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The evapotranspiration of crop protected by windbreak

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Abstract. As a result of the reduction of water resources, it is necessary to adopt agronomic strategies to mitigate crop evapotranspiration (ET) in the Mediterranean environment. The mechanisms with which windbreaks modify the microclimatic components and the evapotranspiration have been studied through laboratory testing (wind-tunnel), observations in the field (in Australia and in USA) and crop models. The extrapolation of the results of these studies does not allow for the quantification of their effective benefit in crop water consumption. This study proposes modifications to the Penman-Monteith formula to allow for calculation of the water requirements of wheat and bean in the presence of windbreaks. The experiments were carried out in Rutigliano, (Southern Italy). The microclimatic data were recorded in an experimental field protected by a windbreak of *Cupressus arizonica* L., positioned in a perpendicular direction to the prevailing winds (N). The analysis of the microclimate highlighted that wind speed was mitigated up to 60% when the winds arrive from the Northern sector up to a distance less than 18 times the height of the windbreak (18 H); moreover the temperature rose up to 3.5°C for a distance less than 5H during the hottest seasons and only with the prevailing winds. These results were used to correct the reference evapotranspiration formula (ET_0) and the crop coefficients (K_c). With these corrections, the action of windbreaks on ET and water consumption were simulated. The simulations highlighted that, during 2000, the reduction of ET near the windbreak was 115mm for wheat and 95mm for bean. Different heights of the windbreak were simulated on a 1ha bean plot to quantify the contribution to effective water savings. The simulation highlighted that 8m high barriers offered the maximum water savings, estimated by 36% greater than consumption for an unprotected plot.

Keywords. Agrometeorology – Dry-farming systems – Evapotranspiration – Natural windbreak – Water use efficiency.

L'évapotranspiration des cultures protégées par des brise-vent

Résumé. Vue la scarsité des ressources en eau, il est nécessaire d'adopter des stratégies agronomiques qui minimisent l'évapotranspiration des plantes (ET) dans la région méditerranéenne. Les mécanismes par lesquels les brise-vent modifient les composantes microclimatiques ainsi que l'évapotranspiration ont été étudiés au moyen de tests en laboratoire (soufflerie), d'observations sur le terrain et de modèles de culture. L'extrapolation des résultats issus de ces études ne permet pas de quantifier leur bénéfice effectif sur la consommation d'eau par les plantes. Cette étude suggère de modifier la formule de Penman-Monteith (FAO, 56) pour permettre le calcul des besoins en eau du blé et des haricots en présence de brise-vent. Ces expériences ont été réalisées dans une région du sud de l'Italie (Rutigliano). Les données microclimatiques ont été enregistrées sur un terrain expérimental protégé par un brise-vent de *Cupressus arizonica* L. placé en position perpendiculaire par rapport aux vents dominants (N).

L'analyse du microclimat met en évidence que la vitesse du vent s'est réduite jusqu'à 60% pour les vents du nord, jusqu'à une distance inférieure à 18 fois la hauteur du brise-vent (18H) ; de plus la température augmente jusqu'à 3.5°C pour une distance inférieure à 5H pendant les saisons les plus chaudes et seulement en présence des vents dominants. Ces résultats ont été utilisés pour corriger la formule d'évapotranspiration de référence (ET_{ref}) et les coefficients culturaux (K_c). Grâce à ces corrections, l'action des brise-vent sur ET et la consommation d'eau ont été simulées. Les simulations ont mis en évidence qu'en 2000 la réduction de ET près du brise-vent était de 115mm pour le blé et de 95mm pour les haricots. Au contraire, pendant la saison 1996 il n'y a pas eu de variations de ET à n'importe quelle distance du brise-vent. Différentes hauteurs de brise-vent ont été simulées sur un champ d'haricots de 1ha pour quantifier sa contribution sur l'économie effective d'eau. La simulation a mis en évidence que des barrières de 8m de hauteur assurent l'économie d'eau maximale, estimée à 36% par rapport à la consommation d'un champ non protégé.

Mots-clés. Agrométéorologie - Systèmes de cultivation à sec - Evapotranspiration - Brise vent naturel - Efficience d'utilisation de l'eau.

I – Introduction

In the Mediterranean environment, the limited availability of water implies the need to search for agronomical solutions that can mitigate the consequences of water deficits and increase the efficiency of the irrigation supply.

One of the various solutions proposed in dry farming, the windbreak, reduces crop evapotranspiration by modifying the aerodynamic and thermal components of the energy balance (Burke, 1998).

However, experimental results have been widely varying (Kort, 1988; Nuberg, 1998).

The information gathered from experiments carried out in the Mediterranean region are fragmentary and limited to a few tests carried out in Italy (Casa *et al.*, 1994) and Tunisia (Ben Salah *et al.*, 1989; Benzarti, 1989).

More numerous and organic specific studies have been carried out in Australia (Cleugh *et al.*, 2002). However, the Australian trials can not easily be transferred to the European Mediterranean environment, since Australia contains widely contrasting climatic conditions.

It is, therefore, necessary to carry out a more up-to-date study of the influence of windbreaks on the cropping systems of the Mediterranean region, as regards micrometeorology, evapotranspiration and crop productivity.

The present work takes into account the effects of the windbreak on the microclimate (aerodynamic and thermal components) and proposes the changes in the Penman-Monteith equation (Allen *et al.*, 1998) to calculate the water requirements of the crops (FAO water balance model).

The experiment was carried out in a typical Mediterranean environment on wheat and bean crop. The forecasts for climatic changes, provided by global circulation models, indicate an increased water deficit for the Mediterranean region (greater climatic demand and lower supply of rain), making easy to hypothesise an increase in water stress for crops in the future. Given this situation, the aim of the study is to answer the question whether windbreaks, by reducing the evapotranspiration demand on the scale of the parcel, can contribute to reduce the water stress risk for crops cultivated in the Mediterranean area.

II – Materials and methods

The trials were carried out at the experimental farm of the Research Unit for Crop Systems in Dry Environments (CRA – SCA), in Rutigliano (lat: 40°59', long: 17° 59', alt: 147m a.s.l.), in Southern Italy. The location is characterized by a Maritime-Mediterranean climate, with a notable aerodynamic component (speed wind > 2.8 ms⁻¹) and dominant winds coming from North. The average rainfall is approximately 600mm with precipitation concentrated mostly during the autumn, while quite scarce during spring and summer. This rainfall is insufficient to meet the evapotranspiration demand of the atmosphere (annual water deficit: 560mm).

The microclimate parameters have been recorded on the wheat and bean cultivated in an experimental field (100 x 200 m) in which is present, in perpendicular position to the dominant winds, a windbreak of *Cupressus arizonica* L., (height 3 m, long 150 m, age 20 years).

During the year 2005, microclimatic surveys were carried out on a central strip of the parcel, perpendicular to the cypress barrier. Measurements were made in various positions, at progressive distances from the windbreak and within the balanced boundary layer (Wieringa, 1993). At the position farthest from the windbreak the direction of the wind was measured while the other inputs (solar radiation, net radiation, wind direction, precipitation) were measured at a single position (3H), as they are not influenced by the action of the windbreak (Marshall, 1967). All the data were automatically registered each hour by the Campbell CR10X data-logger.

It is known that the protected area is linearly reduced when the diagonal flow exceeds 45° (Cleugh e Hughes, 2002). Moreover, the protected area is reduced by 75% when the wind is parallel to the windbreak (Burke, 1998) and it continues even when the direction of the wind is opposite to the barrier (Burke, 1998; Caborn, 1957; Cleugh and Hughes, 2002; Marshall, 1967; Sturrok, 1972). Granted that from previous experience and given the low frequency of winds coming from North-East, East and South-East (Figure 1), the micrometeorological data were selected on the basis of the sector the wind came from:

- *North: North, North-East, North-West;*
- *Lateral: West and East;*
- *South: South, South-East, South-West*

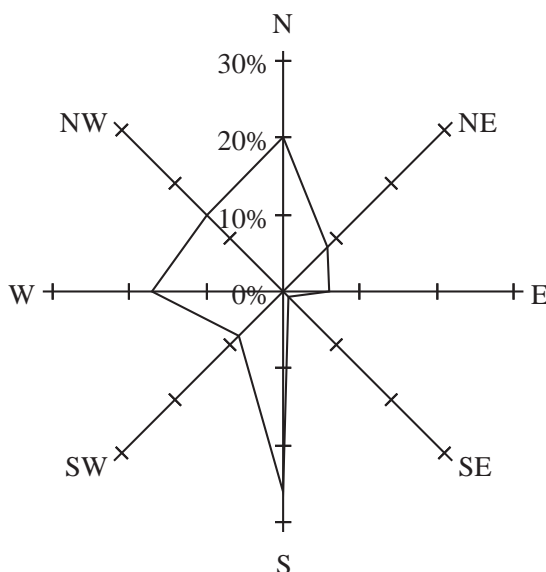


Figure 1. Distribution of the wind direction during the experimental trial.

The coefficients of correction were gotten by the analysis of the climatic data and they were used in FAO water balance model.

III – Results and discussions

The analysis of the microclimate highlighted that the efficacy of the windbreak altered in function of the wind direction. On days with wind coming from the Northern sector, the protection offered by the windbreak determined a reduction in wind speed for a distance of up to 18 times the height of the windbreak (18H). In particular, the slowest speeds were registered in proximity to the barrier ($< 5H$); vice versa, the values increased by 60% in the unprotected area ($> 18H$). When the winds came from the sector E-W and South a maximum reduction was respectively verified by 20% and by 22% for a distance of 10 H (Figure 2).

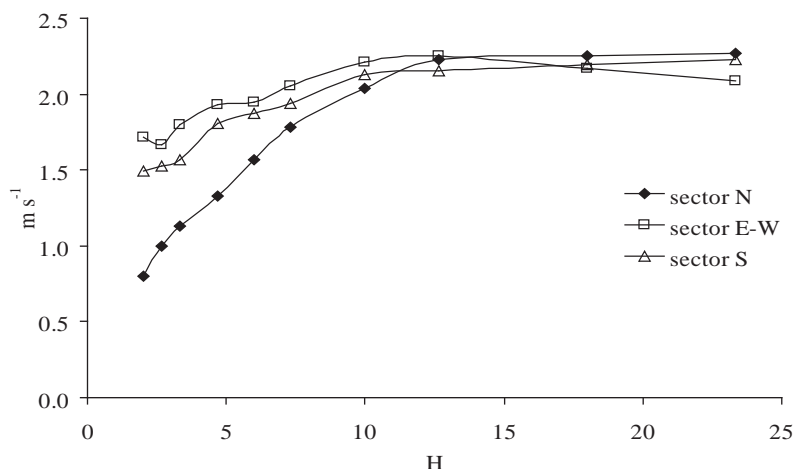


Figure 2. Wind speed (ms-1) as a function of the distance from the windbreak (H) during the cycle of the wheat and bean crop.

During the dominant winds and for both the crops, the temperature remained constant for the entire area in which the micrometeorological measuring sensors were installed, but it increased by about 1° C in the area between the windbreak barrier and 5•H. Instead, if the hours with temperatures above usual (> 29°C) are taken into consideration, the increase in temperature was 3.5°C in the same area (Figure 3).

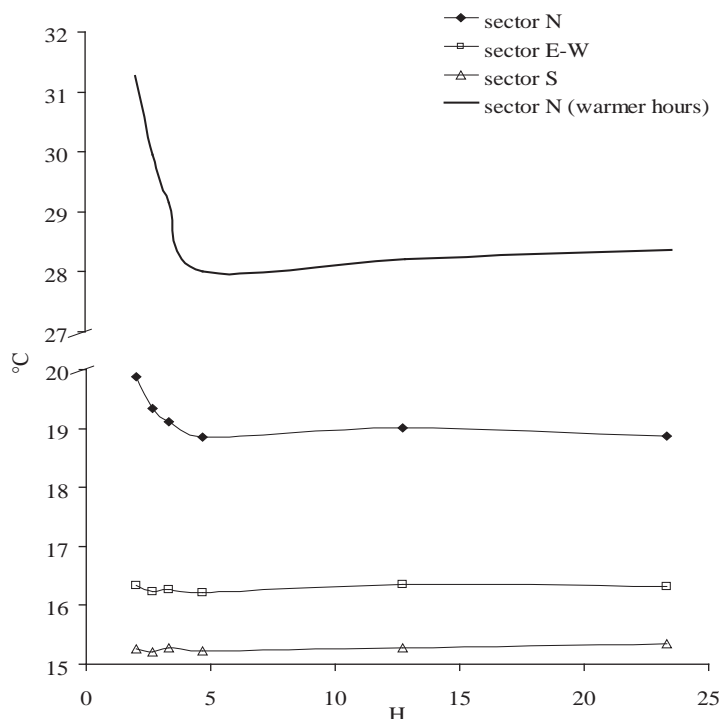


Figure 3. Air temperature (°C) as a function of the distance from the windbreak (H) in the cycle of the wheat and bean crop.

The air humidity (RH) did not vary with the distance from the windbreak (Figure 4).

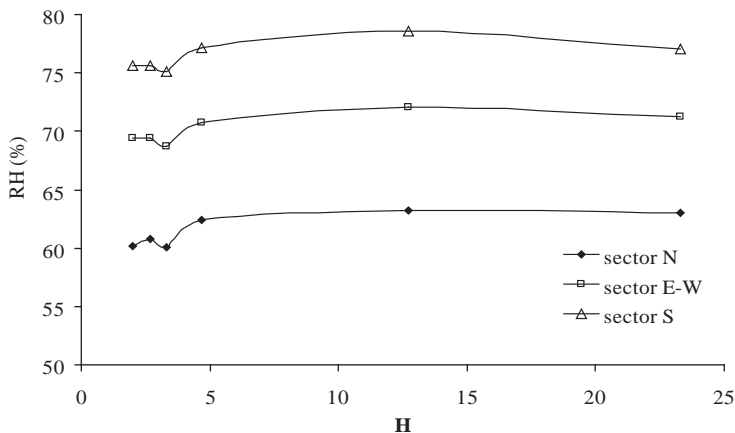


Figure 4. Relative humidity (%) as a function of the distance (H) from the windbreak.

All these experimental results were used to correct the reference evapotranspiration formula (ET_0) and the crop coefficients (K_c -dual) by the coefficients of correction of the wind speed (v_d) and temperature (t_d):

a) correction of the reference evapotranspiration (FAO Penman-Monteith equation)

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (Rn - G) + \gamma \cdot \frac{900}{T + 273} \cdot u_2 \cdot v_d \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 u_2 \cdot v_d)} \quad (1)$$

where vapour pressure deficit ($e_s - e_a$) derives from the pressure of saturated vapor to the temperature of the air ($e^*(T)$) corrected by the coefficient of reduction of the temperature (t_d):

$$e^*(T) = 0.6108 \cdot 2.7183^{\frac{17.27 \cdot T \cdot t_d}{T \cdot t_d + 237.3}} \quad (2)$$

b) correction of the K_c -dual:

$$K_{c_{max}} = 1.2 + \left[0.04 \cdot (u_2 \cdot v_d - 2) - 0.004 \cdot (RH_{min} - 45) \right] \cdot \left(\frac{h}{3} \right)^{0.3} \quad (3)$$

where u_2 is the wind speed at 2 m above round surface and h is the mean plant height during mid-season stage (m).

By these corrections, the action of windbreaks on ET and water consumption were simulated by the FAO water balance model.

The simulations highlighted that, from 1984 to 2006, windbreaks caused an average reduction in ET of 50mm for bean and 60mm for wheat. The effect of the windbreak depends on meteorological conditions. In particular, in 2000 the reduction of ET near the windbreak was 115mm for wheat and 95mm for bean. On the contrary, in 1996 there were no variations in ET at any distance from the windbreak (figure 5).

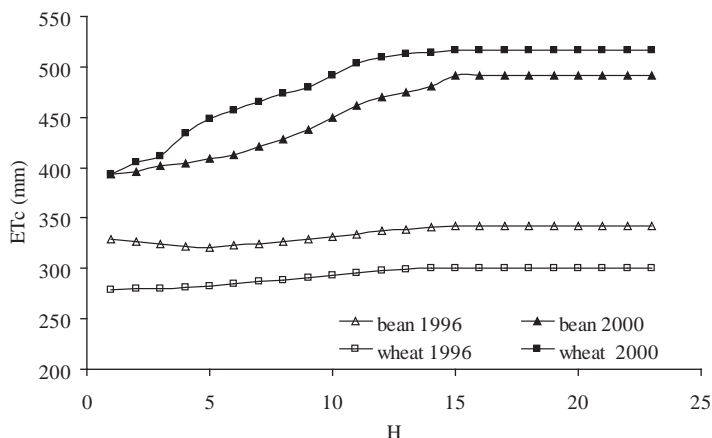


Figure 5. ETc (mm) as a function of the distance (H) from the windbreak.

Different heights of the windbreak were simulated on a 1ha plot (100m x 100m) to quantify the contribution to effective water savings for the bean. The simulation highlighted that 8m high barriers offered the maximum water savings, estimated by 36% greater than consumption for an unprotected plot (Figure 6).

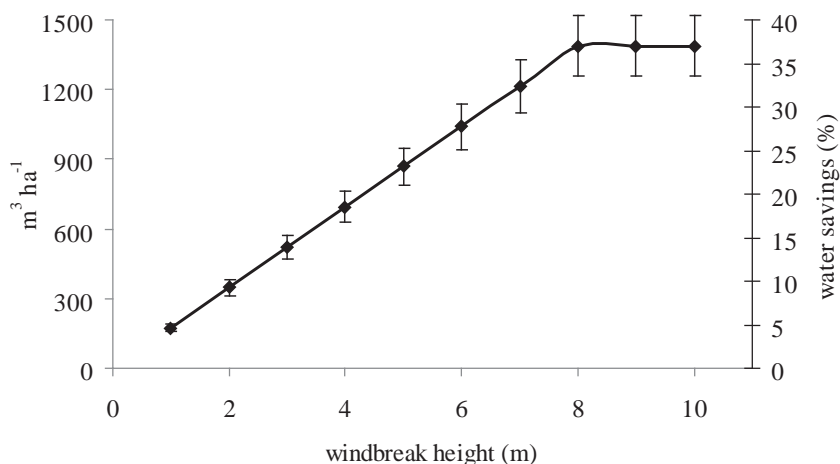


Figure 6. Water saving of the bean as a function of height of windbreak in an area of 1 ha.

IV – Conclusions

The experimental results highlighted the windbreak's potential for containing evapotranspiration and improving the efficient use of water in a typical Mediterranean environment. The study is also a useful update of knowledge about the agronomical role of these protective structures, greatly undervalued in Mediterranean agronomy.

It is useful to specify that the introduction of windbreaks must be preceded by a careful analysis of the aerodynamic characteristics of the environment, with the objective of evaluating how to position the windbreak with regards to the strongest winds. In all situations, it is necessary to opt for a windbreak with adequate vertical growth, so as to increase the extension of the area with maximum protection.

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