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MAIZE PRODUCTION UNDER TWO WATER SAVING TECHNIQUES

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ABSTRACT – By 2020, demand of maize in the developing countries will probably surpass the demand for both wheat and rice. Under rainfed conditions, lack of rainfall leads to an important yield decrement. To avoid this, the practice of supplemental irrigation is a promoting alternative. Nevertheless, as we can't allocate more freshwater for the agricultural sector, the only source of water for such practice could be the non-conventional one. An experiment was conducted in a greenhouse of the Mediterranean Agronomic Institute of Bari (Italy) in order to evaluate the impact of saline water use as supplemental irrigation. Under rainfed conditions, no-yield was registered; when supplemental irrigation was practiced, maize productivity was improved considerably: 2.33 t/ha, 3.13 t/ha and 4.43t/ha when irrigated with a water of 9 dS/m, 6 dS/m and 3 dS/m respectively. At the same time, freshwater application was reduced to 39% (from 172 to 74 l/pot).

Key words: supplemental irrigation, rainfed agriculture, drought, maize, production

INTRODUCTION AND BACKGROUND

The maize (Zea mays L.) is a monoic annual plant which belongs to maideas tribe and the grass family of gramineae. The productivity of maize is due to its large leaf area and its C4 photosynthetic pathway.

One of the major reasons prompting this study is the forecast increase in maize demand. In fact, by 2020, demand for maize in developing countries will probably surpass the demand for both wheat and rice. This shift will be reflected in a 50% increase in global maize demand from its 1995 level of 558 million tons to 837 million tons by 2020. Maize requirements in the developing world alone will increase from 282 million tons in 1995 to 504 million tons in 2020 (IFPRI, 2000). The challenge of meeting this unprecedented demand for maize is daunting.

The dominant constraint to bridging the gap between potential and actual yields is drought/moisture stress; Edmeades *et al*. (1992) estimated that annual drought losses in the early 1990's across tropical maize growing environments represented a 15% in production. Individual episodes of losses, however, can be far more extreme: a devastating drought in southern Africa in 1991–92 reduced maize production by about 60% (Rosen and Scott 1992, as reported in Heisey and Edmeades 1999).

Consequently, drought stress is one of the major physical factors responsible for limiting maize production. There are no technological means, other than the introduction of reliable irrigation, for restoring all maize lost to drought stress.

Drought stress particularly affects the ability of the maize plant to produce grain at three critical stages of plant growth: early in the growing season (when plant stands are established), at flowering, and during mid – to late grain filling:

i. By damaging plant stands at the beginning of a season, drought can strongly curtail yield. This is relatively common because the probability of drought is high at this time. A farmer confronted with this situation has several management options, all requiring replanting later in the season. They include replanting the field(s) with the same cultivar, planting a shorter maturity cultivar, or planting a different species that matures more rapidly.

ii. Mid-season drought is less likely to occur than drought at the beginning or end of the season, but it can be devastating because maize is particularly susceptible to drought stress during this period when the plant flowers. Short of irrigation, the farmer has no management alternatives since it is too late in the season to replant.
iii. Grain yield reductions from mid – to late grain filling are not nearly as severe as those produced by a similar stress during flowering. Again though, farmers are left with no management options for responding to the stress.

Drought affects maize grain yield to some extent at almost all growth stages, but in all cereals the effects of drought stress are most pronounced when the stress falls during flowering (Salter and Goode, 1967).

For maize, Robins and Domingo (1953) first quantified the large yield reductions that occur when drought stress coincides with the flowering period. When Denmead and Shaw (1960) reduced plant water status to the wilting point during the preflowering, flowering, and postflowering stages, yield reductions were 25%, 50%, and 21%, respectively. Claasen and Shaw (1970) observed that stressing plants to wilting prior to silking reduced grain yields by 15%; at silking, by 53%; and when stress was applied in the three weeks after silking, by 30%. Shaw (1976) summarized these and other data (Fig.1) and showed that stress in the period from about 7 days before to 15 days after anthesis reduces maize grain yield two to three times more than at other growth stages.

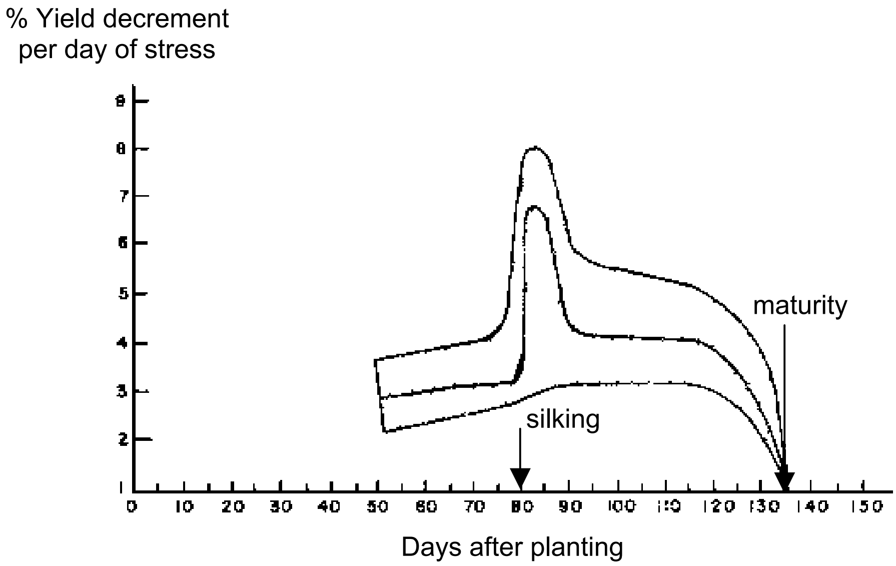


Figure 1. Schematic diagram of relationship between age of crop and percentage yield decrement due to one day of moisture stress (Shaw, 1976)

More recent observations by Grant *et al*. (1989) suggest that extreme sensitivity was confined to the period 2–22 days after silking, with a peak at 7 days after silking, when kernel numbers were reduced to 45% of the control. In the same study, kernel weight also displayed sensitivity when stressed (falling to less than 50% of control) in the period 12–16 days after silking. Yield reductions as high as 90% and an incidence of barrenness reaching 77% were recorded by NeSmith and Ritchie (1992) when plants were stressed in the interval from just prior to tassel emergence to the beginning of grain filling.

Grain yield of maize grown under severe drought stress at flowering is highly correlated with kernel number per plant (r = 0.90) and with ASI (r= -0.60) (Bolaños and Edmeades, 1996).

Drought also lessens the capacity of developing kernels able to use available assimilates because the functioning of a key enzyme, acid invertase, is impaired (Zinselmeier *et al*., 1995; Westgate, 1997). Once kernels enter the linear phase of biomass accumulation about two to three weeks after pollination, they develop the capacity to access reserve assimilates stored in the stem and husk. If kernels successfully reach this stage, they will normally grow to at least 30% of the weight of kernels on unstressed plants, even though the drought may become more severe (Bolaños and Edmeades, 1996).

The critical events that determine how many kernels the plant has, or if it even has a fertile ear, take place between one week before flowering to two weeks after flowering. It is not surprising, therefore, that CIMMYT researchers have concentrated on this period in a search for genetic variability for tolerance to drought that will stabilize kernel numbers per plant, and hence grain yield.

Maize yields in more frequently drought stressed environments are clearly lower and more variable than in less frequently drought-stressed areas. Less evidence can be found that yield growth rates in recent years have been influenced by drought-stress conditions.

In fact, at the global level, there is a positive correlation between drought stress and yield variability. Mean maize yields are lower, yields are more variable, and yield growth less rapid in areas more subject to drought stress.

The difference in production between rainfed and irrigated conditions for the principal cereal crops are reported in Fig. 2.

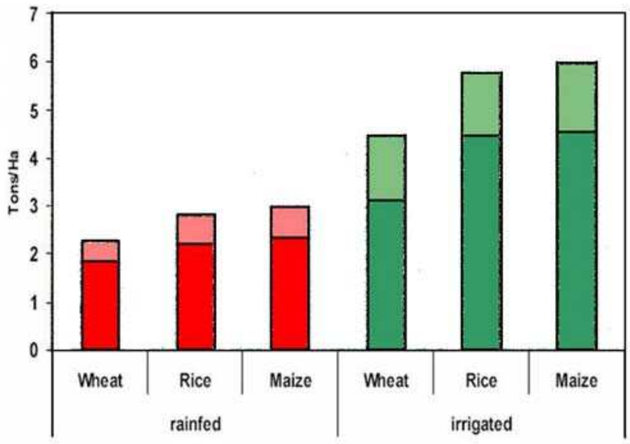


Figure 2. Some cereal yields under rainfed and irrigated conditions (Anonymus, 2003) [1]

Rainfed agriculture has to meet the increasing demands for food production in the world. We have to go a long way in improving the productivity of rainfed crops. We need to improve water use efficiency in the rainfed agriculture by improving management of water, soil and cropping system practices. Substantial yield improvements can be achieved if just a few supplemental irrigations are given to rainfed crop.

The concept of supplemental irrigation can be built on three bases (SWIM, 1999):

- water is applied to rainfed crops that would normally produce some yield without irrigation;
- supplemental irrigation is applied when precipitation fails to provide essential moisture for improved and stabilized production; and
- the amount and timing of supplemental irrigation are scheduled in a mode not meant to provide moisture stress free conditions, but rather to provide minimum water during the critical stages of crop growth to ensure optimal instead of maximum yield.

As a consequence, the aim of the supplemental irrigation is to optimize the production by unit of applied water, rather than maximizing the outputs by unit of surface.

In the Mediterranean-type climate, supplemental irrigation is a common practice in rainfed crops (Duivenbooden *et al*., 1999). In fact, in general, rainfall amounts are lower than seasonal crop water requirements; moreover, their distribution is rarely in a pattern that satisfies the crop needs for water.

[1] available at: http://www.fertilizer.org/ifa/publicat/PDF/2003_rome_alexandratos_slides.pdf

The high water productivity of supplemental irrigation water is mainly attributed to the alleviation of moisture stress during the most sensitive stages of crop growth. Moisture stress during flowering and grain filling (e.g. in wheat) cause a collapse in the crop seed filling and reduce the yields substantially. When supplemental irrigation water is applied before the occurrence of stresses, the plant may produce to its full potential (Oweis, 1997).

Potentially, supplemental irrigation may have three major effects: (1) yield improvement, (2) stabilization of production from year to year (increasing reliability), and (3) providing the conditions suitable for economic use of higher technology inputs, such as high yielding varieties, fertilizers, and herbicides, irrespective of seasonal rainfall. Nevertheless, as we can't allocate more freshwater to the agricultural sector, the only source of water for such practice could be the non-conventional one (saline water, brackish water). But, the use of such water resource could affect not only the final yield (if compared to the use of freshwater), but also the soil fertility (salinity build-up). As a consequence, an experiment was conducted in a greenhouse of the Mediterranean Agronomic Institute of Bari (Italy) in order to evaluate the impact of saline water use as supplemental irrigation.

MATERIALS AND METHODS

In this work, the experiment was conducted in a greenhouse of the Mediterranean Agronomic Institute of Bari (Valenzano), located at an altitude of 72 m, at 41°C 03' 16'' E latitude. It is important to note that the greenhouse where experiments were conducted is equipped with aeration and heating systems (Fig. 3).


(a)

(b)

Figure 3. Greenhouse's equipments: (a) aeration and (b) heating systems

Objectives

The main objectives of this experiment are:

- to determine the impact of deficit irrigation (drought stress simulation) on the vegetative growth of maize,
- to study the use on non-conventional water resources (the saline one) as a supplemental irrigation source and its impact on maize production under simulated rainfed conditions,
- to elucidate the salt concentration level to be used for irrigation able to permit a high production
- to determine the volume of saline water to be supplemented on the critical growth stage and, consequently, the volume of freshwater that can be saved, and
- to evaluate the impact of the use of saline water on the chemical characteristics of the soil (ECe and chloride content changes).

Set-up

The set-up consists on 36 PVC (polyvinyl chloride) pots with the dimensions shown in Fig. 4.

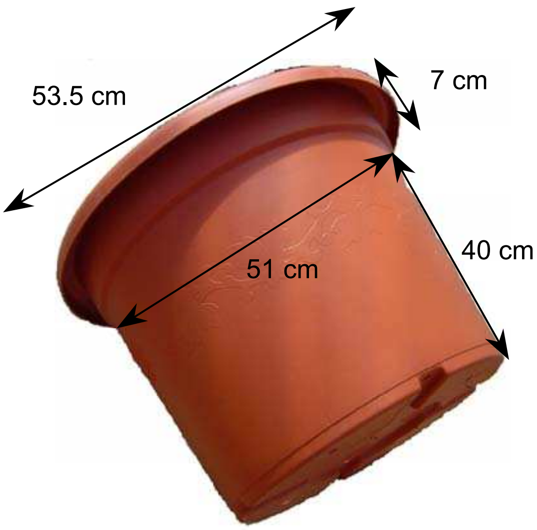


Figure 4. Pot dimensions used in the experiment

At the bottom of every pot, a 4 cm thick layer of coarse gravel was spread in order to provide a proper drainage and, as the used irrigation method is the surface one, at the upper part of the pots, a 3 cm height was left empty. The following figure gives an idea about how every pot is disposed in the greenhouse to facilitate the drainage water collection.

Figure 5. Pot disposition in the greenhouse

The pots were filled with a sandy-clay soil; its physical and chemical characteristics are given in the following table.

Table 1. Physical and chemical characteristics of the soil

Physical characteristics				
Clay (%)	Silt (%)	Sand (%)		Texture
		coarse	fine	
41,5	12,5	16,1	29,9	sandy clay

Chemical characteristics							
Soluble anions (meq/l)				Soluble cations (meq/l)			
CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
-	2	3,3	1,34	4,6	0,7	1,0	0,44

This experiment consisted on 6 treatments resulting from the combination of 2 factors depending upon the physiologic stage of the crop:

1) The application of full and deficit irrigation (50% and 100% of the irrigation water requirement) once the seeds were germinated and established; and
2) The use of water of different salinity levels from the flowering till the end of seed formation as a supplemental irrigation, as we are simulating the rainfed conditions.

The 6 treatments, with six replications, were the following:

	Vegetative growth		Flowering and seed formation	
Treatment	% of irrigation water requirement	Irrigation water salinity (dS/m)	% of irrigation water requirement	Irrigation water salinity (dS/m)
T1	100	1,1	No	-
T2	100	1,1	100	1,1
T3	50	1,1	100	1,1
T4	50	1,1	100	3
T5	50	1,1	100	6
T6	50	1,1	100	9

It is important to note that the salinity of the irrigation water is the result of mixing freshwater (1.1dS/m) with seawater (43.5 dS/m) in order to get those planned different salinity levels (3, 6 and 9dS/m).

The Crop

Maize (*Zea mays*), variety PR33J24, was sown at a density of 25 grains per pot the 27 February 2004. It was irrigated constantly to field capacity without receiving any fertilizer till the end of the seedling establishment (17 March 2004). After this stage of crop development, 15 plants per pot were left; the others were eliminated, the N, P, K fertilization was applied and data was collected for every treatment, as the crops grew and developed.

Regarding the fertilization, we followed the same quantities of fertilizers used by the Italian “Istituto Sperimentale per la Cerealicoltura[2]” for the same maize variety (PR33J24). These consist on:

- K_2O : 210 (kg/ha)
- P_2O_5 : 120 (kg/ha)
- N : 200 (kg/ha)

However, and for statistical purposes, we decided to leave 6 plants till harvesting, which mean a higher density in respect to the field conditions. Consequently, and in order to avoid nitrogen deficit, we increased its supply by a factor of 2.5.

The potassium and phosphate fertilizers were given at once, after thinning; however, the nitrogen fertilization was split into 3 times at equal rate: after thinning, during the vegetative growth and before spike formation.

Regarding the collected data, we focused on:

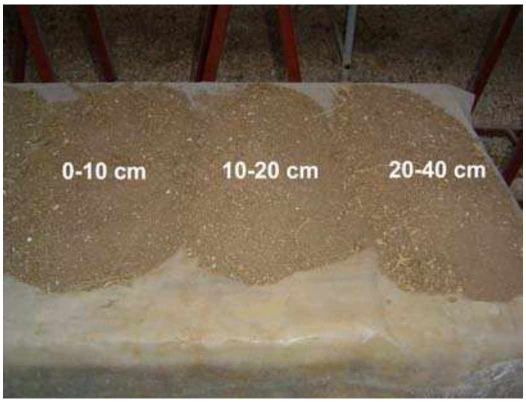
- plant height (m),
- leaf water potential (MPa),
- leaf area (cm^2/plant), and
- plant dry matter (g/plant).

In addition to this, at harvesting, for every treatment, the following data was collected:

- number of spike per plant,
- number of seeds per spike,
- the weight of 1000 seeds, and
- root’s weight (g/pot).

[2] available at: http://www.regione.piemonte.it/agri/ita/news/pubblic/quaderni/num40/dwd/33_35_40.pdf

In order to determine the root's weight, the soil particles were eliminated from 3 among the 6 replicates of every treatment by washing them. Regarding the other 3 replicates, soil samples describing 3 soil layers (0-10; 10-20 and 20-40 cm) were taken and left in the open air till drying (Fig.6a and b).


(a)


(b)

Figure 6. Soil sampling (a) and air drying (b)

The soil samples were then subject to chemical analysis in order to determine the ECe of the extract of saturated paste (dS/m) and the chloride content (meq/l).

Finally, all data were subjected to ANOVA and the differences among the mean values were detected according to DUNCAN test.

RESULTS AND DISCUSSION

Biometric Data

Under this heading we shall consider plant height, leaf area and dry matter.

The different treatments did not influence dramatically plant height, as reported in the figure below.

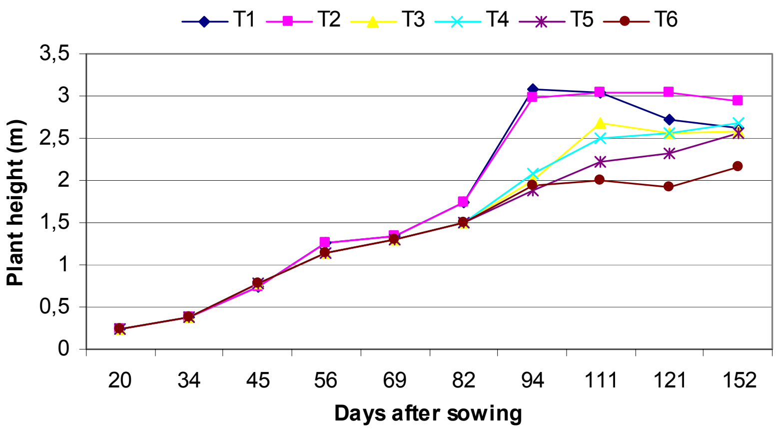


Figure 7. Plant height evolution as affected by the different treatments

Just treatment T2 brought about a significantly higher value, while, opposite to it, only in treatment T6 a significantly lower value was found, compared to the other treatments. It is interesting to note, however, that the top plant height was recorded with T1, but plant early senescence provoked a height decay by about DAS (day after sowing) 100, while in all the other treatments plant growth continued to the end of the experiment (DAS 152).

Leaf area followed a different pattern (Fig. 8) since while again the highest values were recorded in T2, the worst results were recorded in T1; in all the other treatments no statistically significant difference was found in spite of a trend to decreasing with salinity. In this case senescence showed its influence in all the treatments after approximately DAS 100, and its action was more remarkable in T1.

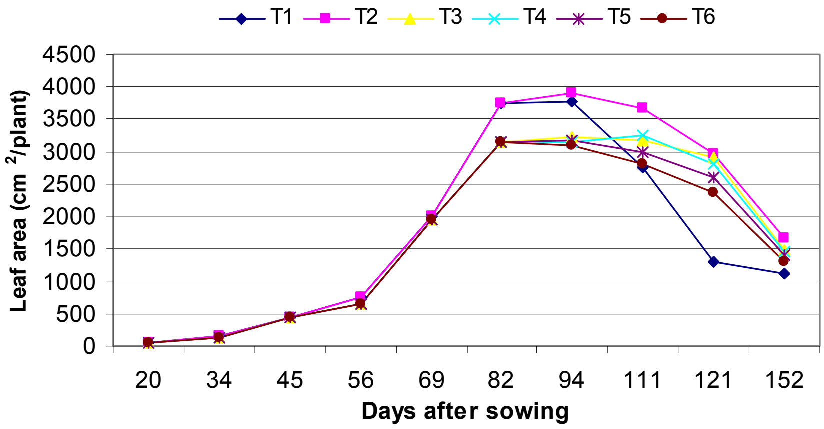


Figure 8. Leaf area evolution as affected by the different treatments

Dry matter production (stems and leaves), as reported in Fig. 9, shows the highest values with T2 and T3 and the lowest values with T1 (due to water stress) and T5-T6 (due to salt stress), with intermediate values in the other treatments. It is however of interest to note that till DAS 94 values in T1 were obviously almost identical to those in T2, and sharply decreased thereafter, while, opposite to that, values in all the other treatments reduced the gap with T2 when fully irrigated, even with brackish water.

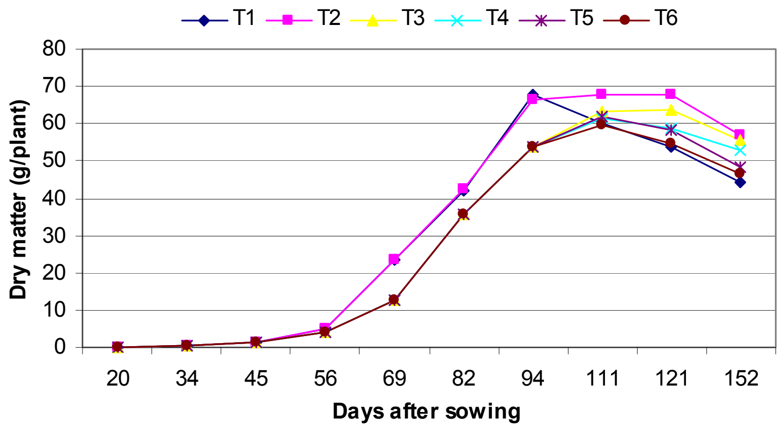


Figure 9. Shoot dry matter evolution as affected by the different treatments

Root dry matter as reported in Fig. 10, measured at the end of the experiment, was again highest in T2, followed by T3 and T4, with the lowest values recorded in T1 and T6; once again water stress produced effects similar to salt stress.

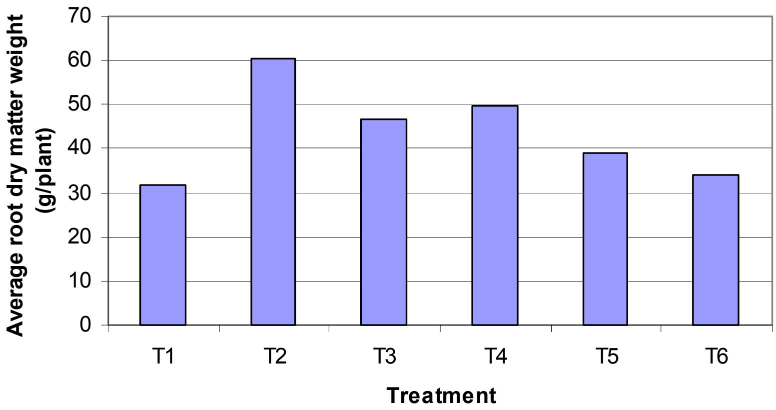


Figure 10. Root dry matter at the end of the plant life cycle, as affected by the different treatments

Production Data

In Table 2, the mean number of ears per plant is reported, showing a trend to increase with salinity (no ear was recorded in T1); however the trend is reversed when fertile rather than total ears are considered (Table 3).

Table 2. Mean number of total ears per plant

T2	T3	T4	T5	T6
1,08 c	1,17 bc	1,14 bc	1,25 ab	1,31 a

Table 3. Mean number of fertile ears per plant

Treatment	T2	T3	T4	T5	T6
Mean	0,81 a	0,75 a	0,72 a	0,56 b	0,42 b

In the latter case the differences between the treatments are magnified, and as a consequence the best results are achieved in T2, as expected.

Furthermore, considering the number of kernels per ear, the highest number is found in T2, with non-significant differences between all the other treatments (with the exception of T1, with zero kernels).

Table 4. Mean number of kernels per ear

Treatment	T1	T2	T3	T4	T5	T6
Mean	0	148 A	104 B	108 B	104 B	107 B

The averaged weight of kernels, as reported in Table 5, was unexpectedly highest in T3, T4 and T5, followed by T6 and T2, with the lowest weight.

Table 5. Average weight of 1000 kernels (g)

T1	T2	T3	T4	T5	T6
0	188 b	212 a	209 a	199 ab	192 b

Finally, the production is reported in Table 6, showing an evident better result in T2, followed by T3 and T4 and then by T5 followed by T6.

Table 6. Final maize production (t/ha)

Treatment	T2	T3	T4	T5	T6
Production (t/ha)	6,10 A	4,50 B	4,43 B	3,13 C	2,33 D

The comparison of biomass production with that of yield confirms the great plant sensitivity in the reproductive phenophases, leading to much more evident reductions in yield than in biomass.

Leaf Water Potential

Monitoring leaf water potential (LWP) is particularly interesting in the management of irrigation, particularly under conditions of water or salt stress, since LWP is able to give useful data otherwise unavailable on plant water status: the plant is the best judge of itself.

Inspecting LWP values in the figure below, it is possible to appreciate the accurate representation given by them of the evolution in time of plant status, including both water and salt stress effects.

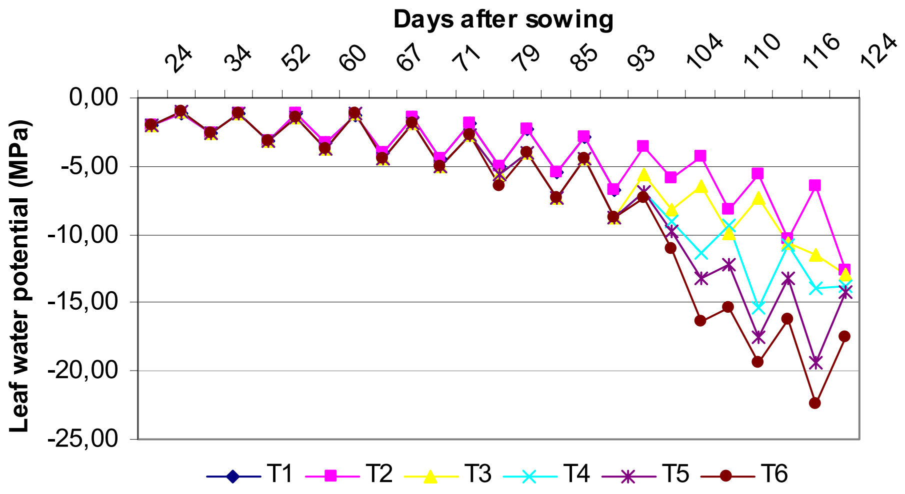


Figure 11. Root dry matter at the end of the plant life cycle, as affected by the different treatments

Two dates are marked in the figure: DAS 60 and DAS 93. The first is the limit of initial vegetative growth, when plant requirements were largely satisfied in all the treatments, and as a consequence no difference appears in LWP. When later plants develop quickly, the response to the differentiated treatments gradually builds up, with LWP higher (lower in absolute values) in T1 and T2 and identical in all the other treatments, since no brackish water had been supplied.

In DAS 93 no differences due to salinity show up and LWP values again are only differing between T1-T2 and the group T3-T6, but not inside the group. After DAS 93 and till the end of the experiment, differences are evident both when deriving from water stress (T2 versus T3) and when deriving from salt stress (T3 versus T4, T5 and T6).

Some apparent inconsistency in values of the latter group in the final period can be easily explained with the well known erratic leaf response due to senescence, exacerbated by salinity.

Such results confirm the potential of LWP as an accurate and easy-to-control parameter in the management of irrigation, particularly if stress conditions are planned.

Salinity Build-up

By the end of the experiment, salinity was controlled through sampling soil in the pots at the depths of 0-10; 10-20 and 20-40 cm. The control was conducted by analyzing the chloride content and EC in the soil saturated paste. Results are reported in tables 7 and 8.

Table 7. Chloride content buildup in the different soil layers under the different treatments

Soil layers	Cl^- (meq/l)					
	T1	T2	T3	T4	T5	T6
0-10 cm	4 D	4 D	6 D	27 C	34 B	55 A
10-20 cm	4 E	7 E	17 D	33 C	68 B	99 A
20-40 cm	5 E	24 D	27 D	37 C	99 B	113 A
Mean	4 E	12 D	17 D	32 C	67 B	89 A

Table 8. ECe buildup in the different soil layers under the different treatments

Soil layers	ECe (dS/m)					
	T1	T2	T3	T4	T5	T6
0-10 cm	1,02 D	0,74 D	1,03 D	1,61 C	4,06 B	5,89 A
10-20 cm	0,87 D	1,51 D	3,65 C	4,20 C	7,90 B	9,89 A
20-40 cm	1,35 C	4,34 B	4,86 B	4,86 B	9,91 A	11,36 A
Mean	1,08 E	2,20 D	3,18 C	3,56 C	7,29 B	9,04 A

While the general trend is obviously towards an increase of both values with salinity in irrigation water, some discrepancies deserve to be underscored, particularly the “softer” response of ECe compared to Cl content.

Limiting the comments to the group T3-T6, the response is parallel at the depth of 0-10 cm, with statistically significant differences between all the groups; if the responses in terms of Cl^- and ECe at the depths 10-20 and 20-40 cm are examined it can be seen that they are no longer parallel. In fact in the case of Cl^-, T3, T4, T5 and T6 differ all evidently and in a statistically significant way, while in the case of ECe statistically significant differences are smoothed.

Not only: if the ratios are considered T6:T3; T5:T3; T4:T3 for Cl^- content and ECe, it appears evident that values are much larger for Cl^-, thus magnifying the differences (see table below).

Table 9. T6, T5 and T4 to T3 ratio of EC_e and Cl^-

	T6:T3	T5:T3	T4:T3
Ratio Cl^-	4.18	3.67	1.37
Ratio EC_e	2.34	2.03	1

In conclusion, Cl^- seems a more sensitive indicator for salinity buildup, which is of a particular interest when using saline water in order to protect soil fertility.

Deficit Irrigation

Assuming treatment 2 (T2) as the control with fully, freshwater irrigated plants, comparison can be made with T1 and T3: the former was fully irrigated till the flowering stage with no water application thereafter, while T3 was irrigated at 50% water requirements till the flowering stage and fully irrigated thereafter.

The resulting water consumption in the three treatments is reported in the table below, along with water savings in absolute terms and the related yield loss.

Table 10. Water savings and relative yield loss under freshwater treatments

Treatment	Absolute water quantities (l/pot)	Relative water quantities %	Relative water savings %	Relative yield loss %
T1	98	57	43	100
T2	172	100	--	---
T3	141	82	18	26

The inspection of the table shows that deficit irrigation, in the terms tested in the experiment, is not a viable option; probably better results can be achieved with an inverse procedure, namely managing irrigation through leaf water potential values rather than simply recording leaf water potential as influenced by water management. Leaf water potential should be used as a guide to irrigation: this would permit, for instance, to determine water volumes to be applied to maintain its values at levels not much below those in the control, and with a water stress degree matching the specific phenophases and their sensitivity, thus saving may be less water but reducing yield losses more than proportionally.

The analysis of water use efficiency (Fig. 12) confirms that T2 is a better solution than T3 (although the difference is not statistically significant); it can be concluded that under the experimental conditions, full irrigation permitted to achieve higher yields both in terms of unit land surface and unit applied water.

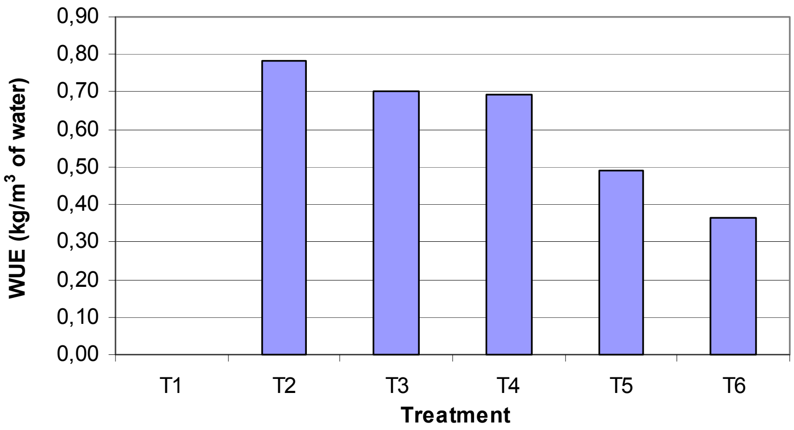


Figure 12. Water Use Efficiency (kg/m^3) per treatment

Saline Irrigation

Limiting the analysis to variations in water salinity while maintaining water volumes constant, the results in T3, T4, T5 and T6 are compared.

In all such treatments, total applied water was 141 liters per pot and the stress period and intensity were identical (50% of water requirement throughout the vegetative growth and 100% thereafter).

Applied freshwater was 141 liters/pot in T3, and 67 liters/pot in T4, T5 and T6.
If we limit the analysis to freshwater input, the results are different than those reported for deficit irrigation, as disclosed by the table below.

Table 11. Water savings and relative yield loss under; the use of saline water

Treatment	Applied freshwater	Applied freshwater (relative values)	Yield	Yield (relative values)	WUE	WUE (relative values)
	(m^3/ha)	%	(tons/ha)	%	kg/m^3	%
T2	7820	100	6.10	100	0.035	53
T3	6430	82	4.50	74	0.032	48
T4	3050	39	4.43	73	0.066	100
T5	3050	39	3.13	51	0.047	71
T6	3050	39	2.33	38	0.034	51

In the table above WUE is computed as the ratio of yield (tons/ha) to applied freshwater (m^3/ha). Assuming that the value of brackish water is negligible, then the best treatment results by far T4, permitting to save over 60% freshwater at the expenses of a loss of 36% in production, compared to T2. This applies also to T5, where production is almost halved but water saving is more than proportional.

In other terms, in those cases, when freshwater is a limiting factor while land is not, adopting the strategy of T5 gives only slightly better results, in terms of total production, than full irrigation (T2), because it is possible to stretch irrigation on a larger surface, thus compensating yield losses. Of course additional expenses must be also computed, which reduces the attractiveness of the solution.

From the available data it is apparent that the salinity threshold for the irrigation of corn under the applied management, when the goal is the maximization of yield per unit of applied water (WUE), is 3dS/m or slightly higher, however less than 6 dS/m as in T5.

Such results confirm the unreliability of official guidelines, according to which, for instance, corn production faces a reduction of 12% per dS/m in soil saturation extract (Maas and Hoffman, 1977); as a consequence yield in T5 should have been about 60% less than in T3 or T4, while actually loss is nearly half that value.

Supplemental Irrigation

Supplemental irrigation, the object of the present work, differs from saline and deficit irrigation since it is supposed that it is an episodical water integration to rainfed crops.

A first consequence is that salinity build-up in the soil is not a major concern, due to the limited water volumes to be applied: it can be safely assumed that rainfall leach away the modest quantities of salt carried by irrigation water, provided that salinity is within reasonable limits.

A second consequence is that water is applied as an integration to rainwater, which due to its unpredictable pattern can be abundant or bring about stress conditions in any phase of the crop, unlike deficit irrigation, where crops are dependent only on irrigation and stress level in all the phases are strictly controlled.

Since this experiment was conceived to simulate conditions in the typically Mediterranean environment, it is to be expected that results in T1, i.e. complete crop failure, express the real outcome in most years, if crop is not irrigated, since an adequate moisture supply was available to plants only in the early period of the cycle and no water was applied thereafter.

A realistic solution is simulated by treatments T4, T5 and T6, namely the assumption of scanty rains in the first period of the cycle and full irrigation with brackish water later.

While T2 is the “reference treatment” to be used as a control, T3 gives information on plant response to reduced water application, with freshwater rather than brackish water.

Results showed that applying water at an EC of 3 dS/m (T4) brings about no reduction, while an appreciable reduction is brought about in T5 by water at 6 dS/m and results are unacceptable in T6, with 9 dS/m.

It is evident from the inspection of results that the best solution is the adoption of conditions simulated by T4, permitting to save almost 3500 m^3 per ha per year at no cost in terms of yield loss.

To transfer the results into the practical agronomic application, it can be stated that integrating rainfalls with brackish water at 3 dS/m (or maybe even 4 dS/m) is a safe and rational practice to protect corn crops from weather vagaries without endangering soil fertility

CONCLUSIONS

The goal traditionally pursued in irrigated agriculture is the achievement of the highest yield per unit land surface; only in relatively recent times was it realized that such a goal entails a wasteful use of water resources and the principles of deficit irrigation were developed, aiming to obtain the highest yield per unit of water.

However, although representing an appreciable step towards a more rational use of water, adopting deficit irrigation principles implies the acceptance of a certain level of reduction in production level, as demonstrated by the results of the present research; supplemental irrigation can reduce yield losses typically linked to deficit irrigation.

The findings of the present research demonstrate that when adopting supplemental irrigation in corn, freshwater can be substituted to some extent with saline water, up to unsuspected values of EC (3 dS/m) without any loss in production, therefore it appears reasonable to propose to integrate the practice of supplemental irrigation with the use of brackish water. This solution would permit to free freshwater resources for more pressing uses or for irrigating a larger surface in the event of particularly dry years, without incurring in heavy yield losses.

It is impossible to precisely know in advance the amount of water required in rainfed agriculture, since water volumes required in SI depend on precipitation amounts and timing in every single season, however the findings reported above can considerably help in supplemental irrigation management, permitting to achieve a more stable level of grain production without the input of precious freshwater, with the additional advantage that, due to the modest amount of salts applied to the soil, the leaching action can be entrusted to precipitations only, without any excess application of irrigation water.

This of course is not to say that a careful monitoring of salt balance in the soil is not needed to secure the long-term sustainability of the practice.

In conclusion it is felt that the large scale application of the findings of the present research, after a necessary calibration and validation for the diverse environments, can be of assistance in securing food and water and therefore social stability to the less privileged populations, while reducing the pressure on the limited and fragile water resources.

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