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The Management Options of Water for the Development of Agriculture in Dry Areas

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Abstract: The natural resource base of land, water and vegetation in arid and semi arid areas is highly fragile and greatly vulnerable to degradation especially in the developing countries. The demand for water is constantly increasing as a result of population growth and the expansion of agriculture and industry. Fresh water resources are limited in the arid and semi-arid areas whereas the existing water resources are often overused and misused. The lack of water management in the arid areas generated numerous economic, social and ecological issues. Agriculture currently accounts for nearly 70-80% of water consumption in the developing countries. The productivity of water use in agriculture needs to enhance in order both to avoid exacerbating the water crisis and to prevent considerable food shortages. More efficient use of existing water resources and adequate management of soils could prove to be the effective tool for improving arid lands. The technologies, skills and capital resources required to overcome the poor and extreme distribution of water resources through storage and transfer are not available and widely used. As a consequence there is critically low access to water for agriculture, drinking and sanitation and the environment. Poor access to water is among the leading factors hindering sustainable development in semi-arid and arid regions. Conventional irrigation management should be revised to ensure maximum water productivity instead of land productivity for dry farming systems. Under conditions of increasing water scarcity, the key to sustaining rural livelihoods is improving the productivity and reliability of rainfed agriculture by using limited rainfall more productively, through optimal on-farm soil, water and crop management practices that conserve soil moisture and increase water use efficiency. Conserving and augmenting water supplies through rainwater harvesting and precision irrigation provide new opportunity for productive dry land farming. Without action, it has been reported that in 2025, two thirds of the world's population would live in water stressed areas. One of the actions necessary to help avert water crisis is to educate people as to the value of this precious resource. A productive water-use system in arid and semiarid areas, where the annual rainfall is scanty, the evaporation rate is higher than precipitation and characterizes insufficient renewable water resources, is the urgent need of the farmers. This study reviews options available for improved utilization and management of water resources and examines the future prospects of sustainable agriculture in water scarce areas.

Key words: Agriculture, dry areas, water management, water harvesting, water conservation, water productivity

THE PROSPECTS OF WATER SCARCITY

The dry areas are regions of water scarcity. Renewable water resources are limited and rainfall is highly variable and unpredictable, both spatially and temporally, increasing the risks and uncertainty involved in agricultural production. The natural resource base of land, water and vegetation in arid and semi arid areas is highly fragile and greatly vulnerable to degradation (Irshad *et al.*, 2007). Water scarcity is a significant problem of Africa, Asia and the Near East where 80-90% of the water withdrawals are used for agriculture (FAO, 2000). Water played a major role in poverty alleviation by providing food security, protection against famine and expanded opportunities for employment both on and off the farm. The causes of water scarcity are varied. Some are natural and others are as a result of human activity. In many areas the dry season is becoming longer, rivers are drying up and farmers are unable to grow crops. In recent decades the intensity and scale of water use has increased dramatically with the rapid rise in population and urbanization and would continue to grow along with economies. The development of agriculture and industries require more and more water each day.

Water scarcity is a serious problem throughout the world for both urban and rural communities. The rate of withdrawal is far in excess of the rate of recharging the water table. Pollution and over exploitation have shrunk the availability of fresh water to a trickle. Urbanization has resulted in over exploitation of ground water, reduction

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in open soil surface and water infiltration rate and deteriorated the quality of waters. The rural scenario is equally grim. The population explosion necessitates a proportionate increase in food production, which in turn demands more land, more fertilizers/pesticides and more water.

Arid and semi-arid areas are accommodating one sixth of the world's population. The inhabitants of these regions are among the poorest people in the world who totally depend on the renewable natural resources for their livelihoods. This poverty is partly caused by inadequate availability of water for crop, livestock and other enterprises. Unsustainable agricultural activities including inadequate soil conservation, cultivation of steep slopes, cultivation without adequate fallow periods, unbalanced fertilizer use and improper irrigation management coupled with the misuse of prime agricultural land for urbanization/industrialization had a devastating impact on natural resources (Irshad *et al*., 2007). The shortage of water is not caused by low rainfall as normally perceived but, rather by a lack of capacity for sustainable management and use of the available water. The most critical management challenge is how to deal with the poor distribution of rainwater leading to short periods of too much water and flooding and long periods of too little water. The technologies, skills and capital resources required to overcome the poor and extreme distribution of water resources through storage and transfer are not available and widely used. As a consequence there is critically low access to water for agriculture, drinking and sanitation and the environment. Water security is an increasingly important element of any poverty eradication program. Poor access to water is therefore among the leading factors hindering sustainable development in semi-arid and arid regions.

The water scarcity is increasing and an estimated 300 million of the region's expected population of one billion will be living in a water-scarce environment within next two decades. Given the current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 (Qadir *et al*., 2006). The demand for water will grow and the pressure on scarce water resources will intensify over the next decades. There is also a limited choice for many countries of the world except to utilize marginal quality water for irrigation as the water resources of good quality for agriculture are becoming scarce (Irshad *et al*., 2005a). As the cities grow, the water degradation, deforestation and pollution are also advancing. The growing scarcity and competition for water, however, stands as a major threat to future advances in poverty alleviation. As land and population pressures grow, sustainable agriculture in marginal areas is becoming a major issue. Establishing vegetation along with appropriate on-farm management strategies could maintain ecological balance and provide an opportunity to improve deserted lands (Irshad *et al*., 2005b). A large proportion of marginal land includes arid and semi-arid areas, where farmers struggle to cultivate crops and raise livestock despite irregular rainfall, recurrent drought and soil degradation.

The earth's capacity to store water is decreasing. Trees and their root systems that normally soak up and store water and replenish the supply of ground water are disappearing. When the land is stripped of trees and ground cover, as is the case in many developing countries, little rainwater filters into the soil, instead flowing rapidly to the ocean, taking rich, productive topsoil along with it. An equally threatening trend to the poor and their water resources is unpredictable and often extreme weather patterns attributed to the greenhouse effect. Higher temperatures lead to the more surface evaporation, more precipitation and increase in runoff. This can cause severe flooding or drought, which threaten the lives and livelihoods of millions of people around the world.

The hope for better future lies in the fact that water is a regenerative resource. It is also possible to change behaviour and farming practices to reverse the current water trends. Community efforts to manage and protect water supplies should be activated. The adoption of appropriate management to minimize the water losses from the land surface and their impacts on crops' productivity is of significant importance. Approaches to manage water in water scarce areas include technologies for enhancing the productivity of water in rain-fed production, rainwater harvesting, water conservation practices and precision irrigation. This paper discusses the options available for improved utilization and management of water resources for reversing the prevalent scarcity of waters in the arid and semi-arid areas.

WATER RESOURCES MANAGEMENT OPTIONS

Water harvesting: There is a general consensus that the rain-fed areas and natural wetlands offer the greatest potential for agricultural production in the near future. Uneven rainfall with time or space make the rainfed agriculture less viable (Reij *et al*., 1988) therefore the water harvesting and supplemental irrigation technologies hold greater promise for increasing crop yields. The high variation in the rainfall may cause a complete loss of the crop (Rockstrom and Falkenmark, 2000). But the adoption of these practices by farmers has been extremely limited, as the risk and costs seem to have outweighed the benefits (Oweis *et al*., 1999).

Rainwater harvesting involves concentrating and collecting the rainwater from a larger catchment area onto a smaller cultivated area. The managing, controlling and making use of rainwater *in situ* or within the vicinity of rainfall is termed as rainwater harvesting. This often involves collecting rainwater from a catchments area and then channeling the runoff directly on the fields or collected in some way to be used at a later time. Through controlled concentration of runoff into target areas, water harvesting increases water availability and controls soil erosion and can provide a buffer against drought. Efficient ways of collecting rainwater and preventing soil degradation contribute to the development of agriculture and conservation of resources in marginal areas.

Pacey and Cullis (1986) classified water harvesting techniques as macro-catchments, micro-catchments and rooftop runoff collection. The rooftop runoff may be used almost exclusively for non-agricultural purposes. In micro-catchment systems, water is collected from land adjacent to the growing area. Examples of such water harvesting systems include small basin micro-catchments, small and low-cost farm reservoirs used to store and release runoff water several times over the season. Some specific microcatchment techniques include contour or semi-circular bands made of earth, stone or trash, pitting, strip catchment tillage etc. These methods are often used for medium water demanding crops such as maize, sorghum, millet and groundnuts (Habitu and Mahoo, 1999). While with macro-catchment systems large flows are diverted and used directly or stored for supplementary irrigation. The types of macro-catchment systems include runoff farming, which involves collecting runoff from the hillsides into flat areas. Larger structures that store run-off from a large catchment area can be used to support agricultural intensification and higher value crops. At the larger scale, methodologies have been developed for using remote sensing combined with ground information in a GIS framework to identify suitable areas and appropriate methods for water harvesting. This type of water harvesting can be used for different crops including row crops, trees or closely growing crops (Oweis *et al*., 1999).

Traditionally, rainwater harvesting has been practiced in arid and semi-arid areas and has provided drinking water, domestic water, water for livestock, water for small irrigation and a way to replenish ground water levels. This method may have been used extensively by the Indus valley civilization. As a counter measure to the unpredictability of rain, communities developed various agricultural practices to suit 'low water intensive' agriculture. Rainwater harvesting is one such method. In water scarce areas farmers are aware that both crop and livestock production can be improved substantially through concentration of scarce rainwater as well as provision of supplementary water during critical times. Bruins *et al*. (1986) estimated that an additional 3-5% of the arid areas could be cultivated using runoff farming. This facilitates production/growing of high-water demanding crops such as vegetables, rice and maize in the lower part of landscape. Some water harvesting in Burkina Faso, Kenya, Niger, Sudan and Tanzania have shown increased yields of 2-3 times those achieved in dryland farming (FAO, 2000). In short the aim of water harvesting is to exploit the natural concentration of rainwater and nutrients flowing into the valley bottoms from the surrounding high grounds in the landscape.

Water conservation: Water conservation methods, are often referred to as *in situ* rainwater harvesting, include activities such as mulching, deep tillage, contour farming and ridging (Habitu and Mahoo, 1999). The purpose behind these methods is to ensure that the rainwater is held long enough on the cropped area to ensure infiltration. These techniques are best suited to areas where rainfall and water holding capacity are sufficient to meet the crop water requirement but the amount of water infiltration is not adequate to reach the required moisture level (Habitu and Mahoo, 1999). Some methods such as mulching or the addition of organic matter may also help to enhance the physical properties of the soil. Water conservation is often used together with water harvesting techniques in order to achieve beneficial results. Deep tillage is a water conservation technique that improves soil moisture capacity by increasing soil porosity. In addition, runoff is reduced through increased roughness at the soil surface, which increases the time available of water to infiltrate the soil. The increased infiltration would increase the availability of water to the root zone and assist better plant growth. Contour farming is the tilling and weeding technique along the contours to help stop water runoff. Mulching or the addition of organic matter to the soils may both increase soil water availability by enhancing water holding capacity of soil and decreasing evaporation and improve the quality of the soil. Mulching has been reported as a common method controlling evaporation and preventing water losses (Cadavid *et al*., 1998; Li, 2003; Smith *et al*., 2001). Mulches not only reduce evaporation losses; they also reduce soil temperature and rain-impact energy, serve as a protective barrier against wind/water erosion, increase infiltration and percolation into soil profile and increase soil organic matter if plant/animal residues are used as mulches and they may play a role in solute accumulation in solute accumulation, particularly the salts that induce salinity (Rasiah and Yamamoto, 2002). It is reported that organic matter in the soils decreases soil erosion (Rockstrom and Falkenmark, 2000), increases water retention (Emerson and McGarry, 2003) and enhances soil aggregation (Haynes, 2000). The beneficial effects of waste material applied to the soil in any environment include not only the supply of essential plant nutrients but also the preservation of soil chemical, physical and biological properties (Irshad *et al*., 2004).

Conservation tillage: Conservation tillage measures such as minimum till and no-till have been tested to conserve soil water and decrease the rate of soil water evaporation. Reducing evaporation loss help to conserve soil moisture and control salt accumulation (Yamanaka *et al*., 2004). Conservation techniques are helpful in the areas where farmers do not have the capital or labour for the expensive techniques. Fall and Faye (1999) found reduced production costs, diminished soil erosion, decreased runoff and less soil compaction during the direct seeding in the dry soils. Zero tillage technology has been found to improve soil moisture conservation and thus reduce crop failure in dry years, particularly in arid or semi-arid areas. No-till systems usually enhance soil structure and increase organic matter content.

Precision irrigation: The surface irrigation approach often leads to high losses of water by evaporation from the soil and water surface, leading to low productivity of water. Water productivity can be improved by introducing precision irrigation. This involves the application of the required quantity of water, when it is required and in the root zone where it is required. This will include for example application of a small amount of water to overcome a stressful dry spell within the growing period. Technologies for achieving the necessary high levels of control are already available. One example, are micro-drip techniques for high frequency, low volume, partial-areas application of water and nutrients to crop fields.

Precision irrigation overcomes the problems of unproductive depletion of water from the soil. By applying the water directly to the root zone, transpiration by plants is increased due to improved contact between water and roots while soil evaporation and deep percolation are reduced. This increases the productivity of water. Furthermore, improved control of the timing of application of water makes it easy to implement supplementary irrigation strategically to overcome seasonal dry spells.

Supplemental irrigation: Rainfed production can also be enhanced through the strategic use of sources of renewable water to augment essentially rainfed production. Supplemental irrigation is another method used in low rainfall areas to assure that crops receive enough water in order to survive. While water harvesting is generally used in areas that receive between 100-300 mm of rainfall annually, supplemental irrigation is used in areas with slightly greater annual rainfall of approximately 300-600 mm (Oweis *et al*., 1999). Supplemental irrigation has been described as technique used on crops that can be grown using rainfall alone, which applies a limited amount of water during the times of low rainfall to ensure that enough water is received to support crop growth and stabilize yields (Oweis *et al*., 1999; Perrier and Salinki, 1987). Supplemental irrigation is the application of a limited amount of water to rainfed crops. The additional water is applied only when rainfall fails to provide the moisture essential for normal crop growth.

This differs from conventional irrigation in that the amount of water applied in supplemental irrigation would not by itself be sufficient to ensure crop growth. Conversely, conventional irrigation supplies the entire water needs to the crop because rainwater may not provide sufficient water for plant growth for all or part of the season (Perrier and Salinki, 1987). Conventional irrigation is used where water is plentiful, while supplemental irrigation is often used in places where water is often scarce. Timing of water application is one of the important factors to be determined when supplemental irrigation is used. It is important when water is scarce during the critical growth periods. Potential benefits that can be achieved through the use of supplemental irrigation include increased yields, stabilization of yields across the year and creating conditions that allow for the use of higher technology inputs such as high-yielding varieties, herbicides and fertilizers (Oweis *et al*., 1999).

Enhancing water productivity: Sustainable increases in food supplies must come from increased productivity of both rainfed and irrigated agriculture. A limited quantity of additional water supplies is available by developing marginal quality water and through desalinization, but costs and environmental concerns limit the use of these resources. Consequently, the only option available to support agricultural production is to increase the productivity of water by producing 'more crop per drop'. Despite the scarcity of water, current water use in agriculture in the dry areas is highly inefficient. The role of water management and investments for irrigated agriculture and food security has received substantial attention in the recent years (Hofwegen and Svendsen, 2000; Rosegrant, 1997). Rainfed agriculture produces by far the highest proportion (over 60%) of food crops in the world (Rosegrant *et al*., 2002). When animal grazing is counted the contribution of rain-fed agriculture to food and commodity production is very high indeed. The rainfed areas currently account for 58% of the world food production. Insufficient attention has been paid to the potential agricultural production in the rainfed areas to meet future food demand in the developing countries.

In order to increase production, farmers have two options, either to use extensive systems (which expand the area plants) or intensive systems (which increase inputs on a planted area in order to increase yields). To meet the food demand in the rainfed areas, farmers have expanded production into marginal lands. These fragile areas are susceptible to environmental degradation, particularly erosion, due to intensified farming, grazing and gathering. This problem may be especially severe in areas of Africa, in which the transfer from extensive to intensive systems was slower than in other regions (De Haen, 1997). The expansion of the production into marginal areas can cause many environmental problems. When these areas are cleared, many plants native to the area may be lost and disease and pest problems may also develop due to the changes in the ecosystems. Soil erosion is also often a significant problem in the areas (Scherr, 2000). McNeely and Scherr (2001) noted that under some circumstances, increasing production on the same land may ease the pressure to use marginal lands for crops and help to keep those natural habitats from being destroyed. Therefore, intensive cropping systems that involve increased inputs such as labour, fertilizers, pesticides or improved varieties to increase yields would be essential for rainfed crop production. The sustainable intensification of rainfed agriculture development can increase production while limiting environmental impacts.

Research has shown that only a small fraction of rainwater reach and remains in the root zone, long enough to be useful to the crops. It is estimated that in many farming systems, more than 70% of the direct rain falling on a crop-field is lost as non-productive evaporation or flows into sinks before it is used by plants. It is only in extreme cases that only 4-9% of rainwater is used for crop transpiration. Therefore, in rain fed agriculture wastage of rainwater is a more common cause of low yields or complete crop failure than absolute shortage of cumulative seasonal rainfall. This was significantly ahead of improved varieties (30%) and fertilizer practices (5%). Furthermore, unreliable availability of water for plant growth is perhaps one of the reasons that the green revolution did not happen in sub-Saharan Africa.

Reducing water losses at the farm level by improving irrigation efficiencies and increasing water productivity at the farm level, field and basin levels through improved water, soil and crop management practices are the effective strategies for water saving in dry areas. The necessary technologies for overcoming loss of water in rain fed agriculture are the well known soil and water conservation techniques. The principle requirement is the improvement of infiltration, water holding capacity and water uptake by plants. For example, it has been shown that sub-soiling coupled with manure can lead to fourfold increase in yields of crop per unit of land in dry areas. The use of manure is value source of fertilizer and soil amendment for the sustainable crop production (Irshad *et al*., 2002). There are therefore win-win benefits of converting erosion-causing runoff into plant available soil-water and non-productive evaporation to productive transpiration. The production of dry plant matter is often linearly correlated to the seasonal transpiration, while the amount of available water taken up by the plants is dependent on the extent to which roots are in contact with water. However, in some areas, even capturing all the rainwater where it falls may not be enough. This may then call for rainwater harvesting.

FUTURE STRATEGIES

A comprehensive strategy is needed to improve the productivity of water in both irrigated and rain-fed agriculture and the access of the poor farmers to the water and technologies should be ensured. One of the outstanding development challenges in water scarce region is the wide adoption of the well known rainwater management practices. The management of irrigation systems for multiple uses i.e., for agriculture, domestic uses and environmental needs to be strengthened. The policies and institutions must be developed through integrated efforts to halt over exploitation of existing water resources. The farmers in water scarce areas should be facilitated to adopt options for improved utilization and management of water resources through a well coordinated and monitored system.

CONCLUSIONS

Development of agriculture in arid and semiarid areas can be a major engine for the economic growth and poverty reduction. Rainfed agriculture can maintain an important role in the growth of food production. However, appropriate investment and policy reforms would essentially be required to enhance the contribution of rainfed agriculture. Water harvesting has the potential to improve rainfed crop yields and can provide farmers with improved water availability, increased soil fertility and reduced soil erosion. The comprehensive understanding also necessitates that we continue to strive for systems that are efficient in their use of water and nutrients in arid and semi-arid areas. Enhancing the productivity of water in rain-fed production, adoption of the precision irrigation and the water conservation techniques are the key aspects of water resources management. Such management options for water would certainly provide new opportunities for sound environment and food security of the dry areas.

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