Improving water use efficiency for a sustainable productivity of agricultural systems in Lebanon

Karam F., Geagea L., Saadeh M.

in

Rana G. (ed.), Mastrorilli M. (ed.), Albrizio R. (ed.).
WEMED workshop: how to advance the knowledge on water use efficiency in the Mediterranean region ?

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 72

2007
pages 57-62

IMPROVING WATER USE EFFICIENCY FOR A SUSTAINABLE PRODUCTIVITY OF AGRICULTURAL SYSTEMS IN LEBANON

F. Karam*, L. Geagea and M. Saadeh*****
*Department of Irrigation and Agro-Meteorology, Lebanese Agricultural Research Institute, Tal Amara, P.O. 287 Zahlé, Lebanon
**Faculty of Agricultural Sciences, Holly Spirit University of Kaslik, P.O. Box 446 Jounieh, Lebanon
***Environmental Unit, Litani River Authority, Bchara El Khoury Street, Beirut, Lebanon

ABSTRACT - The sustainability of agricultural production depends on conservation and appropriate use and management of scarce water resources. Improving the efficiency of water use through a proper improvement of water management techniques and other production factors is essential to boost on-farm productivity. An important aspect is to link on-farm issues to the scheme level and to apply an integrated management of water management at regional level. However, policies and practices of irrigation water management under water scarcity must focus on specific objectives treating the causes of water scarcity. Valuing water as an economic and marketable good may be insufficient since water acts not only for producing but is also supporting other natural resources. A coupled agricultural, environmental, and socio-economic is required in valuing the water, while an integrated technical and scientific approach is essential to develop and implement the appropriate management practices to deal with water scarcity.
The term efficiency is very often used to express irrigation systems performance. It can be defined by the ratio of water depth delivered by the system to water depth supplied to the system. Another efficiency term often used is water use efficiency (WUE). This is defined by the ratio of crop biomass or grain production to the amount of water consumed by the crop, including rainfall and/or the irrigation water applied. The WUE indicators defined by those ratios is useful to identify the best irrigation scheduling strategies for rain fed and irrigated agriculture, and to analyze the water saving performance of irrigation systems and respective management, and to compare different irrigation systems, including deficit irrigation (DI). The water use indicators are yet far from common usage but they have the potential to be very useful for water resource planning and management at the farm and scheme levels. For farm irrigation, indicators for the uniformity o water distribution are still of great usefulness. Therefore, it is necessary to perform a rigorous analysis of on-farm water management practices and their possible improvements in order to develop a sustainable irrigated agriculture, that tend to preserve the environment through a more rational use of the scarce water resources.
The objectives of this paper are to (i) describe the problems in current water management at on-farm and scheme levels and to propose corrective measures aiming to increase the productivity of water for sustainable production systems in Lebanon, (ii) establish best management strategies under rain fed and irrigation conditions and to set up a list of indicators that tend to increase water use efficiency, and (iii) analyze a case study brought in the light of the local knowledge gained in this field.

Keywords: - Lebanon, water use indicator, regulated deficit irrigation, sustainable productivity.

INTRODUCTION

The sustainability of water resources in agriculture is one of the major concerns in Lebanon, from both quantitative and qualitative points of view. Agriculture is the largest user of water in the country (up to 70% of the total available water). Therefore, water security can be warranted by a large increase in agricultural water use efficiency. This can be achieved only when a sustainable water management policy is applied at both network and farm levels. Such policy is largely based on the adoption of modern irrigation techniques, such as drip and sprinkler, known to have higher water application efficiency than traditional surface irrigation, and to allow in the same time water conservation in limited-water resources environments.

Excessive irrigation in agriculture is an important source of pressure on surface and ground water. This is in part the result of intensive farming methods requiring large inputs of water. In a good part, however, it is the result of inappropriate techniques as well. Farmers, for reasons of poverty, lack of basic security and lack of training and agricultural know-how rely basically on inefficient furrow irrigation techniques and, for the larger farms, sprinklers. There is little investment in much more efficient irrigation systems, notably drip irrigation, used elsewhere in the region.

Lebanon, with its 1,045,200 ha of total area, has a cultivable area of 360,000 ha (or 36% of its total area). The Ministry of Agriculture, in assistance with the Food and Agriculture Organization of the United Nations, counted a total cultivated area of 247,939.50 ha, of which 104,008.7 ha (or 44% of the cultivated area) are irrigated, and the remaining 143,931.0 ha (or 58% of cultivated area) are under rainfed conditions (MOA/FAO, 2000). The Bekaa Valley accounts by itself to 42% of the total agricultural land. Of the total cultivated area in Lebanon, 22% are cropped with cereals, 26% with fruit trees, 22% with olive, 11% with industrial crops and 19% with vegetables. While cereals and olive are kept under rainfed conditions, fruit trees, industrial crops and vegetables are irrigated. Add to this cultivated area a total of 4,994.82 ha of greenhouses and tunnels spread all over the country, mainly cropped with vegetables and flowers.

The whole range of extensive cropping to the very intensive systems is applicable under Lebanese agriculture. However, the most suitable production system for Lebanon would be an intensive cropping, which makes the best use of the limited water and land resources and where potential for high productivity could be exploited. This can be achieved using multiple crops and appropriate irrigation technologies, such drip. However, the following three aspects have to be taken into account in an intensive cropping system:

1. *Multiple cropping*; where farmers try to concentrate on short-season crops, so they can produce more than one crop annually. For example, an early potato cropping in March is usually followed with a late plantation of the same crop in July. Lettuce follows winter crops, mainly winter, and beans follow early vegetables like lettuce or late-growing potato;

2. *Intercropping*; where farmers try to make the best use of land and the maximum use of the growing season. Intercropping is commonly practiced in Mount-Lebanon, and north Bekaa valley, where summer vegetables are grown in interspacing with orchards, mainly apricots and apples; Usually in this type of cropping micro sprinklers are used.

3. *Protected agriculture;* being the most intensive production system, protected agriculture requires high agricultural and economic inputs. However, production potential under protected agriculture is much higher than under field conditions. In Lebanon, production of tomatoes and cucurbitaceous vegetables is very common under greenhouses during winter and summer periods. Also ornamental plants occupy a considerable place in the agricultural production under protected conditions. Since agricultural inputs are relatively high under protected agriculture, drip irrigation and its related fertigation system are considered suitable for greenhouse production.

IMPACTS OF USING MODERN IRRIGATION TECHNIQUES

There are serious concerns in Lebanon about the inefficiency of the irrigation system. At scheme level, overall efficiency (storage and conveyance efficiencies) does not exceed 40%. At on-farm level, water use efficiency includes distribution uniformity and application efficiency of the irrigation method. It could vary from 50% with surface irrigation techniques, to 70% with sprinkler irrigation, to 85% with drip irrigation. Drip irrigation system has been taught to be the most efficient irrigation technique, and has the highest distribution uniformity with comparison to sprinkler and surface irrigation techniques.

In any irrigation scheme, the three components of the overall irrigation efficiency, i.e. storage efficiency, conveyance efficiency and on-farm efficiency, should be improved. Moreover, uniformity of water application is necessary to increase efficiency. This implies controlled water application associated with good land preparation and leveling. Adequate design of head and field ditches with appropriate flow rates also remain essential in surface irrigation. For sprinkler and drip systems, good design, operation and maintenance of performing equipment are key factors to be evaluated.

A border system (basin and/or delimited flood irrigation) involves wetting almost all the land surface and is normally not an efficient irrigation method. Furrow irrigation does not wet the entire soil surface, and is still not considered an efficient irrigation method. However, if the water conveyance system is consisting of pipes instead of open canals, in such a way to deliver water into the furrows by means of gated pipes or siphons, in this case the efficiency of the system could be improved. However, the use of traditional irrigation methods is not satisfactory because they consume huge volumes of water.

Pressurized automated or mechanized sprinkler system (side roll, center pivot, linear move systems and self-propelled giant sprinklers) have the advantages of reducing significantly the number of operators directly involved in irrigation, with comparison to semi-automated mechanized sprinklers (portable or semi-portable sprinklers) which are hand-operated systems. Furthermore, sprinkler systems are more sensitive to water quality than surface irrigation methods, mainly for clogging problems in sprinkler heads. Potential toxicity effects on plant health can also occur when water is saline and contains toxic elements (Na^+ and Cl^-). Usually, sprinklers can be used on the condition salinity level is acceptable and within the ranges of use.

Due to its high application efficiency and distribution uniformity, drip irrigation has the advantage to be the most efficient technique because it irrigates more lands with less water volumes with comparison to other irrigation techniques. When drip method is used, water is given directly to the root zone, and is not influenced by the climatic factors that increase water evaporation from the soil, as in sprinkler and surface irrigation. Moreover, drip irrigation tends to reduce weed development and control by restricting the wetted area to the root zone. Furthermore, drip irrigation requires less pumping pressure and energy cost with comparison to sprinkler and surface irrigation techniques. When initial investments are provided, drip irrigation seems to be more profitable irrigation to farmers and to the farming system.

Drip irrigation, in general, might be the one to be recommended for irrigation in semi-arid regions. In sprinkler irrigation and trickle irrigation application (micro-jets and micro-sprinklers), a considerable volume of water is lost by wind drift in windy places, so that undesirable plots are wetted, making the water waste high. Under drip irrigation, such waste doest not exist since water application is localized near the plant's stem. However, when water quality for irrigation is low, the high concentration of suspended solids may interfere with the flow of water in pipes and emitters and clogging of emitters becomes a serious concern. Therefore, water quality is of primary importance in the design operation and maintenance program of sprinkler and drip systems; because clogging induces growths of slime and bacteria in the sprinkler head, emitter orifices or supply lines, as do heavy concentration of algae and suspended solids. The most serious clogging problems occur with drip irrigation systems. For this reason, suspended solids should be removed as much as possible before water could reach the drippers, using sand and screen filtrations.

PROBLEMS FACING IRRIGATION MODERNIZATION IN LEBANESE AGRICULTURE

The Lebanese farmer sounds to be fed-up of his status. He complains of the public sector poor interest and little care. This phenomenon is not new in the farming community as farming is and has been a very risky business depending on climatic conditions, weather changes and marketing problems. Production is becoming more expensive, and farming life becomes more difficult. This can be attributed to many points among them:

Optimal water use is unknown: Farmers often don't know the precise water needs of crops. What farmers know, however, is that shortage of water equals yield loss, whereas seldom damage is done by over-irrigation. In practice, irrigation is often related to the availability of water resources, regardless of actual water needs. Hence, water stocks are used inefficiently in time and place. If used carefully, limited-water resources may contribute to yield increase when appropriate irrigation methods, based on water saving approach, such as sprayers and drippers, are used.

Inefficient management of irrigation water services: In the case of irrigation, farmers must often deal with the constraints due to the need of sharing water within a network. In Lebanon, however, water for irrigation purposes is in most of the cases used individually, without any participative interest to use water collectively from the part of the agricultural communities. This in reality is due on one hand to lack of collective irrigation networks established by the competent authorities, and on the other hand to the absence of water users associations, which practically supervise the irrigation operations. These two factors contributed to the disorganization of the irrigation sector in Lebanon, and increased the conflict to water in many parts of the country.

Technological inadequacy: In Lebanon, differences prevail in the technological levels at both the on-farm water management systems and the water conveyance and distribution systems. Adequate technology is a prerequisite both for high irrigation efficiency and for implementation of volume-related incentives.

The general objectives of using modern irrigation techniques, such as sprinkler and drip systems, instead of using the traditional surface irrigation, are to ensure a water saving policy based upon increasing the economic water use efficiency of the irrigated agriculture. This will be achieved by developing and testing a system to assess real water need and optimal water allocation, in combination with context-specific incentives aimed to improve water use efficiency and reduce waste.

Unknown knowledge of exact crop water needs: Yields increase with water availability until a "saturation level", above which there is little effect of water application on yield. Therefore it is difficult for a farmer to tell at any given moment whether there is a water deficit or not. Since overabundant water, short of water logging, usually does not cause harm, growers tend to "play safe" and increase irrigation amount, especially when associated costs are low.

ACTION PLAN TOWARDS INCREASING THE EFFICIENT USE OF WATER IN AGRICULTURAL

To cope with the above-mentioned objectives, an action plan was launched in mid ninety's by the Department of Irrigation and Agro-Meteorology of the Lebanese Agricultural Research Institute to increase water use efficiency of most of the irrigated crops in Lebanon. The plan was largely base on the concept of deficit irrigation (DI), known to be a common practice in many areas of the world (English and Raja, 1996) that increase the efficiency of water used by crops. A number of studies have analyzed the economics of deficit irrigation in specific circumstances and have concluded that this technique can increase net farm income (English, 1990). The potential benefits of deficit irrigation derive from three factors; increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water. Deficit irrigation may be implemented during part of the growing season by regulating moisture within a desired deficit range. DI aims to optimize water use efficiency and therefore maximize the yield returned per unit of water applied. Any minor yield loss which may result from the implementation of a mild moisture deficit/stress under DI is offset by the benefits of reduced water use leading to a reduction in excessive vegetative growth (Kirnak et al., 2002). A variety of crops have been found to benefit from a DI strategy including maize, wheat, sunflower, potatoes, tomatoes and cotton. Irrigation using drip is typically able to apply smaller quantities of water more frequently, and is better able to maintain soil moisture at the mild deficit required to implement DI.

A seven year experiment (1998-2004) was conducted at Tal Amara Research Station in the Bekaa Valley to determine water use, yield and water use efficiency in four annual crops; maize (1998-1999); soybean (2000-2001); cotton (2001-2002) and sunflower (2002-2003). Reference evapotranspiration ($ET_{rye\text{-}grass}$) and crop evapotranspiration (ET_{crop}) were measured each in a set of two drainage lysimeters of 2m2m1m size cultivated with rye grass (*Lolium perenne*). Crop evapotranspiration (ET_{crop}) was measured using weighing and drainage lysimeters of different sizes. In the plots, evapotranspiration (ET) was measured using a simple soil water balance model. Crop coefficients (K_c) in the different crop growth stages were derived as the ratio ($ET_{crop}/ET_{rye\text{-}grass}$). At harvest, 1$m^2$ quadrates were sampled randomly from the different irrigation treatments to determine yield and its components. Water use efficiency at grain (WUE_g) and seed (WUE_s) bases was calculated as the ratio of dry yield to crop evapotranspiration (Y/ET), while water use efficiency at biomass-basis (WUE_b) was calculated as the ratio of dry biomass to ET (B/ET). Water use efficiency of cotton (WUE_l) was calculated as the ratio of lint yield at dry basis to evapotranspiration.

Hybrid maize (*cv. Manuel*) was sown on 19 May in 1998 and 25 May in 1999 at 10 plants m^{-2}. Soybean hybrid (*cv*. Asgrow 3803) was sown on 10 May 2000 and 25 April 2001 at a density of 12 plants m^{-2}. Cotton (*cv*. AgriPro AP 7114) was sown on 5 May in 2001 and on 13 May in 2002 at a density of 10 plants m^{-2}. Sunflower (*cv*. Arean) was sown on 20 May 2003 and 10 May 2004 at a density of 10 plants m^{-2}.

For maize, crop evapotranspiration (ET_{crop}) was measured using a set of two drainage lysimeters of 4 m^2 surface area (2m×2m) by subtracting the volume of drainage from the irrigation amount. The lysimeters, 1.2 m deep, 24 m apart, aligned N-S, are situated in the middle of 1-ha field (200 m N-S by 50 m W-E) (Karam et al., 2003). For soybean, ET was measured by a weighing lysimeter of 16 m² surface area (4m4m) and 1.2 m deep, containing the same clay soil as in the drainage lysimeters. Watering of the lysimeter was made upon a 30% soil depletion of the available water in the 0-100 cm soil layer. The weight loss of the lysimeter due to soil evaporation and plant transpiration was measured with load cells and recorded at a 15-minute interval on a computer located near the lysimeter. For cotton and sunflower, ET_{crop} was estimated using the FAO method (Doorendos and Pruit, 1977) by multiplying reference evapotranspiration ($ET_{rye\text{-}grass}$) by crop coefficients (K_c):

$$ET = ET_{rye\text{-}grass} \ K_c$$

Reference evapotranspiration ($ET_{rye\ grass}$) was measured in a set of two rye-grass drainage lysimeters of 4 m² surface area (2m2m) and 1m depth. The lysimeters are 24 m distant, aligned W-E, and located inside the weather station (40 m 40 m), 50 m apart of the experimental plots. Table 1 illustrates deficit irrigation treatments for the crops under study.

At physiological maturity, all individual plants in the 1m^2 sampling quadrates were harvested to determine above ground biomass production (B) and yield (Y). For maize, grain number per m^2 and the 1000-grain weight were determined. For soybean and sunflower, seed number per m^2 and the 1000-seed weight were also determined. For cotton, yield was determined by weighting lint at dry basis in the sampling areas. In maize, soybean and sunflower, water use efficiency at grain or seed-basis ($WUE_{g,s}$) was calculated as the ratio of yield at dry basis to crop evapotranspiration (Y/ET), while water use efficiency at biomass-basis (WUE_b) was calculated as the ratio of biomass at dry basis to ET (B/ET). In cotton, water use efficiency at lint-basis (WUE_l) was calculated as dry lint yield to the amount of water evapotranspired from the crop. WUE was expressed in kg m^{-3} (1 kg m^{-3} = 1 g m^{-2} mm^{-1}).

Table 5 shows the values of evapotranspiration (ET), yield (Y), biomass (B) and water use efficiency of the crops under well and deficit irrigation conditions. Grain-related water use efficiency (WUE_g) of lysimeter grown maize was 1.52 kg m^{-3} in 1998 and 1.34 kg m^{-3} in 1999. However, fully-irrigated maize had a WUE_g of 1.68 kg m^{-3} in 1998 and 1.54 kg m^{-3} in 1999. Higher WUE_g values of 1.88 kg m^{-3} and 1.87 kg m^{-3} were obtained in 1998 and 1999, respectively, from the I-60 treatment. On a biomass basis, I-100 treatment had values of water use efficiency (WUE_b) of 3.16 kg m^{-3} and 2.46 kg m^{-3} in 1998 and 1999, respectively, while the I-60 treatment had values of 3.23 kg m^{-3} and 2.97 kg m^{-3}, respectively. On the lysimeter, these values were 3.0 kg m^{-3} and 2.34 kg m^{-3}, respectively.

Table 1. Crop evapotranspiration, yield, biomass and water use efficiency of crops under study

Crop	*Variety*	*Year*	*Treatment*	*ET* mm	*Yield* t ha^{-1}	*Biomass* t ha^{-1}	*WUE_y* kg m^{-3}	*WUE_b* kg m^{-3}
Maize*	Manuel	1998	Lysimeter	952.0	15.2	28.6	1.60	3.00
			I-100	863.0	14.5	27.3	1.68	3.16
			I-60	575.0	10.8	18.6	1.88	3.23
		1999	Lysimeter	920.0	13.4	21.5	1.46	2.34
			I-100	833.0	12.8	20.5	1.54	2.46
			I-60	556.0	10.4	16.5	1.87	2.97
Soybean**	Asgrow 3803	2000	Lysimeter	800.0	3.38	7.96	1.95	4.61
			C	720.0	2.82	6.88	1.81	4.43
			S-1	596.0	2.50	5.66	1.94	4.40
			S-2	632.0	1.76	6.21	1.29	4.55
			S-3	647.0	2.57	6.64	1.84	4.75
		2001	Lysimeter	725.0	3.65	8.23	2.33	5.26
			C	652.0	3.59	7.65	2.55	5.43
			S-1	541.0	3.65	6.53	3.12	5.59
			S-2	580.0	2.93	7.38	2.34	5.89
			S-3	567.0	3.43	7.50	2.80	6.12
Cotton***	AgriPro AP7114	2001	C	577.4	0.4233	2.47192	0.34	1.98
			S-1	473.9	0.6534	1.90098	0.64	1.86
			S-2	537.6	0.5682	2.11622	0.49	1.82
			S-3	542.6	0.5398	2.16691	0.46	1.85
		2002	C	602.2	0.4906	2.80900	0.35	2.16
			S-1	482.9	0.6239	2.16020	0.61	2.07
			S-2	531.8	0.5856	2.40480	0.50	2.09
			S-3	569.6	0.5535	2.46240	0.44	2.00
Sunflower	Arena	2003	C	688.0	5.46	19.2	0.79	3.39
			S-1	534.0	3.95	16.6	0.74	3.16
			S-2	579.0	4.63	17.6	0.80	3.34
			S-3	629.0	5.59	19.6	0.89	3.68
		2004	C	769.1	5.26	20.5	0.68	4.18
			S-1	598.0	4.06	16.4	0.68	3.76
			S-2	647.0	4.65	18.2	0.72	4.05
			S-3	700.0	5.41	20.6	0.77	4.46

Seed-related water use efficiency (WUE_s) of the well-irrigated soybean treatment was 0.47 kg m^{-3}, showing no consistent difference with the lysimeter grown soybean. Apparently in this experiment, WUE_y of the deficit-irrigated treatments S1 and S3 were 13% and 4% higher than the control. However, the S2 treatment had a WUE_s value 17% lower than the control. For the biomass-basis, water use efficiency (WUE_b) of the control averaged 1.06 kg m^{-3}, whereas WUE_b of treatments S2 and S3 were 6% and 9% higher, respectively. No significant difference was found between treatment S1 and the control.

The highest lint water use efficiency (WUE_l) was encountered for cotton in S1 treatment, and averaged 0.62 kg m^{-3}, followed by S2 (0.50 kg m^{-3}), S3 (0.46 kg m^{-3}) and the control (0.36 kg m^{-3}). These values are very close to those obtained by Gilham et al., (1995). At biomass basis, WUE_b varied from 2.07 kg m^{-3} in the control, to 1.97 kg m^{-3} in S1 treatment, to 1.96 kg m^{-3} in S2 and 1.93 kg m^{-3} in S3.

Average seed-related water use efficiency (WUE_s) of sunflower fully-irrigated control an average of 0.80 kg m^{-3} while WUE_s values of the deficit-irrigation treatments were 0.76, 0.81, and 0.87 kg m^{-3}, in S1, S2 and S3, respectively. At biomass basis, WUE_b varied from 3.79 kg m^{-3} in the control, to 3.46 kg m^{-3} in S1 treatment, to 3.70 kg m^{-3} in S2 and 4.07 kg m^{-3} in S3.

CONCLUSIONS

The use of modern irrigation technologies is necessary in several ways towards ensuring significant improvements in the efficiency of the irrigation system. A major obstacle to significant water saving is the difference between actual water need and the supplied water by farmers, who tend in most of the cases to overestimate the irrigation needs. Such overestimation depends on both water management method and irrigation technology. Large differences in water delivery exist among the irrigation techniques used by farmers (surface, sprinkler, and drip). And the efficiency of the different techniques varies significantly. Research programs can play a major role in promoting the use of new irrigation technologies in two different ways:

- Preparation of a compendium of the data available on the performance of innovative irrigation technologies to be used in the final assessment of the on-farm water requirements;
- Field tests of irrigation technologies have to be performed in pilot farms as part of the case-studies, where farmers, have the opportunity to react and exchange knowledge with researchers and extensionists.

The expected results form an efficient irrigation strategy have to improve in the short-run the farming income, by increasing the area of the irrigated land and crop production and reducing in the same time energy and other production costs.

REFERENCES

Doorenbos, J. & Pruit, W. O. (1977). Guidelines for prediction of crop water requirements. Food and Agriculture Organization of the United Nations, Irrigation and Drainage Paper 24, Rome, Italy.

English, M. & Raja, S. N. (1996). Perspectives on deficit irrigation. Agriculture Water Management, 32: 1-14.

English, M. J. (1990). Deficit irrigation. I: Analytical framework. J. Am. Soc. Civil Eng., 116 (IR3): 399-412.

MOA/FAO. (2000). Ministry of Agriculture, Food and Agriculture Organization of the United Nations. Agricultural Census in Lebanon.

Karam, F., Breidy, J., Stephan, C. & Rouphael, Y. (2003). Evapotranspiration, Yield and Water Use Efficiency of Drip Irrigated Maize in the Bekaa Valley of Lebanon. Agricultural Water Management, 63: 125-137.

Karam, F., Masaad, R., Sfeir, T., Mounzer, O. & Rouphael Y. (2005). Evapotranspiration and seed yield of field grown soybean under deficit irrigation conditions. Agricultural Water Management, 75(3): 226-244.

Karam, F., Lahoud, R., Masaad, R., Daccache, A., Mounzer, O. & Y. Rouphael. (2006). Water use and lint yield response of drip irrigated cotton to the length of irrigation season. Agricultural Water Management, 85, 287-295.

Kirnak, H., Tas, I., Kaya, C., & Higgs, D. (2002). Effects of deficit irrigation on growth, yield, and fruit quality of eggplant under semi-arid conditions. Aust. J. Agric. Res., 53: 1367-1373.