainfed	-	24.1 b	23.5 b	-

* Different letters within the same column indicate significant differences at a=0.05 (LSD-test)

Before implementing RDI it is necessary to know the crop yield response to water (growth stage or whole period). Crop yield response for deficit irrigation is described by the equation $Y/Ym = 1\text{-}Ky\ [1\text{-}ETa/ETm]$ (Stewart et al., 1977), where Y and Ym are the expected and maximum crop yield, ETa and ETm the actual and maximum ET, and Ky the crop response factor. Ky gives an indication of whether the crop is tolerant to water stress and depends on crop species, cultivar, irrigation method and growth stage. High yielding varieties are more sensitive to water stress. Crops or varieties with a short growing season are more suitable for RDI. Furthermore, in order to ensure successful RDI, it is necessary to consider the water retention capacity of the soil.

The development of RDI is not possible without first understanding patterns of tree and fruit growth. RDI must be applied during the period that shoot growth is rapid while fruit growth is slow. RDI has been applied successfully for row crops like maize, soybean, sugar beet, sunflower, potato, wheat (Stegman et al., 1990; Kirda et al., 1999), and tree crops like citrus, olives, peaches, grapevines etc (Domingo et al., 1996; Boland et al., 1993).

3.4.2 Partial Root Drying

Partial root drying (PRD) is a new irrigation technique, first applied to grapevines that subject one half of the root system to dry or drying conditions while the other half is irrigated. Wetted and dried sides of the root system alternate on a 7-14 day cycle. PRD uses biochemical responses of plants to water stress to achieve balance between vegetative and reproductive growth. During water stress development the vine's first line of defense is to close its stomata to conserve moisture. One of the principal compounds that elicit this response is the abscisic acid (ABA). As soil water availability falls following the cessation of irrigation, the ABA is synthesized in the drying roots and transported to the leaves through the transpiration stream (Loveys et al., 1999). Stomata respond by reducing aperture, thereby restricting water loss. Improvement of WUE results from partial stomatal closure. However, an inevitable consequence is reduced photosynthesis. With PRD, switching the wet and dry sectors of root zone on regular basis, this transient response was overcome (Dry and Loveys, 1998).

PRD has been successfully applied with drip irrigation in grapevines (Dry et al., 2000), with subsurface irrigation in grapevines (Loveys et al., 1997) and even furrow irrigation in pear, citrus and grapevines (Clancy, 1999). The cost of PRD application varies according to the irrigation system employed and whether it is applied to new or existing vineyards. In pre-existing irrigation systems an additional line must be added. The additional cost of installing PRD is economical where the cost of irrigation water is high and as water becomes an increasingly valuable and scarce resource. In these areas the true environmental cost of water justifies the implementation cost of PRD.

3.5. Subsurface Drip Irrigation

Subsurface drip irrigation (SDI) is a low-pressure, low volume irrigation system that uses buried tubes to apply water. The applied water moves out of the tubes by soil matrix suction. Wetting occurs around the tube and water moves out in the soil all directions. The potential advantages of SDI are: a) water conservation, b) enhanced fertilizer efficiency, c) uniform and highly efficient water application, d) elimination of surface infiltration problems and evaporation losses, e) flexibility in providing frequent and light irrigations, f) Reduced problems of disease and weeds, g) lower pressure required for operation. The main disadvantages are the high cost of initial installation and the increased possibility for clogging, especialy when poor quality water is used.

Subsurface irrigation is suitable for almost all crops, especially for high value fruit and vegetables, turfs and landscapes. A large variety of tubes are available in the market from PE tubes with built-in emitters or porous tubes that ooze water out the entire length of the tube. The tube is installed below the soil surface either by digging the ditches or by special device pulled by a tractor. The depth of installation depends upon soil characteristics and crop species ranging from 15-20 cm for vegetables and 30-50 cm for tree crops.

3.6. Agricultural Practices

Agricultural practices, such as soil management, fertilizer application, and disease and pest control are related with the sustainable water management in agriculture and the protection of the environment. Agricultural practice today is characterized by the abuse of fertilizers. Farmers very rarely carry out soil and leaf analyses in order to clarify the proper quantity and type of fertilizer needed for each crop and they apply them empirically. This practice increases considerably the cost of agricultural production and is potentially critical for the deterioration of the groundwater quality and the environment. Agrochemicals (herbicides and pesticides) are also excessively used, endangering the quality of the surface water and negatively affecting the environment. Plant-protection products (pesticides) are often used preventively, even when there is not real threat in the area.

There is a large variety of traditional and modern soil and crop management practices for water conservation (runoff control, improvement of soil infiltration rate, increase soil water capacity, control of soil water evaporation) and erosion control in agriculture, some of which apply also for weed control (Pereira et al., 2002). Effort should be made in their rational use of chemicals for pest and weed control in order not to further pollute the environment. The soil management consists of:

Soil surface tillage, which concerns shallow tillage practices to produce an increased roughness on the soil surface permitting short time storage in small depressions of the rainfall in excess to the infiltration.

Contour tillage, where soil cultivation is made along the land contour and the soil is left with small furrows and ridges that prevent runoff. This technique is also effective to control erosion and may be applied to row crops and small grains provided that field slopes are low.

Bed surface profile, which concerns cultivation of wide beds and is typically used for horticultural row crops.

Conservation tillage, including no-tillage and reduced tillage, where residuals of the previous crop are kept on the soil at planting. Mulches protect the soil from direct impact of raindrops, thus controlling crusting and sealing processes. Conservation tillage helps to maintain high levels of organic matter in the soil thus it is highly effective in improving soil infiltration and controlling erosion.

Mulching with crop residues on soil surface which shades the soil, slows water overland flow, improves infiltration conditions, reduces evaporation losses and also contributes to control of weeds and therefore of non-beneficial water use.

Increasing or maintaining the amount of organic matter in the upper soil layers, since it provides for better soil aggregation, reduced crusting or sealing on soil surface and increased water retention capacity of the soil.

Addition of fine material or hydrophilic chemicals to sand/coarse soils. This technique increases the water retention capacity of the soil and controls deep percolation. Thus, water availability in soils with low water holding capacity is increased.

Control of acidity by liming, similarly to gypsum application to soils with high pH. This treatment favors more intensive and deep rooting, better crop development and contributes to improved soil aggregation, thus producing some increase in soil water availability.

Adoption of appropriate weed control techniques to alleviate competition for water and transpiration losses by weeds.

4. Recommendations for Best Irrigation Practices

The major agricultural use of water is for irrigation and its supply is decreasing steadily due to competition with municipal and industrial sectors. Therefore, technological, managerial, policy innovation and human resources management are needed to increase the use efficiency of the available water. Sustainable water management in agriculture can be achieved by:

Reduction of water losses in the conveyance, distribution and application networks. Water leakages should be detected via advanced technologies, e.g. telemetry systems, GIS, remote sensing. Old water projects experiencing considerable water losses should be rehabilitated and modernized.

Improve the efficiency of irrigation system used. Improvements in sprinkler irrigation systems (efficiency up to 85%) include the adoption or correction of sprinkler spacing, the design for pressure variation not exceeding 20% of the average sprinkler pressure, the use of pressure regulators in sloping fields, the monitoring and adjustment pressure equipment, application of irrigation during no windy periods, adoption of smaller spacing and large sprinkler drops and application rates in windy areas, the adoption of application rates smaller than the infiltration rate of the soil and careful system maintenance. Improvements in localized irrigation systems (Efficiency 95%) aiming to reduce the volumes of water applied and increase the water productivity include the use of a single drip line for a double row crop, the use of micro-sprayers in high infiltration soils, the adjustment of duration of water application and timing to soil and crop characteristics, the control of pressure and discharge variations, the use of appropriate filters to the water quality and the emitter characteristics used, the adoption of careful maintenance and automation.

Increase water use efficiency. Can be achieved with the obligatory use of localized irrigation systems by the farmers (with or without subsidies), the proper irrigation scheduling according to actual needs of the crops, the establishment of a system for advising farmers on their irrigation schedules, the introduction of appropriate agronomical practices and the application of salinity management techniques.

Adoption of innovative irrigation techniques. In water scarce regions irrigation approaches not necessarily based on full crop water requirements like regulated deficit irrigation (RDI) or subsurface irrigation (SSI) must be adopted. Fertigation (efficient fertilizer application) and chemigation (easy control of weeds and soil born diseases) should also be promoted.

Water pricing policy. For proper water pricing volumetric water metering and accounting procedures are recommended. Progressive, seasonal and over-consumption water tariffs as well as temporary drought surcharges rates contribute to water savings and should be promoted. Furthermore, an increasing block tariff charging system, that discourages water use levels exceeding crop's critical water requirements, must me established. It will be the basis for promoting conservation, reducing losses and mobilizing resources. Furthermore, it could affect cropping patterns, income distribution, efficiency of water management, and generation of additional revenue, which could be used to operate and maintain water projects.

*Reuse of marginal waters (*reclaimed or brackish) for irrigation. Reclaimed waters can be used under some restriction for irrigation of tree, row and fodder crops. In addition to water they provide the soil with nutrients, minimizing the inorganic fertilizer application. Treated sewage is looked upon with skepticism by farmers. They instead prefer to use surface and/or groundwater. Special effort should be given in educating farmers to accept treated sewage. In addition the tariff for this source of water should be lower than the tariff of the primary sources. This may not be difficult to achieve because the primary and secondary levels of treatment are regarded as sunk costs since they are required by the new WFD. When using low quality water for example brackish or saline water an integrating approach for water, crop (salt tolerant varieties) field management (suitable tillage) and irrigation system (adequate leaching, suitable devices) should be considered.

Wider and more effective participation of the public, NGOs and end users for the preparation of the plans, in decision-making, in monitoring the implementation and generally in the management of water. The participation of these groups in the above processes safeguards the acceptability of the plans by the general public, raises support on the part of the body politics and promotes success in possible conflict resolutions.

Capacity building. The existing “capacity building” is poor. It requires an appropriate mix of competent personnel, technologically advanced devices and facilities, legal guidelines and administrative efficient and effective processes for the sustainable management of the water resources. It includes:

a. Education and training of professional, technical staff and decision makers and others, including non-public organizations, on a wide range of subjects related to sustainable water management.
b. Manpower build-up. Institutions to be staffed with qualified manpower (managers, engineers, technicians, social scientists) that should be adequately compensated.
c. Facilities and procedures. Water authorities at all levels of management should be equipped with technologically advanced devices and programs e.g. computers and software for the application of new techniques such as GIS, remote sensing etc. These advanced techniques facilitate the multi-sectoral information availability and use and help water managers in their decision- making.
d. Legislative changes to the fragmented and antiquated legislation should be promoted. Responsibility of water resources planning and operation, especially at the overall national level, should be under one institution for proper organization and non-conflicting actions by the various authorities. Water authorities should participate fully in the formulation of agricultural policies because the development of water and land should be fully integrated. In practice, agricultural decisions are water decisions and vice versa.

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