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Alghariani S.A.

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REDUCING AGRICULTURAL WATER DEMAND IN LIBYA THROUGH THE IMPROVEMENT OF WATER USE EFFICIENCY AND CROP WATER PRODUCTIVITY

S. A. Alghariani
Prof. of Water Science and Engineer in Academy of Graduate Studies
Tripoli, Libya

SUMMARY- The looming water crisis in Libya necessitates taking immediate action to reduce the agricultural water demand that consumes more than 80% of the water supplies. The available information on water use efficiency and crop water productivity reveals that this proportion can be effectively reduced while maintaining the same, if not more, total agricultural production at the national level. Crop water productivity, which is depressingly low, can be doubled through implementing several measures including: relocating agricultural crops among different hydroclimatic zones and growth seasons; crop selection based on comparative production advantages; realization of the maximum genetically determined crop yields; and several other measures of demand water management. There is an urgent need to establish the necessary institutional arrangements that can effectively formulate and implement these measures as guided by agricultural research and extension services incorporating all beneficiaries and stakeholders in the process.

INTRODUCTION

Similar to most countries of West Asia and North Africa (WANA), Libya has always been in a delicate balance between the limited available water resources and the basic human needs of a subsistence way of life. During the last few decades, however, the introduction of modern ways of resource utilization developed in the highly industrialized western humid zones has shifted the balance towards water resources exploitation at levels far exceeding their rates of renewal. The situation has been exacerbated by unchecked population growth demanding more food and a better standard of living under conditions of scarcity, poor resource management and low production efficiency. To meet these demands agriculture has been dramatically changing from its traditional rained practices into an extensively expanded large scale irrigation and intensively exploited water resources base. The available renewable water resources are insufficient to meet the present rate of expansion on sustainable basis. The deficit between renewal and utilization has been presently satisfied through overdraft and mining of groundwater aquifers and increasing dependence on poor quality water supplies. The result is lower piezometric levels, seawater intrusions, soil salinization and more salt accumulation and pollution in production environments. When the other rising water demands of urbanization and industrialization that compete with irrigated agriculture are considered, the present situation is by all measures highly unsustainable and calls for serious interventions and reconsideration of the presently established growth and development models, especially those related to irrigated agriculture that represents more than 80% of the total national water consumption. This paper is intended to clarify some aspects of irrigation water management that are potentially promising to getting more agricultural production with less water use through increasing water use efficiency and improving crop water productivity.

WATER RESOURCES SITUATION

The Libyan population increased from less than one million in 1955 to 6 million in 2005 and it is expected to reach more than 12 million by the year 2025 (NASID, 2006). As indicated in *Table 1*, the total available fresh water supplies on sustainable basis has been estimated at the fixed rate of 2279.5 million cubic meters per year (GWA, 2000). According to these figures the national annual average per capita water availability has been reduced from 2280 cubic meters in 1955 to 380 cubic meters in 2005 and is expected to reach 190 cubic meters by the year 2025. Thus, the whole country is already experiencing water scarcity that is getting severer with time.

Table 1. Sustainable water supplies from all available sources in the major water basins of Libya in million cubic meters per year (MCM/Y)

Water Basin	Groundwater Resources	Surface Water Resources	Unconventional Water Resources	Total
Jefara Plain	200	52	27.5	279.5
Jabal Alakhdar	200	92	45.5	337.5
Alhamada Alhamra	230	48	50.5	328.5
Kufra and Sarir	563	-	-	563
Murzuk	771	-	-	771
Total	1964	192	123.5	2279.5

Source: GWA (2000).

Table 2. Historical development and future predictions of water use by all socioeconomic sectors in Libya in million cubic meters per year (MCM/Y)

Water Use	Year				
	1984	1995	2000	2010	2020
Agricultural	1978	3376	3860	4825	5790
Industrial	90	145	176	261	386
Municipal	247	364	457	708	1060
Total	2315	3885	4493	5794	7236

Source: GWA

National averages, however, mask the spatial and temporal variability of the severity of water scarcity on a water basin by water basin basis (*Table 1)*. Even within the same water basin water availability varies widely from one location to another. This fact implies that any meaningful irrigation water management strategies should be based on the full understanding of the hydroclimatic components and their interrelationships with agricultural crops at the separate water basin levels.

The significant share of irrigated agriculture in the overall national water budget is reflected in *Table 2*, which indicates the historical development and expected future predictions of water demand, by the different socioeconomic sectors of the country. Water deficits have been experienced since the middle 1980's of the last century and are increasing exponentially unabated. This situation urged the national authorities to search for effective measures to bridge this widening gab through the development of new water resources to augment the presently available water supplies in addition to the selection and implementation of specific technical and institutional arrangements related to demand water management.

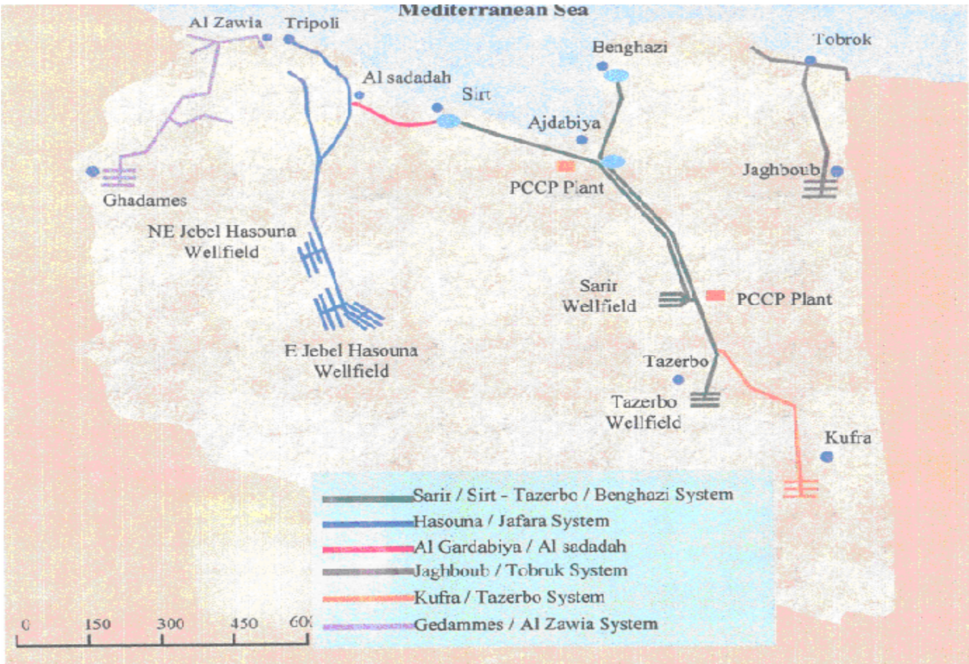

Fig. 1. Phases Of The Libyan Man-made River

The first approach is reflected in the huge water transfer and redistribution system usually known as the Great Man-made River project (GMR) that has been planned and designed to be implemented through five consecutive phases (Algharlani, 1997). After its completion the project will transfer and redistribute a total of more than 2000 million cubic meters per year of water through probably the largest and most complicated man-made water distribution network of its kind in the dry areas of North Africa and the Middle East (Fig. 1).

But although this huge project will provide significant augmentation of the national water budget it is considered only a partial solution to the water deficit problems of the country as clearly indicated in *Table 3*. Other large-scale nonconvenational water resources development such as seawater desalination and wastewater treatment and reuse are contemplated at the present time.

Table 3. Past, present and expected future water balance at the national level including the contribution of the Great Man-Made River Project in million cubic meters per year

Year	Water Demand	Water Supply		Balance
		Without GMR	With GMR	
1995	3885	2279.5	2360.5	-1524.5
2000	4493	2279.5	3912.5	-581.0
2010	5794	2279.5	4506.0	-1288.0
2020	7236	2279.5	4506.0	-2730.0
2025	8022	2279.5	4506.0	-3516

Source: General Water Authority (2000).

The second approach of implementing measures of demand water management seems to be immediately needed at the present time. One of the most apparent aspects of water management related to this approach is reducing agricultural water demand and producing more crops with less water through improving water use efficiency and increasing crop water productivity that are the major subject to be discussed in the following sections of this paper.

WATER USE EFFICIENCY AND CROP WATER PRODUCTIVITY

The term "Water Use Efficiency" as a widely used concept in irrigation management is highly controversial and can be clarified only according to one's perspective and purpose within the context of several interrelated factors. When generally defined as the total benefits (material goods, services, crop yields or financial returns) produced by each unit volume of water diverted or consumed beneficially or nonbeneficially, it can be directly linked to water productivity, demand water management, opportunity cost of water uses, comparative production advantages of agricultural crops and other macroeconomic manipulations.

Water Use Efficiency (WUE) is used and defined in this report as the ratio of volumetric crop transpiration (m^3) to the volume of total water supply diverted to irrigate the crop (m^3). But since it is impossible to separate crop transpiration and measure it directly under field conditions the numerator of the ratio is replaced by volumetric crop evapotranspiration (ET) which can be easily estimated or directly measured by several available methods and techniques.

Water Productivity (WP), however, is defined as the ratio of economic yield of a crop in kilograms (Kg) to total water supply diverted to irrigate the crop (m^3).

These two concepts as defined here are selected because they are easier to calculate fewer than two field conditions and reflect the total water losses for beneficial and non-beneficial water use from both the engineering and agronomic perspectives. Thus, they provide a wider spectrum for manipulations and interventions towards real savings in irrigation water supplies.

COUNTRY REVIEW OF WUE AND WP FOR MAJOR CROPS

During the preparation of this paper extensive and intensive available data related to crop water uses and crop yields throughout the country had been reviewed and assessed. Twelve major crops were selected on the basis of data accuracy, coherence and reliability. They represent several horticultural and field crops grown under two hydroclimatic zones in the country; one is along the coastal strip of the Southern Mediterranean sea characterized by its relatively milder climate and the other one is deeper into the Sahara desert in the Fezzan region known for its extreme hydroclimatic aridity.

Both WUE and WP are calculated for these crops on the same basis as defined in the previous section of this report. The final results are presented in *Table 4.* It is very important to mention that all irrigation water supplies to the selected crops are derived from pumped groundwater wells and diverted to closed conduit pressurized water distribution networks to be applied by sprinkler irrigation systems. Only in the limited cases of olive trees and grapes localized irrigation systems are used. The volumes of water diverted for irrigation and used to calculate the values of both WUE and WP that are presented in *Table 4* are based on measured and estimated crop evapotranspiration according to the prevailing hydro meteorological conditions in both locations and supplied to the crop with an overall irrigation efficiencies of 75% along the coastal strip and 70% deep in the Sahara desert. A leaching fraction of 5-15% of irrigation water has been included to control soil salinity and ensure sustainability of irrigated areas under the harsh climate of severe aridity and the relatively high salt content of the groundwater resources used for irrigation.

Effective rainfall is considered a significant part of the total water supply to the winter crops grown in the coastal strip zone. It is interesting to note the relatively high values of WUE for most crops in both locations especially where localized irrigation systems are used. This is mainly due to the fact that in the absence of any significant surface water supplies, all irrigated agriculture depends on groundwater resources. The relatively low discharge rates from irrigation wells and high infiltration rates of the agricultural soils that are mostly sandy eliminated all surface irrigation systems and replaced them by pressurized conveyance networks and highly efficient sprinkler and localized irrigation systems.

When considering the WP values (*Table 4*) it is interesting to note the large variation between the two-hydroclimatic locations and among the different crops in the same location. This fact offers the opportunity for significant improvements at the crop level and at the local and national levels of water management as discussed in the following sections of this paper.

PROSPECTS FOR IMPROVEMENT INCREASING WUE

As mentioned in the previous section the calculated values of WUE (*Table 4*) are relatively reasonable compared with corresponding values reported elsewhere in the

Table 4. Values of water use efficiency (WUE) and water productivity (WP) in kilogram per cubic meter for selected major crops grown at different agro climatic zones

Major Crops	Along the Coastal Strip		Deep Sahara Desert	
	WUE	WP (Kg/m^3)	WUE	WP (Kg/m^3)
Wheat	0.72	0.66	0.66	0.29
Barley	0.74	0.96	0.67	0.42
Alfalfa	0.67	1.03	0.63	0.53
Oats	0.75	1.45	0.69	0.67
Sorghum	0.61	0.97	0.61	0.38
Citrus	0.64	1.56	0.61	0.74
Grapes "Sprinkler"	0.63	1.73	0.61	0.72
Grapes "Localized"	0.87	3.02	0.86	1.28
Potato	0.67	4.73	0.62	2.10
Onions "Winter"	0.67	7.10	0.58	2.53
Onions" Summer"	0.59	4.03	0.58	1.68
Tomato "Spring"	0.65	3.54	0.63	2.16
Tomato "Summer"	0.64	3.11	0.64	2.08
Watermelon	0.64	2.87	0.63	1.28
Olives "Sprinkler"	0.68	0.49	0.63	0.16
Olives "Localized"	0.87	0.80	0.86	0.28

Source: Calculated by the author.

WANA region and other parts of the world, since aside of the actual evapotranspiration and the minimum leaching requirements all other no beneficial water losses are included in the overall irrigation efficiency, any attempt to increase WUE within any uniform hydro climatic zone can be achieved only through increasing irrigation efficiency, which is already close to 75%. The only potentially available option to realize any further increases above this value is to shift from sprinkler to localized irrigation systems.

It is very important, however, to realize that any significant increases is WUE through further improvements of irrigation efficiency will depend on the hydrological conditions of the water basins in which these improvements are sought after.

If the presently practiced irrigation efficiency reflects significant water losses that are considered water outflows of acceptable quality out of any given water basin, then any local improvement of irrigation efficiency within that basin will tend to increase WUE at the basin level. But if the wasted outflows are recaptured and reused for irrigation or any other beneficial water use within the same basin as it is most likely to happen in the mostly closed water basins in Libya, then any local improvements in irrigation efficiency and WUE are only apparent gains while the overall basin WUE remains the same. In this case improvements at the agricultural field level can only be achieved on the expense of water shortage in other locations within the water basin.

Irrigation efficiency and WUE as defined in this report should be optimized within the constraints of achieving the maximum potential yields of crop plants and maintaining the minimum water basin outflows that are required by the environmentally acceptable salt balance for sustainable irrigated agriculture. Precautionary measures should be taken against deficit irrigation and the urgent calls recently made for the introduction and expansion of supplementary irrigation with its correlates of crop water deficiencies and soil salinization.

IMPROVING CROP WP

Because evapotranspiration (ET) represents a more or less fixed proportion of the total water supply diverted for irrigation under similar irrigation efficiencies and leaching requirements, WUE is not significantly influenced by changes in the hydroclimatic conditions of different locations as indicated in *(Table 4)*. But unlike WUE, water productivity (WP) of the same crops grown in different geographical locations varies widely depending on the prevailing hydroclimatic conditions in each location. As presented in (*Table 4*), the WP of most crops grown in the deep Sahara desert of the southern regions of the country is much less than 50% of the WP of the same crops grown in the northern regions along the coastal strip. This is due to the fact that while evapotranspiration is highly sensitive to changes in the weather elements associated with the given hydroclimatic zones. The economic yields of the same crops are almost the same under similar agricultural and agronomic practices in both locations. This fact alone proves that the concept of WP as defined here offers a wider scope than WUE for manipulations and interventions leading towards improved water management.

Using the WP concept as a planning tool, large water savings could be achieved by moving crop production from the southern regions that are characterized by high ET rates to the coastal strip regions of much lower ET values. Also in regions of water scarcity, like most water basins in Libya, large water savings can be achieved by substituting crops grown in the hot seasons by cops grown in the cooler seasons, or growing the same crop in the cooler season of the year instead of the hot season as in the case of onions and tomato (*Table 4*). The concept of WP can be used as a planning tool for water allocation among competing crops under the limited water supplies of the country. When WP is expressed in terms of economic returns per unit volume of water consumed, it can be used for crop selection according to the principles of comparative economic advantages and the opportunity cost of water in addition to helping water managers in setting the most appropriate and effective irrigation water pricing policies. *Table 5* presents the economic returns on irrigation water use for some selected crops grown in the Libyan hydroclimatic zones discussed in this paper.

Table 5. Economic returns on water use for some selected crops grown at different hydroclimatic zones in Libya

Crop	Along the Coastal Strip		Deep Sahara Desert	
	WP Kg/m^3	Economic return US Dollars/m^3	WP Kg/m^3	Economic return US Dollars/m^3
Wheat	0.66	0.11	0.29	0.06
Barley	0.96	0.08	0.48	0.04
Oats	1.45	0.15	0.67	0.09
Alfalfa	1.03	0.09	0.54	0.06
Citrus	1.56	0.64	0.70	0.30
Potato	4.73	1.04	2.10	0.46
Watermelon	2.87	0.98	1.28	0.74
Winter Onion	7.10	1.38	2.53	0.65
Spring Tomato	3.54	1.92	2.16	1.17

Source: Calculated by the author.

WATER POLICIES RELATED TO IMPROVING WUE AND WP

The expected future national water balance (*Table 3*) necessitates the formulation and implementation of drastic water management policies and strategies that reduce the unbridgeable increasing water deficits.

The present concerns of water management are mostly related to allocation problems of the limited available water supplies among the different sectors of water use. The economic and sociopolitical challenges are enormous but not insurmountable. The opportunity cost of water in the competing sectors for water use should be one of the guiding criteria for water allocation. Irrigation water subsidies must be limited to the minimum equity requirements for the poor and unprivileged farmers. Water pricing and water rights systems should change the present conception of water resources from water as a free common pool resource to water as an economic commodity in the market place.

Irrigated agriculture will certainly be a looser under these institutional arrangements. But irrigation does not have to be necessarily expanded or even maintained at its present level as long as the water supplies reallocated from the agricultural sector to the other sectors produce economic activities for the population and sufficient financial returns for food importation from the international markets. Agriculture may be restricted to crops of relatively high and competitive comparative production advantages at the national, regional and global levels. If this approach is adopted the selected crops with the highest economic comparative advantages should achieve their maximum genetically determined potential yields with the least amount of water used. To realize these objectives, several agronomic and water management interventions as presented in *Table 6* after Kijne (2002) should be implemented.

The implementation of the above policies and strategies requires the establishment of effective and efficient institutional arrangements, which are presently lacking at both the public and private levels. There is an urgent need to establish these institutions as soon as possible.

Table 6 Principles, strategies, options and practices for enhancing crop water productivity at different scales. *After: Kijne et al (2002)*

Strategies	Options and Practices: *Plant level*	Options and Practices: *Field level*	Options and Practices: *Agro-ecological level*
Principle 1: Enhancing marketable yield of the crops for each unit of crop transpiration			
Increasing yield or value of the product	• Increasing harvest index (short stature: Sd1, Rht) • Increasing photosynthesis (e.g., C photosynthesis; PEPC, PPDK, ME) • Increasing sink strength (cell wall invertase)	• Crop and resources management for enhancing yield • Synchronizing water application with crop water demand • Changing to higher value crops	• Improving water management to synchronize system water supply and field-level water demand • Reallocating water from lower-value to higher-value uses • Spatial analyses for maximum production and minimum transpiration
Reducing transpiration	• Reducing non-stomatal transpiration, e.g., waxy cuticle • Reducing stomatal transpiration • Shortening crop duration	• Crop scheduling to match season with low evaporative demand • Deficit irrigation	
Principle 2: Reducing non-beneficial atmospheric depletions and the outflows from the domain of interest			
Reducing evaporation from soil and water	• Early shading • Seedling vigor	• Crop scheduling to reduce evaporation during fallow period • Plant spacing and row orientation • Tillage and soil management (e.g., minimum tillage, mulching) to reduce evaporation • Irrigation techniques (e.g., drip, subsurface irrigation) • Saturated culture with rice on bed	• Land use planning over the whole domain of interest to reduce evaporation from fallow land, decrease free water surfacing...
Reducing transpiration from weeds	• Increasing weed competitiveness • Seedling vigor	• Weed management	• Land use planning to reduce weeds and other non-beneficial vegetations
Reducing percolation	• Deep roots • Aerobic rice	• Leveling and precision irrigation • Water-saving irrigation in rice	• Reducing percolation and runoff into sinks • Water reuse
Reducing runoff		• Water harvesting • Tillage to increase infiltration	
Principle 3: Enhancing the effective-use of rainfall, water with marginal quality and water stored in the domain of interest			
Effective use of rainfall	• Drought escape • Drought tolerance • Submergence tolerance	• Risk management in rain-fed agriculture • Synchronizing crop demand and rainfall • Nutrient management to reduce drought effects • Drainage	• Irrigation scheduling to account for rainfall variability • Utilization of medium and long-term weather forecasts for reducing risk • Water table control, flood control
Effective use of water storage	• Deep rooting for drought avoidance	• Water harvesting and supplementary irrigation	• Conjunctive use of surface water and groundwater • Increasing water storage within the domain to capture runoff
Effective use of water with marginal water quality	• Salinity stress tolerance	• Mixing marginal water with water of good quality • Crop management to reduce salinity effects	• Land management to reduce salinization hazard

CONCLUSIONS AND RECOMMENDATIONS

Based on the available information about the potentially available water resources and the calculated WUE and WP presented in this paper it is recommended that:

- In view of the relatively reasonable values of WUE the only available option for improvement of this water management parameter is through increasing irrigation efficiency by replacing sprinkler irrigation with localized irrigation systems.

- In contrast to WUE, the depressingly low values of WP offer a wider range for improvement such as concentrating most irrigated areas in the northern regions, substituting crops grown in the hot season by crops grown in the cooler season and introducing agronomic and water management policies and strategies that maximize crop yields and minimize water supplies diverted for irrigation through an efficient agricultural extension service and effective irrigation water pricing system respectively.

- The concepts of WUE, WP and economic returns per unit volume of water consumed by irrigated crops should be used as a guiding criteria to reduce, or prevent altogether, the production of crops with lower values of WP and economic returns such as cereal and forage crops and reallocating their irrigation water requirements either to irrigate more water efficient crops or to other beneficial uses.

- The widening gab of water deficits in the national water resources budget must be bridged either through the reduction of irrigated areas and more dependence on virtual water in the form of imported agricultural products or by transboundary water importation and large scale water desalination and reuse.

- There is an urgent need to establish both public and private institutional arrangements that enable decision makers and water users to implement the above suggestions and recommendations through a realistic and relevant action programs that involve all stakeholders including planners, water specialists and direct beneficiaries.

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