

SUPPLEMENTARY IRRIGATION IN ARID AND SEMIARID REGIONS

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The purposes of irrigation are many but the prevailing one consists in supplying crops with water when natural precipitation is insufficient to satisfy the evapotranspiration demand of the atmosphere, i.e. wetting irrigation. Wetting irrigation has different facets depending on the purpose for which it is practiced, the climatic characteristics of the area under study, and especially on the rainfall regime and water availability for irrigation.

If the objective is to satisfy full crop water requirements, the irrigation regime has to ensure a permanent optimal water regime. This is possible through a uniform irrigation regime: temporary or permanent.

The optimal water regime of the crops is ensured through a temporary irrigation regime in environments where rainfall satisfies crop water requirements at least partially, as it is the case in arid and semiarid regions of the mediterranean area where the yearly rainfall is no less than 500-600 mm and it is concentrated in the rainy season. Conversely, the optimal water regime is obtained by a permanent irrigation regime in desert environments, where rainfall can only marginally contribute to crop water requirements.

In environments where natural contributions of water by rainfall or groundwater are insufficient to satisfy full crop water requirements only occasionally, the permanent optimal irrigation regime can be ensured through supplementary irrigation, i.e., by a temporary and discontinuous irrigation regime. Such situations are observed in northern Italy regions, in Friuli, Veneto and Emilia, for herbaceous crops such as soya bean, maize and sugarbeet, and for some tree crops, where the rainfall amount and distribution are such that to optimize crop yield occasional supplementary irrigations are sufficient.

Abstract

The meaning of supplementary irrigation in arid and semi-arid areas is illustrated; criteria to establish when to irrigate with supplementary irrigation are described; supplementary irrigated main crops and their yield response are outlined; some considerations on irrigation methods usable for supplementary irrigation are reported.

Résumé

Après avoir illustré la signification d'appoint dans les régions arides et semi-arides, les auteurs décrivent le critère pour le déclenchement de cette irrigation; ils indiquent les principales cultures irriguées par ce type d'irrigation et leurs réponses de rendement; ils concluent par quelques remarques sur les méthodes d'irrigation d'appoint.

Finally, in the regions where natural contributions of water by rainfall and groundwater and available water resources for irrigation are insufficient to ensure a permanent optimal water regime to crops, supplementary irrigation is mainly used at the critical periods of the crop growth cycle, in order to stabilize and improve yield quantity and quality. This is the case in arid and semiarid regions of the mediterranean basin, like southern Italy and its islands. In these environments, supplementary irrigation is practiced for species generally grown without irrigation and with a good economic profitability, like autumn-spring herbaceous crops, for instance autumn sown cereals, and summer-winter crops, some crucifers, and generally unirrigated tree species: olive tree, vine, almond tree, etc.

Supplementary irrigation can then have different purposes: a) to optimize yield in environments where water deficit is occasional and of short duration; b) to optimize water use efficiency of limited available natural and irrigation water resources. In the latter case, supplementary irrigation can be considered to be a dry farming technique since it aims at exploiting limited water resources; it is practiced either to prevent complete yield loss, for instance in exceptionally dry years, irrigation of wheat at sowing and/or at the booting stage or olive tree irrigation at vegetative resumption or to improve yield quantity and/or quality, for instance in years not excessively dry, irrigation of wheat at the booting stage or of olive tree at the fruit enlargement stage.

From all the above, one can easily infer that supplementary irrigation aiming at optimizing water use efficiency can be practiced in environments where the rainfall regime is such to satisfy at least a part of crop water requirements. On the contrary, in desert regions, where rainfall only marginally contributes to satisfy crop water requirements, permanent irrigation rather than supplementary irrigation can be practiced, although not necessarily to provide an optimal water regime to the crop.

When to irrigate

Supplementary irrigation is then a «limited» type of irrigation (Stewart B.A. and Musick J.T., 1982) and its strategy consists in optimizing yield per unit of volume of water applied rather than per unit of cultivated surface; in other terms, supplementary irrigation in these areas aims at increasing total farm yield and water efficiency by minimizing the unirrigated surface.

Therefore, the problem is to irrigate by using limited amounts of water at the growth stages – the «critical stages» – in which more or less severe water deficits can severely affect yield. For this purpose, during the growth cycle of the cultivated species, in general, and of the species subject to supplementary irrigation in particular, several growth stages sensitive to water stress but to a different extent can be detected. In order to maximize water use efficiency, it is of great importance to know the sensitivity level of the said growth stages to water stress.

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Different authors agree in stating that for most of the cultivated species, the stages of maximum sensitivity to water stress are those from pre-flowering to fruit-setting both for herbaceous and tree crops; moreover, for the latter, irrigation proves to be quite useful also during the stage of cellular extension of fruits.

The appearance of stress symptoms at different growth stages is dependent on climatic characteristics and variability over the years, as a consequence, the growth stage at which irrigation is more useful can be different in different climatic regions and, within the latter, depending on the climatic pattern of each single year. For instance, in literature it is reported that the most sensitive stages of wheat to water stress are the booting and the early earing stage according to some Authors (Fisher and Slatyer, 1973; Sandhu and Horton, 1977a, 1977b; Green and Kirkham, 1980; Catalano, 1989), and the pre-flowering and ear formation (milk and wax ripeness stage) according to other authors (Tedeschi and Zerbi, 1987); whereas seed germination and crop emergence are only exceptionally considered to be sensitive to water stress. Moreover, for vine and olive tree, the most sensitive stage to irrigation reported in literature is the fruit cellular extension stage (early change of colour and stone hardening, respectively), whereas the early stages of vegetative resumption, because of sufficient water storage present in the soil from the previous rainfall season, are exceptionally reported to be sensitive to water stress. In particularly dry years during the October-December period or in winter, as it was the case from 1987 to 1989-90, irrigation at sowing for autumn-winter cereals and immediately before vegetative resumption for vine and olive trees is decisive for yield.

Therefore, for a given species the growth stages sensitive to water stress are different and of a different sensitivity level. Irrigation at a given growth stage depends on the crop sensitivity to water stress, on the climatic pattern and on the need to exploit natural water resources. For the latter purpose, irrigation of autumn-winter cereals at sowing, in particularly dry years during October-December, aims at ensuring an optimal plant density to exploit rainfall water of the following winter period.

The chance or the possibility to irrigate at one or more growth stages sensitive to water stress depends on the water availability and the marginal income increase resulting from one or more irri-

gations applied to the same species or to several species grown in the farm or in the irrigation scheme.

It was mentioned that the strategy of supplementary irrigation is to optimize the yield per unit volume of water applied, that is to optimize the income per m^3 of water supplied to the crop. This objective can be differently fulfilled depending if one refers to a single species or to several cultivated crops in the same farm or scheme.

If we refer to only one species, it is a matter of defining the water volume and the number of irrigations corresponding to the highest income per m^3 of water applied to a given species. But, if we refer to several species grown in the farm or in the irrigation scheme, it is necessary to find out the water volume and the number of irrigations for each species and the corresponding highest income value per m^3 of water used within the farm or the irrigation scheme or the standard hectare. In the last case, the highest income per m^3 of applied water doesn't necessarily result from the highest income per m^3 of water applied to each single species; it is often more profitable to give less water to a species at one or more growth stages, although sensitive to water stress, and to use the water saved to irrigate other species which, meanwhile, reached their «critical period» and exploit irrigation water better than the less irrigated crop.

Finally, deciding when to supplementary irrigate is a physiological and economic criterion, whereas the chance to irrigate at one or another critical growth stage or several growth stages depends on the climatic pattern and the availability of irrigation water.

Crops irrigated by supplementary irrigation

The crops irrigated by supplementary irrigation are the ones profitably grown without irrigation, but their yields are subjected to great variations over the years because of rainfall variability. These species are: winter cereals (for instance wheat), autumn sowing legumes (such as broad bean and pea); some spring-summer herbaceous crops having a dense and deep rooting system, such as sorghum, cotton, tobacco (sun cured levantine varieties - Xanthi Jakà, Perustitza, Erzegovina), sunflower; some tree crops having a dense and deep rooting system, which under water shortage conditions behave as xerophytes with-

out excessive yield losses, like olive trees, vine, almond tree, fig tree, carob tree and Indian fig-tree.

Wheat, in view of its interest for human feeding, is the species mostly irrigating by supplementary irrigation in many mediterranean countries. Experimental results reported in literature indicate that water stress conditions at any growth stage between booting and wax-ripe stage cause yield losses, and that the most sensitive stages are booting and earing (**figure 1**) (Catalano *et al.*, 1989). But, in particularly dry years during the October-December period, an irrigation immediately after sowing is decisive in favouring a rapid crop emergence, an optimal plant density and satisfactory yields. In this connection, the experimental data obtained in southern Italy, in particularly dry years, during the October-December period and quite rainy season in the successive January-May period, stress that, with respect to the un-irrigated crop, one irrigation immediately after sowing resulted in a grain yield increase of 132% (2.03 against 4.71 $t \cdot ha^{-1}$) whereas irrigations only at the booting stage or at sowing and during the booting stage caused yield increases, respectively, of 23 and 146% (2.03 against 2.50 and 4.90 $t \cdot ha^{-1}$) (**figure 2**) (Caliandro *et al.* 1989).

In dry years during spring, one or two irrigations to broad bean and pea in the period from flowering to seed enlargement, result in significant increases of yield quantity and quality.

Sun-cured tobacco is normally grown without irrigation in order to obtain small leaves with high content in sugar, resins and minerals which are indispensable in most of blends. However, numerous experimental results showed that one or two supplementary irrigations during the early growth stages not only cause significant yield increases, but also improve quality considerably (Tarantino, 1991).

Cotton benefits from one irrigation at sowing, if soil moisture and rainfall pattern are not such to favour seed germination and seedling, and, in particular, during the flower bud formation (Doozenbos and Kassam, 1979).

Under optimal soil moisture conditions, for sunflower, one irrigation in the period between flower bud appearance and flowering results in significant yield increases. Under deep soil conditions and limited initial water storage, one abundant irrigation at pre-sowing could be sufficient to guarantee a satisfactory yield (Tarantino, 1991).

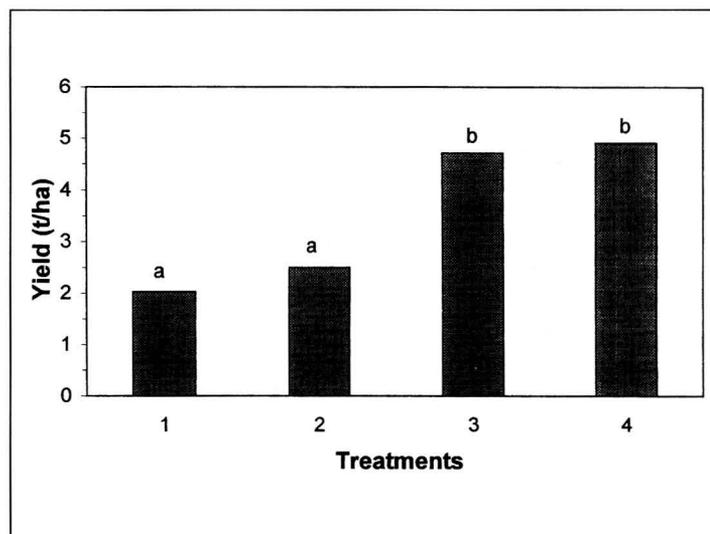
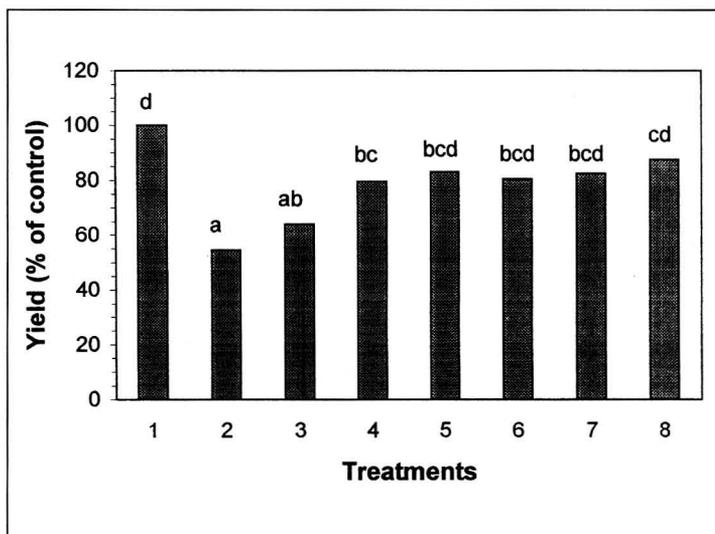
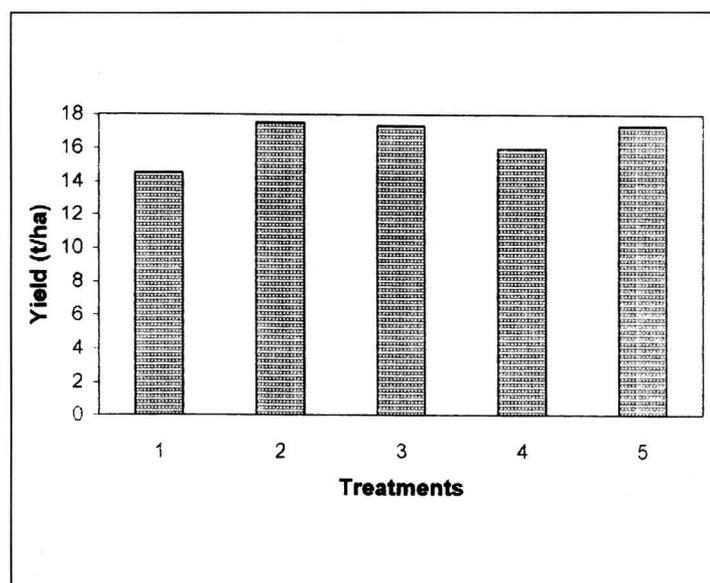


Figure 1 - Influence of water stress at different growth stages of a durum wheat cv, on grain yield. 1=unstressed control; crop stressed at 2=booting stage - earing; 4=flowering; 5=early milk ripeness; 6=full milk ripeness; 7=wax ripeness; 8=full ripeness. The bars marked by the same letter represent the values not significantly different from each other at 0.01 P according to the Newman-Keuls method. (from Catalano M. et al, 1989).

Figure 2 - Influence of supplementary irrigation on durum wheat (average of 5 cv) at different growth stages. 1=unirrigated control; crop irrigated at sowing (2); at the booting stage (3); at sowing and at the booting stage (4). The bars marked by the same letter represent values non significantly different from each other at 0.01 P according to Newman-Keuls (from: Calian-dro A. et al, 1989).

tary irrigation performed two or three weeks before flowering, if the winter period is dry, during the stone hardening stage, which is considered to be the most

Figure 3 - Influence of water stress at different growth stages of grain sorghum. 1=un-stressed control; crop stressed at 2=the booting stage; 3=flowering - fruit - setting; 4=fruit - setting - grain filling; 5=booting, flowering - fruit - setting and fruit - setting - grain filling (from Brahim A., 1992).



Also for sorghum, under optimal soil moisture conditions at sowing, only one irrigation during the booting stage can be enough to obtain acceptable yield. The booting stage, in fact, is the most sensitive to water stress (Aloi Brahim, 1992) (Figure 3).

The number of irrigation can vary according to the climatic pattern, the water retention capacity of the soil and to the type of crop, whether it is a main or a catch crop after wheat for instance. If the soil is dry at sowing one irrigation is indispensable, preferably before sowing, to avoid any crust formation which can greatly hamper seedling emergence. This situation is quite frequent in silty or silty-clay soils, as a consequence of water supply, either natural or by irrigation, during the periods of high evapotranspirative demand of the atmosphere.

Among tree species, vine, in view of its economic interest, is the crop to which irrigation, especially supplementary irrigation, is more widely practiced. Table grape vine in almost all arid and semi-arid environments is irrigated with a uniform irrigation regime during the period from fruit-setting to early maturity. Conversely, wine grape vine is almost always irrigated by supplementary irrigations at different growth stages. As for the latter, specific trials carried out in Apulia and Sicily (southern Italy and islands) indicate that the change of colour and the fruit-setting stages and/or early maturity are the most sensitive to irrigation, as it is observed from figures 4 and 5 (Lombardo, 1979; Miali et al., 1985).

Olive tree, although it is a typical species of mediterranean climate environments, generally grown without irrigation, greatly benefits from supplementen-

sensitive stage to water stress, at the change of colour of fruits, the cellular extension of fruits, if no rainfall occurs at late summer (Doorenbos and Kassam, 1979). Almond tree, since it starts its growth cycle very early, when the rainfall season is not yet complete and the moisture of the soil layer explored by roots is at field capacity, is always considered to be a species which fits well to mediterranean climate environments or which can be grown without irrigation. However, also for almond trees, yield can greatly vary over the years because of temperature pattern variations at vegetative resumption and the rainfall patterns during fruit formation. Temperatures lower than 0°C during the fruit-setting and early fruit enlargement stage can greatly damage yield and cause fruit drop. Early water stresses can reduce the fruit size, whereas water stresses after

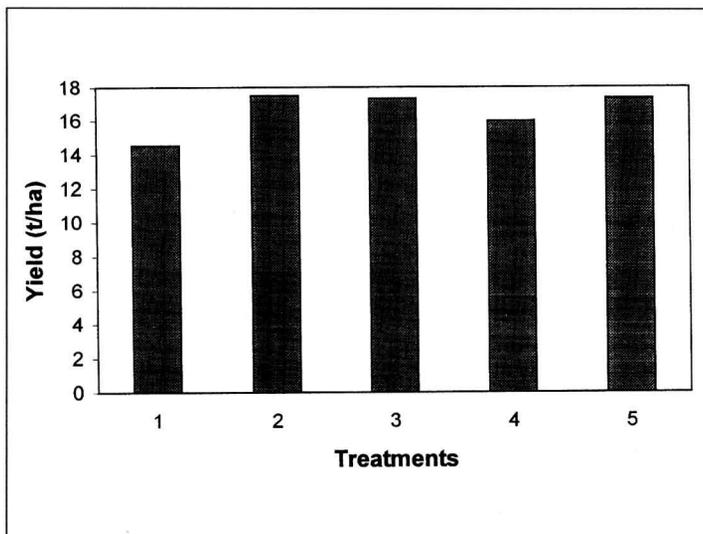


Figure 4 - Influence of supplementary irrigation to wine grape vine (average of 4 cv), at the following growth stages: 1=change of colour; 2=fruit - setting and change of colour; 3=fruit - setting and maturity; 4=change of colour and maturity; 5=fruit - setting, change of colour and maturity. Trials conducted in Sicily, southern Italy (from Lombardo V., 1979).

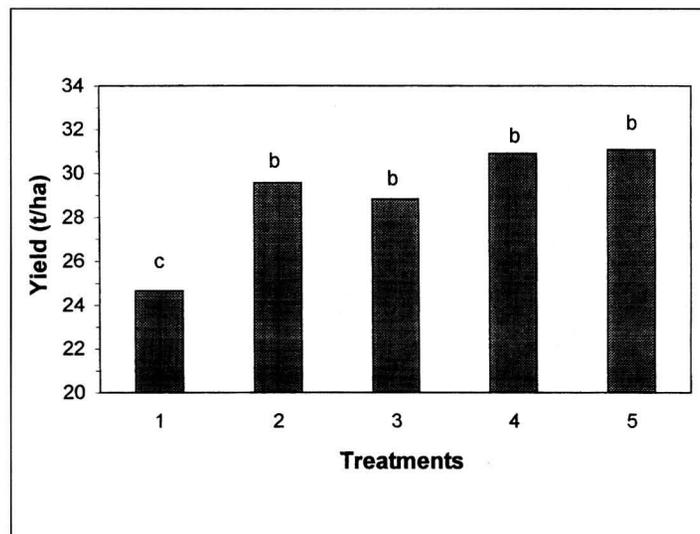


Figure 5 - Influence of supplementary irrigation to wine grape vine (average of 3 cv), at the following growth stages: 1=unirrigated control; 2=fruit - setting and maturity; 3=change of colour and maturity; 4=fruit - setting and change of colour; 5=fruit - setting, change of colour and maturity. Trials conducted in Apulia, southern Italy.

The bars marked by the same letter represent values not significantly different from each other at 0.01 P according to Duncan test (from Miali G. et al., 1985).

stone hardening can reduce the seed size. Therefore, irrigations, when necessary, during the period between fruit enlargement and seed development can result in better yield quantity and quality.

Irrigation methods

Supplementary irrigation aiming at optimizing the limited water resources is practiced to generally low income crops, which thus impose to curb costs. In order to satisfy these requirements, costs of water and its distribution have not to be high. The result is that deep ground waters and high installation or running cost irrigation methods are not so suitable.

Therefore, the irrigation methods usable for supplementary irrigation should have one or more of the following requisites: low initial capital investments per unit of irrigated surface; easy transferability of any installation within the farm or from one farm to another; limited labour; high water distribution efficiency; possibility to satisfy specific needs of the crop during the growth stages in which watering could probably be performed; possibility to dose the watering volume accurately, to make timely irrigations, not to damage crops upon watering, for instance by trampling, and to control any excess water during the rainy season. Among the available methods one can choose either the surface methods (flooding, surface runoff and furrow irrigation) or sprinkling. The surface methods can be applied on clay soils with limited and uniform slopes; sprinkler irrigation can be used under all pedological conditions; both groups of methods can be used for herbaceous and tree crops.

Surface methods generally require: low initial capital investments, at least when the land is flat and doesn't need high capital for levelling; low energy cost for water distribution and fair labour requirements. On the contrary, they do not dose watering volume accurately; they do not always allow to reach high water distribution efficiencies and to control any excess of water during the rainy season; they often give rise to waterlogging at the lower end of the field.

Sprinkler irrigation, performed by using different machines, is the method which better fits to supplementary irrigation. Among the irrigation machines, one can mention self-propelled guns for irrigating herbaceous crops; self-propelled sprinklers and skid-mounted sprinklers to irrigate tree crops; center pivot sprinklers or linear move laterals for supplementary irrigation of herbaceous crops conveniently grown in succession with other herbaceous crops to be irrigated with uniform irrigation regime. The mo-

bile systems, because of their high running cost, and the fixed systems, because of their high installation cost, are poorly suitable for supplementary irrigation. Low pressure localized irrigation or micro-irrigation cannot be used for supplementary irrigation both because of high installation costs and of the type of water distribution: localized with reduced soil water storage.

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