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'More crop per drop' : how to make it acceptable for farmers ?

D. Luquet[1], Alain Vidal[2], Martin Smith[3] et Jean Dauzat[4]

[1] *CIRAD/Amis/Agro, Avenue Agropolis, Lavalette Bât 1, TA40/01, 34398 Montpellier cedex 5, France*
[2] *Cemagref, BP 5095, 34033 Montpellier Cedex 1, France*
[3] *FAO/AGLW Viale delle terme di Caracalla 00100 Rome, Italy*
[4] *CIRAD/AMAP, TA 40/PSII, 34398 Montpellier Cedex 5, France*

E-mail : `delphine.luquet@cirad.fr`

Abstact - In countries facing water scarcity, governmental water agencies try to transfer this constraint to farmers, e.g. by inciting farmers to shift from traditional to localized irrigation methods to save water. However, water shortage is often much less felt by farmers than soil limitations, their objective being mostly to maximize their income per cultivated area (US$ per ha rather than per m^3 of water). This discrepancy can only be solved if governments find ways to 'transfer' water scarcity, e.g. through economic incentives such as water pricing and/or subsidies. The aim of this study was to bring some discussion elements to the question of how to match both water managers and farmer's interest. We aimed particularly at evaluating to which extent shifting to drip irrigation is a relevant way to save water and increase farmer's income. This stood on an analysis of crops net productivity considering interactions between economic, environmental, technical and methodological parameters. We focused on the study case of Turkey considering two crops with contrasted gross productivity : tomato and cotton, characterized by partial vegetation cover during a large part of crop cycle. A 3D crop energy balance model was applied showing that crop transpiration is increased by up to 10% when shifting from furrow to drip irrigation. These results were used to correct the ETm estimated with the Kc method and thus to provide more accurate values of crops net productivity both with furrow or drip irrigation. By this way drip irrigation appeared definitely relevant when considering high value crops as tomato. Inversely, the divergences between farmer and water manager's interests are amplified with low-medium value crops as cotton ; the combination between water pricing and subsidies could be a way of agreement, but with irrigation equipment subsidies of at least 40 percent (for low water tariff) to 60 percent (around sustainable water price) to make the transfer from furrow to drip irrigation acceptable. This approach appeared generic enough to be applied in other economic, technical or environmental conditions, to modernize irrigation by harmonizing constraints faced by governments and farmers.

Key words : Drip and furrow irrigation, water saving, evapotranspiration modeling, crop productivity, water price.

1 Introduction

Due to an increased resource scarcity, water saving in agriculture is more and more a necessity in the Mediterranean Region. Therefore international organizations and governmental agencies often recommend farmers to adopt so-called 'water saving' irrigation methods such as drip instead of traditional methods.

The justification for shifting from traditional surface irrigation to localized irrigation is not as straightforward. Analyzing case studies in five Mediterranean countries, Vidal et al. (2001[22]) showed that localized irrigation is not a miracle technology, since excellent as well as poor results were obtained from these technologies and their adoption really depends on the ability of farmers to finance and operate them and the type of crop production. They also showed that modernized surface irrigation could be a water-saving technique comparable with more costly drip or sprinkler irrigation, and was more easily adopted by farmers, since it is closer to traditional practices. Also, Seckler (1996[20]) showed that such a technological choice should consider whether it would result in 'wet' or 'dry' water saving : if a water conservation technique simply reduces the amount of drainage water from a particular use, this would be only 'dry' or paper water saving. But if the drainage water flowed directly into a salt sink, 'wet' (or real) water would be saved. Therefore Seckler (1996[20]) introduced the expression 'more crop per drop' to mean that increasing crop water productivity was more relevant than just save water. In most cases however, drip and more generally localized irrigation has been shown to increase crop water productivity, by increasing yields and decreasing the amount of water used (e.g. Cetin et al. (2002[3]) for cotton ; Fedaku and Teshome (1998[6]) for tomato crop). Hence it is recognized that it usually increases farmer's income. From this economic point of view, a common obstacle to shift from traditional surface to localized irrigation is the investment cost of on-farm equipment, which is often not affordable to poor or even medium-income farmers. Therefore governments have sometimes introduced equipment subsidies, like in Tunisia (Vidal et al. 2001[22]) where such subsidies range from 40 to 60 percent and not only concern localized irrigation but any modernization effort such as modernized furrow irrigation.

The need to save water led to numerous methods of water consumption estimation (crop maximal and actual evapotranspiration ETm and ETa) mainly used to schedule irrigation according to environmental (crop, soil, climate) and technical (irrigation system) conditions. The most common and worldwide used are the FAO crop coefficient (Kc) methods (Allen et al. 1998[1]), from the simplest single Kc (that does not account directly for bare soil evaporation in water consumption) to the more recently improved dual Kc method (separating crop transpiration and soil evaporation according to the irrigation method used). Beside of these useful methods, some detailed crop water/energy balance models were developed during the last ten years, allowing evaluating and/or improving these simplified crop coefficient approaches.

The aim of this article is to discuss the interest of drip irrigation against modernized furrow method in a region with given climatic conditions where drip is often recommended by governmental agencies to save water, while farmers are more concerned about generating additional income than about saving water.

Two crops are considered, tomato (high value crop) and cotton (low-medium value crop), usually watered with either drip or furrow irrigation in the Mediterranean region and characterized by contrasted added values. A semi-theoretical analysis of crop gross and net productivity (US$/ha to US$/m^3) is provided according to economic, technical (irrigation) and climate conditions. This analysis is based on the Southeast Anatolia region of Turkey, considered as representative of climatic conditions encountered in the Mediterranean basin (from a purely Mediterranean to a near semi-arid climate) and for which detailed economic data are available (IPTRID, 2002[7]) in terms of crop yield, water prices with different farms strategies, equipment cost, and charges per hectare). It provides further elements of discussion to the question of how to match both farmers (increase incomes from irrigation) and state (water savings) goals ?

Three-dimensional (3D) crop energy - water balance model presented and validated by Dauzat et al. (2001[4]) and Luquet (2002[11]) is used to improve the estimate of crop water consumption with the dual Kc method.

Once defined the terms and theory used in this study, we present how the collected data sets are used to apply the improved Kc method for ETm estimation. The results are considered in terms of gross and net crop productivities per hectare and per m^3 of water used, leading to a discussion on irrigation technical choices according to water manager and farmer's points of view.

2 Theory and definitions

2.1 Productivity indicators

The gross productivity is the value of crop productivity expressed in US$ per unit surface (hectare, ha) (Malano et al. 2001[12] ; Molden et al. 1998[13]) or per unit of water consumed (m^3), that we differentiated in the case of Turkey between furrow and drip irrigation yields.

The net productivity or gross margin is the value of crop productivity (US$/ha or US$/m^3) minus all applicable charges consisting of equipment price (considered per hectare and per year of life length), water price (usually known per m^3 or per ha), and other production charges.

Water pricing : The full-cost water pricing recovers the full economic cost of the service provided, e.g. capital expenses, ongoing operation and maintenance... The sustainable cost of water (Tardieu and Préfol, 2002) is designed to ensure the long term balance of the service provision : it includes the cost for operation, maintenance and renewal costs including all the staff costs linked to the service, but not the full financial cost of the initial investment or of the most recent rehabilitation.

2.2 Modeling tools

FAO methods to estimate crop water requirements stand on the use of crop coefficients (Kc) given in FAO Land and Water Bulletin 56 (Allen et al. 1998[1]) to be multiplied by the reference evapotranspiration (ETo Penman-Monteith) at a daily time step to compute ETm. ETo is usually defined as the evapotranspiration of a theoretical crop with a height $h_c = 0.12$ m, a crop resistance of 70 s/mand an albedo of 0.23, characteristics closed to the one of uniform lawn grass, well watered, actively growing and fully covering the soil. Allen et al. (1998[1]) provide Kc values for the main crop stages coupled with methods to extrapolate these values all along crop cycle. Several levels of detail and complexity were developed in the application of Kc method. This mainly concerns two approaches : the 'single' and the 'dual' Kc approaches. 'Single' Kc means that soil evaporation and vegetation transpiration are not accounted for separately but integrated in an adjusted unique Kc value :

$ETm = Kc * ETo$(Eq.1)

In a second time, 'dual' Kc was elaborated as an improvement of single Kc, since it allows to separate soil evaporation and crop transpiration estimation :

$ETm = (Kcb + Ke) * ETo$(Eq.2)

Where Kcb is the basal crop coefficient and Ke the soil evaporation coefficient. Soil and vegetation separation enables to consider vegetation cover as well as the wetted soil fraction after an irrigation event (according to the type of irrigation applied).

However the dual Kc simplifies or occults some biophysical processes. This is the case of the effects of dry and hot soil heat transfers towards vegetation that could induce, under drip irrigation, an increase of about 20% of crop transpiration, in comparison to other irrigation methods where bare soil surface is nearly totally wetted (Moran et al., 1994[14]). Therefore we propose here to account for such biophysical processes by using a detailed 3D modeling approach of crop water/energy balance. This 3D modeling approach is based on a detailed description of plants in 3D mock-ups. Here simplified crop representations are used, meaning chosen volume shapes filled with a definite number of rectangular leaves randomly distributed according to crop real characteristics (figure 1). Such representations can be used to estimate energy and water balances (at a chosen time step, here one hour) at the level of plant leaves and of soil elements. Then, heat fluxes interaction between soil and vegetation are considered, allowing to evaluate bare soil heat fluxes effects on crop transpiration...

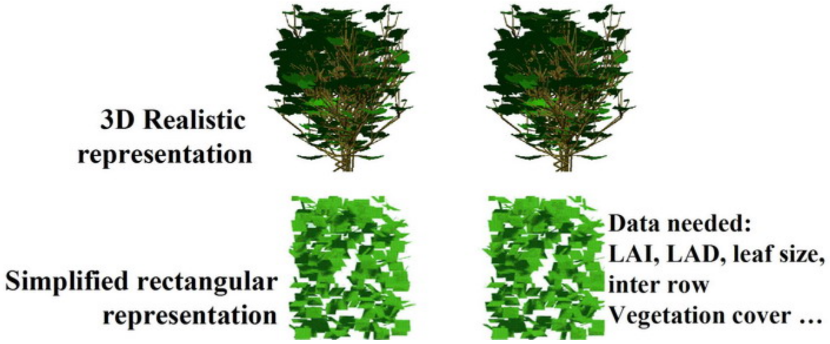

Fig. 1 – 3D realistic representation of cotton plants (top) and corresponding simplified 3D rectangular representation of rows (bottom) that are used in this study. LAI is Leaf Area Index and LAD Leaf Angle Distribution.

The present study will be limited to a theoretical situation where irrigation scheduling would enable to keep the crop at maximal evapotranspiration.

3 Maerial and methods

3.1 Economic considerations

During an identification mission to Turkey conducted by IPTRID in 2001 (IPTRID 2002[7]), a series of economic data was collected on main types of irrigated farms in Southeastern Anatolia, where a large project of the socio-economic development of the region (known as GAP - *Güneudogu Anadolu Projesi :* Southeastern Anatolia Project) is based on using Euphrates and Tigris rivers water for hydropower and irrigation development. The GAP region extends over an area of 7.5Mha. Cotton is the main crop grown and makes up a third of the national cotton output. Other objectives of rural development in the GAP region include raising the level of income in rural areas, among others by shifting from medium added value crop under surface irrigation (such as cotton) to higher added value crops under drip irrigation (such as tomato).

Economic data including gross product, water price, equipment cost (considering a life time of 5 and 10 years respectively for drip and furrow irrigation (CEP and Cemagref, 1992[2]), other charges (manpower, fertilizers, pesticides) and subsidies, were collected on 3 types of farms :

Small farms of the Sanli Urfa - Harran irrigation scheme (100 000 ha) organised in Irrigation Associations (each around 8 000 ha), mostly cultivating cotton (95 percent of the irrigated surface) ;

A state farm of 176 000 ha operated in Ceylanpinar by TIGEM, a state company, with 64 000 ha irrigated and more diversified crops ;

Two groundwater irrigation associations, the Nurdag Gedikli Water Users Cooperative near Gaziantep (1 000 ha irrigated) and the Cırcıp Groundwater User Association near Ceylanpinar (9 000 ha irrigated), both cultivating mainly cotton and facing a significant watertable falling.

All components of the gross productivity are estimated (on the basis of these data) at hectare level and converted into values per m^3 by considering crop water consumption per year as assessed by the three methods in either drip or furrow irrigation context. Figure 1 presents the initial values per hectare used in this study.

Tab. 1 – Minimal and maximal water prices, equipment cost, other charges and gross productivity for cotton and tomato per m^3 and per hectare in Turkey (IPTRID, 2002[7]).

	Tomato	Cotton
Water price US\$/m^3		
Surface water users association (WUA)	0.003	
Groundwater users association	0.028	
Drip equipment /year on 5 years US\$/ha/y	700	
Furrow equipment /year on 10 years US\$/ha/y	32.5	
Other charges US\$/ha/y	2500	800
Gross productivity drip US\$/ha/year	7500	2150
Gross productivity furrow US\$/ha/year	5000	1750

3.2 Theoretical modeling considerations

A reasonable number of crop characteristics are needed in order to give a simplified 3D crop representation. Field growth tomato crop characteristics come from in several bibliographic sources (Fedaku et al. 1998[6] ; Katerji et al. 1998[8] ; Li et al. 2002[9] ; Lowengart-Aycicegi et al. 1999 ; Romero-Aranda et al. 2001[18] ; Scholberg et al. 2000[19]), whereas a detailed data set characterizing cotton crop is provided by Luquet (2002[11]). Both tomato and cotton data are weekly data : LAI (Leaf Area Index), height, row width, leaf size and orientation. Otherwise Kc, Kcb and crop length stages values given by Allen et al. (1998[1]). are used in order to apply either Single or Dual Kc method.

The detailed meteorological data set provided by.. Luquet (2002[11]) both at a daily and hourly time step is used for ETm computations in Mediterranean conditions. Semi-arid conditions are simulated using hourly and daily meteorological data (Maricopa, Arizona, US) available on one of the USDA (AZMET) website (USDA 2002[21]).

Dual Kc method is applied for furrow and drip irrigation cases. Wetted soil fraction is chosen at 60 percent of the total area in the case of furrow irrigation and 20 percent for drip irrigation. In parallel, the 3D modeling approach is applied in order to simulate instantaneous ETm values in the same conditions, at three given stages of crop development : developing stage (vegetation cover of 40 percent), flowering (70 percent) and late season stage (full covering crop). Such computations concern 4 consecutive days within the considered stages, allowing testing crop transpiration variability according to irrigation method (wetted soil fraction) and vegetation cover. In every case, we consider a typical silt clay loam soil with the corresponding parameters provided in Allen et al. (1998[1]) for FAO methods application and in Noilhan and Planton, (1989[15]) for 3D model application.

4 Study cases results

4.1 Modeling results

Table 2 shows the ratio between averaged single and dual Kc values for the different crop stages for every studied case. This ratio is, by definition, equal to the ratio between maximal evapotranspiration (ETm) obtained from single (Eq. 1) and dual (Eq. 2) Kc methods, respectively. Obviously the strongest ratios and variations between ratios (according to irrigation method) are generally observed in the earlier crop stages. When the crop is partially covering, the contribution of soil evaporation to ETm is strong and quite different between drip and furrow irrigation. These results are true for every studied case (table 2) and illustrated in figure 2 through the case of cotton crop in semi-arid conditions.

Tab. 2 – Single Kc/dual Kc ratio for tomato and cotton in semi-arid and Mediterranean conditions

Single Kc/dual Kc ratios	initial	development	mid-season	late-season
Tomato semi arid (furrow)	1.36	0.93	1.06	1.25
Tomato semi arid (drip)	1.65	1.26	1.06	1.26
Tomato Mediterranean (furrow)	1.40	0.81	0.98	1.37
Tomato Mediterranean (drip)	2.07	1.22	1.00	1.42
Cotton semi arid (furrow)	0.75	0.94	1.05	0.94
Cotton semi arid (drip)	1.35	1.19	1.05	0.98
Cotton Mediterranean (furrow)	0.67	1.01	1.04	1.03
Cotton Mediterranean (drip)	1.29	1.30	1.05	1.11

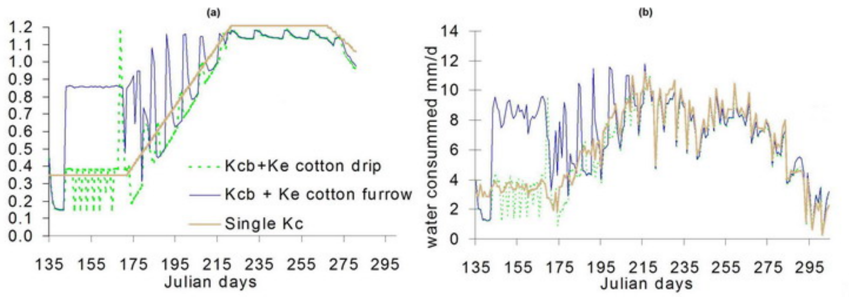

Fig. 2 – Single and dual Kc (a) and ETm values (b) along cotton crop cycle in semi arid conditions

Once applied the two crop coefficient approaches, the 3D modeling approach proposed by Dauzat et al. (2001[4]) .was used in order to correct for the impact of a dry soil heat flux on crop transpiration (under drip irrigation). Results show that water consumption differences occur mainly during early stages of development for partially covering crops (developing and flowering stages). As it could be expected according to the Kc methods results, strongest water consumption differences between furrow and drip systems are due to soil evaporation rate (around 80 percent more evaporation with furrow irrigation at developing and flowering stages).

However, an increase of crop transpiration rate can be observed in the caseof drip irrigation for both cotton and tomato : 10% during developing stages and 4% at flowering. These results are not so significant in comparison to the assumptions made by Moran et al. (1994[14]) but they remain interesting enough to be accounted for to correct transpiration estimation by dual Kc method. Values of ETm estimated with the dual Kc method improved by 3D modeling are summarized in table 3.

TAB. 3 – ETm estimation by dual Kc method improved by 3D modeling results.

	ETm	**Tomato**		**Contton**	
		Forrow	Drip	Furrow	Drip
Semi arid	m^3/Ha/an	12000	10340	12000	1400
Mediterranean	m^3/Ha/an	7000	5900	7000	5800
Iniial added value (AV) in Torkey	in m^3	0.5	0.75	0.17	0.21
AV + transpiration correction	in m^3	0.5	0.73	0.17	0.2

ETm values presented in table 3 are used to estimate the crops' gross and net productivity. For this, the economic (table 1), technical (irrigation) and environmental (crop, soil, climate) parameters detailed above are considered. The results are presented in figure 3 for the case of cotton and tomato crops in semi arid conditions. Obviously, drip irrigation is relevant in the case of high value crops such as tomato. The net productivity reached with drip is twice the one obtained with furrow irrigation (cf. bold values within the bars in figure 3-a-b). On the opposite, furrow irrigation remains the most interesting application technique for cotton. The results obtained with the single Kc method are quite relevant even if they generally reinforce the interest of drip irrigation. However, such results cannot be generalized without their further testing on other study cases.

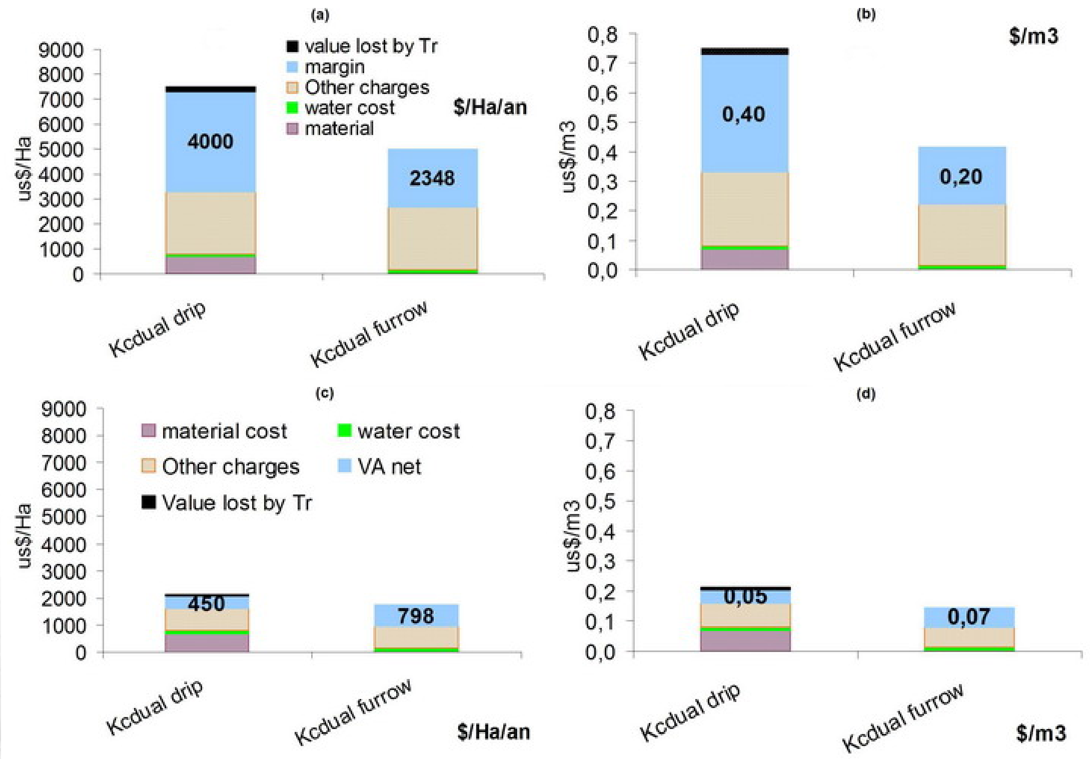

FIG. 3 – Net productivity per hectare and per m^3 of tomato (a-b) and cotton (c-d) in semi arid conditions.

The relevance of an irrigation strategy obviously depends in a large part on crop value. A low or medium value crop such as cotton cannot reach a level of productivity high enough to make the cost of drip equipment affordable. The trends observed per hectare (figure 3-a-c) remain the same when relating the data to m^3 (figure 3-b-d) even if drip irrigation interest is slightly amplified. This points out that metering water efficiency and productivity should be most interesting from the water manager's point of view than from the farmer's one, mainly in the critical cases of low/medium value crops. We don't discuss the results observed in the case of a Mediterranean climate leading to the same conclusions.

4.2 Sensitivity of crop net productivity to water tariffs and subsidies on equipment

Above results provide a interesting basis to bring further discussion elements to balance farmer's demand and governmental water resource management by testing what would be the effect of water fees and of subsidies on equipment on farmer's income (expressed in terms of crop net productivity). For this, the most efficient ETm estimation method is used combined with economic values from Turkey (IPTRID, 2002[7]). Various levels of subsidies are applied as percentage of the equipment cost. Water tariffs vary from the lowest cost (0.003US$/m^3) encountered in Turkey to a fictive higher price (0.25US$/m^3) through prices approaching worldwide average values of sustainable (0.07US$/m^3) and full cost prices (0.10US$/m^3) (Dinar et al. 1997[5]).

4.2.1 Price variations with different equipment subsidies

In the case of tomato crop (figure 4-a-b), drip irrigation is definitely more efficient and interesting from both farmers and water manager's point of views. As already observed in figure 3, the tomato crop net productivity in figure 4 is twice higher for drip irrigation compared to furrow irrigation for the lowest water price level (0.003US$/m^3 as in state farms in Turkey). When water tariff reaches full-cost water price (around 0.10US$/m^3), tomato net productivity under drip irrigation decreases to the value of net productivity under furrow irrigation values at lowest water price.

In the case of cotton (figure 4-c-d), furrow irrigation remains more interesting than drip irrigation, except when drip equipment gets subsidized at a 60 percent level. If water tariff reaches or exceeds the sustainable cost (0.07US$/m^3), neither drip or furrow irrigation enable cotton to be economically interesting. However, around the sustainable cost, drip irrigation should become the most efficient when equipment gets subsidized at a 40 percent level.

5 Discussion and conclusion

This semi-theoretical study brought some discussion elements to evaluate how to match both water saving issues and farmer incomes improvement in a context of shifting from traditional furrow to localized irrigation in the Mediterranean Region. This study case was focused on cotton and tomato in Turkey.

The results showed that even if drip irrigation is a relevant technique to enhance water use efficiency (in terms of ratio between water consumed by the crop and water supplied on-farm or at plot entrance), its interest did not appear so obvious from the farmer's point of view. Required equipment is expensive and not necessarily affordable, mainly in the case of low-medium crop values, where it represents 10 percent of the crop gross productivity per ha. Crop gross productivity was shown as a determinant criterion to opt either for drip or furrow irrigation. With high value crops such as tomato, drip irrigation is definitely more interesting both for farmers and water manager's point of view, net productivity being twice the one reached with furrow irrigation. Inversely, furrow irrigation remains substantially more relevant than drip in the case of low-medium value crops such as cotton, except when both high water tariffs and significant irrigation equipment subsidies are applied. Expressing crop net productivity per m^3 instead of

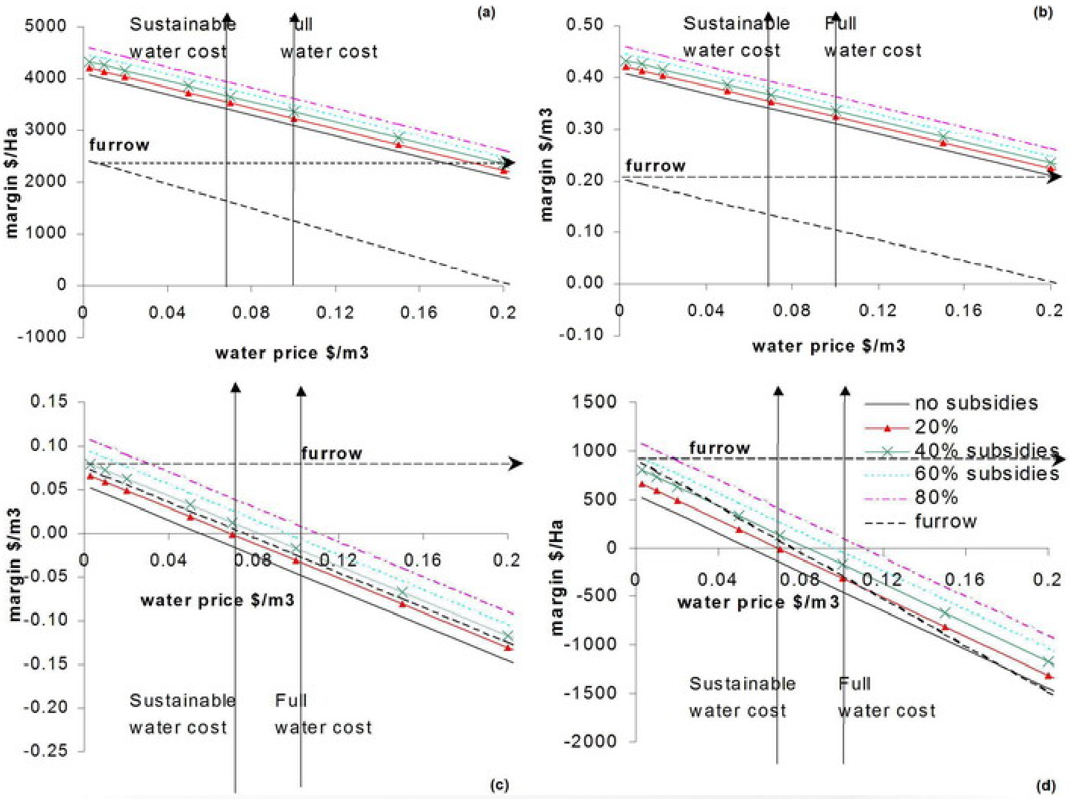

FIG. 4 – : Tomato (a-b) and cotton (c-d) crop net productivity in US$/ha and US$/m^3 with water tariff variation according to different levels of equipment subsidies, in semi-arid conditions.

per hectare confirmed above results. However the volumetric (m^3) expression of irrigation performance indicator tended to accentuate the relevance of drip irrigation and hence the interest of governmental agencies supporting water savings efforts often more than farmers income.

Such results were confirmed when analyzing crop net productivity according to water pricing, equipment subsidies and crop added value. This supported the fact that in the critical case of low/medium value crops, irrigation performance estimation cannot be approached without considering environmental, technical and economic aspects. This is the only way to make technical relevant decisions both from farmer and water manager point of view since. This pointed out that combination between water pricing and subsidies could match partially both farmers and water manager's interests. However in the studied case, subsidies of at least 40 percent (for a low water tariff) to 60 percent (for a water tariff close to sustainable water price) of irrigation equipment should be provided to make the transfer from furrow to drip irrigation acceptable (in the case of low/medium value crops).

Finally, the provided semi-theoretical method of crop margin analysis appeared generic enough to be applied in various scenarios (in economic, technical, agricultural or environmental terms). It allowed adopting either farmers or water manager's point of view to support a consensus building process. In the same way, it could allow a bottom-up approach to evaluate the relevance of performance irrigation indicators applied at system level rather than at on-farm level. Finally these results could be integrated in the decisions and orientations taken in the field of irrigation management modernization.

Références

[1] Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). Crop evapotranspiration-Guidelines for computing crop water requirements. Rome, FAO. FAO56 : 300 pp.

[2] CEP and Cemagref, (1992). Irrigation- guide pratique, CEMAGREF - Groupe France Agricole.

[3] Cetin, O. and L. Bilgel, (2002). Effects of different irrigation methods on shedding and yield of cotton. Agricultural Water Management. 54 : 1-15.

[4] Dauzat, J., D. Luquet and A. Bégué, 2001. Energy balance modelling and thermography simulation on 3D plant models. Application on cotton trees. Third International Workshop on Functional-Structural Tree and Stand Models, Montreal- Canada, GREFi.

[5] Dinar, A. and A. Subramanian (1997). Water pricing experience : an international perspective. Washington DC, World Bank.

[6] Fedaku, Y. and T. Teshome, (1998). Effect of drip and furrow irrigation and plant spacing on yield of tomato at Dire Dawa, Ethiopia. Agricultural Water Management. 35 : 201-207.

[7] IPTRID (2002). Research and Development opportunities on agricultural water management. Report of the IPTRID identification mission to the GAP region, Turkey. Rome, IPTRID/FAO : to be published.

[8] Katerji, N., J. W. v. Hoorn, A. Hamdy and M. Mastrorilli, (1998). Response of tomatoes, a crop of indeterminate growth, to soil salinity. Agricultural Water Management. 38.

[9] Li, Y. L., C. Stanghellini and H. Challa, (2002). Response of tomato plants to a step-change in root-zone salinity under different transpiration regimes. Scientia Horticulturae. 93 : 267-279.

[10] Lowengart-Aycicegi, A., H. Manor, R. Krieger and G. Gera, (1999). Effects of irrigation scheduling on drip-irrigated processing tomatoes. Acta Horticulturae. 487(ISHS - Workshop on Irrigation and Fertigation of Processing Tomato - Part 2) : 513-517.

[11] Luquet, D. (2002). Suivi de l'état hydrique des plante par infrarouge thermique : analyse expérimentale et modélisation 3D de la variabilité thermique au sein d'une culture en rang de cotonnier. Paris. Paris, France, Institut National Agronomique Paris Grignon : 164.

[12] Malano, H. and M. Burton (2001). Guidelines for benchmarking performance in irrigation and drainage sector. Rome, IPTRID/FAO : 44pp.

[13] Molden, D., R. Sakthivadivel, C. J. Perry, C. Fraiture and W. H. Kloezen (1998). Indicators for comparing performance of irrigated agricultural systems. Colombo (Sri Lanka), IWMI International Water Management Institute : 26pp.

[14] Moran, M. S., (1994). Irrigation management in Arizona using satellites and airplanes. Irrigation Science,. 15 : 35-44.

[15] Noilhan, J. and S. Planton, (1989). A simple parametrization of land surface processes for meteorological models. Monthly Weather Review,. 117 : 536-549.

[16] Perry, C. J. (2001). Charging for irrigation water : the issues and options, with a case study from Iran. Colombo, Sr Lanka, IIMI International Irrigation Management Institute : 1-16.

[17] Perry, C. J., M. Rock and D. Seckler (1997). Water as an economic good : a solution, or a problem ? Colombo, Sr Lanka, IIMI International Irrigation Management Institute : 1-16.

[18] Romero-Aranda, R., T. Soria and J. Cuartero, (2001). Tomato plant-water and plant-water relationships under saline growth conditions. Plant Science. 160 : 265-272.

[19] Scholberg, J., B. L. McNeal, J. W. Jones, K. J. Bootes, C. D. Stanley and T. A. Obreza, (2000). Growth and canopy characteristics of field-grown tomato. Agronomy Journal. 92 : 152-159.

[20] Seckler, D. (1996). The new era of water resources management : from ”dry” to ”wet” warter savings. Colombo (Sri Lanka), IWMI International Water Management Institute : 17pp.

[21] USDA (2002). Azmet website, USDA. 2002.

[22] Vidal, A., A. Comeau, H. Plusquellec and F. Gadelle (2001). Case studies on water conservation in the Mediterranean region. Rome, IPTRID/FAO : 52pp.