ENVIRONMENTAL STUDIES ON ARUNDO DONAX

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EXTENDED ABSTRACT

The objective of this study is to evaluate, in terms of yields performance and water use efficiency, the influence of irrigation and nitrogen fertilization on the productivity of *Arundo donax* L. and provide information on the crop production using reduced water supplies and low inputs. *Arundo donax* L. is a native species to Mediterranean region. It is characterized by a high yielding potential as well as by efficient use of the natural resources.

To achieve the goals of this work, two trials have been set up, one by CRES in south Greece and the other by University of Catania in south Italy where *Arundo donax* was grown under several regimes of irrigation (I) and nitrogen fertilisation (N), namely I_0=dry control, I_1=50% of ET max, I_2=100% of ET max, N_0=40 kg N/ha and N_1=120 kg N/ha in the first trial and I_0=control, I_1=50% of ET max, I_2=100% of ET max, N_0=0 kg N/ha, N_1=60 kg N/ha and N_2=120 kg N/ha in the second trial.

Comparing the yields of the first, second and third years, it was revealed that total dry matter in the I_0 treatment ranged from 10 to 21 t/ha, depending more on the treatment applied than the experimental site. I_2 treatment ensured high dry matter yields from as early as the first year, which reached 20-25 t/ha in both fields. These yields remained the same in all years in the Greek trial, while in the Italian one a decrease (15-20 t/ha depending on the nitrogen treatment) was noticed in the second year, which however applied to all treatments.

Concerning the water use efficiency (WUE), the reduction of the water consumed by the crop resulted in an increase of the WUE, attaining maximum values of 6 g d.m./l in Vagia and 10 g d.m./l in Catania. The reduction of nitrogen fertilisation determined a generally small reduction of WUE in Catania, whereas it did not affected WUE in Vagia.

In general, the irrigated plants had a tendency to show better growth and yield performance. In conditions of low soil water availability the plant was able to improve the water use efficiency and maintain a high level of production, to a certain extent similar to that of the well watered plots (I_2). This means that *A. donax* could be successfully grown under moderate irrigation. It is also worth to be noted that *Arundo donax* was able to make useful use, at least in the conditions of Catania, of the nitrogen fertilisation, showing also the good capacity of the crop to catch the nitrogen in the soil preventing thus nitrate leaching in the subsoil.

Key words: arundo, biomass production, water and nitrogen treatments, water use efficiency

1. INTRODUCTION

Several scientists have warned for a 'Global water crisis' in the near future. According to estimates made the world population will increase by a percentage ranging from 35% to 100% within the next 50 years (Wallace, 2000). By the year 2050, 25-65% of the world population is estimated to live in areas of water shortage (Niemezynowicz, 1999). However even the most optimistic scenario will be adopted, by the middle of this century nearly two billion people is expected to live under water-shortage conditions.

Among the potential water consumers, agricultural factor constitutes the largest consumer globally using about 69% of the available water resources. In the Mediterranean region because of the prevailing climatic conditions the relevant percentage is much higher amounting for 75% of the total available water (Rana and Katerji, 2000). The high demand of Mediterranean agriculture sector for water along with the recent periods of below-average rainfall has led to over-abstraction of groundwater resources, which has resulted in unsustainable situation in many areas (Batchelor, 1999).

In spite of the huge amounts of water resources used for irrigation, only 13-18% of the total water resources at sources are used for transpiration of the crops (Wallace, 2000). Consequently, action towards higher water use efficiency in agriculture should be taken immediately. It could be achievable mainly via two ways. The first one is to use more water resource for crops' transpiration and the second refers to increase the amount of carbon fixed per unit of water transpired (Wallace, 2000).

Introduction of plant species that can use the water applied as efficiently as possible and produce a heat and/or power product could be an outlet of these problems. Among the most promising identified options so far are the perennial energy crops, which provide high biomass yields by using in a more efficient way the natural resources and the inputs. *Arundo donax* L. (giant reed) presents all the above benefits indicating it as a suitable solution for South Europe. It is considered as one of the most promising grass species for non-food uses, such as energy, pulp and paper production as it has high biomass yielding potential (40-75 t/ha/year fresh matter, up to 34 t/ha of dry matter) with simultaneous low agrochemical inputs (Szabo et al., 1996, Christou et al., 1998, Christou et al., 2001). Sharma et al. (1998) reported that the annual net primary production of above ground and below ground organs was estimated at 2080g m^{-2} and 1620g m^{-2}, respectively.

Arundo donax L. is a perennial rhizomatous C_3 grass native to the Mediterranean basin (Perdue, 1958, Rossa et al., 1998, Tucker, 1990). As a perennial herbaceous crop, it develops a permanent and deep root system with root length more than 100cm (Sharma et al., 1998) so that it can absorb water from deep water table and tolerate severe and prolonged drought conditions. Also, due to its abundant root system and almost the full year-round existence of the canopy, it prevents soil resources from being eroded (Rezk and Edany, 1979, Kort et al., 1998, Ranney and Mann, 1994, Wynd et al., 1948). In spite the fact that A. *donax* is considered as a low water demanding species this issue is hardly studied so far. Only Morgana and Sardo (1995) provided values for the Water Use Efficiency (WUE, determined as the ratio of net photosynthesis to transpired water) for giant reed.

Arundo donax is reported to tolerate various types of soils, from heavy clays to loose sands and gravely soils and in warm temperate and tropical regions (Perdue, 1958, Wynd et al., 1948). As a perennial herbaceous crop, it can tolerate severe drought conditions because of its abundant root system that contributes to efficient water absorption and prevents soil from erosion (Rezk and Edany, 1979, Kort et al., 1998, Ranney and Mann, 1994, Wynd et al., 1948). The crop can overcome severe droughts and still produce high yields, up to 19t/ha dry matter, although with sufficient irrigation significantly higher yields can be achieved (Christou et.al, 2001).

2. WORK DESCRIPTION

2. 1 Site descriptions

In 1997 two experiments were set up one in central Greece and the other in Sicily, Italy. In Figures 1 and 2 air temperatures and precipitation for the period of experiment are presented for the Greek and the Italian trial respectively.

Field experiment in Greece: The experimental field was located in Thebes, Vagia plain (latitude 38.23', longitude 23.06', altitude 110 m above sea level). The soil texture was homogeneous sandy clay loam with 52% sand, 16% clay and 32% silt. Average hydraulic characteristics for the soil layer 0-180cm, were: hydraulic conductivity 33.31 cm/day, bulk density 1.45 g/cm^3, Field Capacity (FC) 35.67% cm^3/cm^3, Wilting Point (WP) 18.01% cm^3/cm^3 and available soil water 17.66% cm^3/cm^3. The planting material was rhizomes extracted manually from a very vigorous natural stand in Crete and divided in smaller pieces containing 2-3 visible nodes.

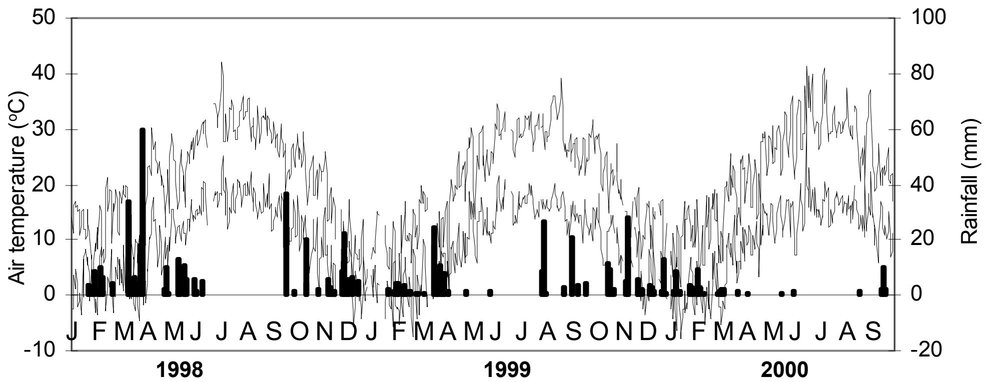


Figure 1: Air temperatures (min, max) for the period 1998-2000 in the field trial in Greece

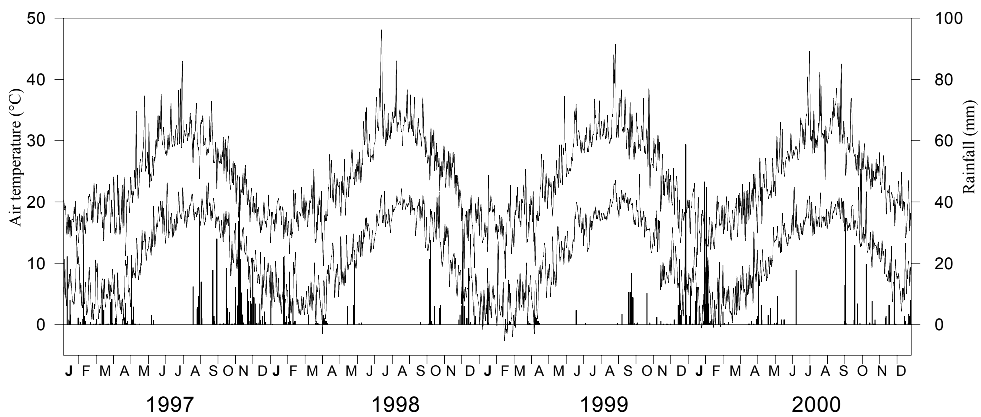


Figure 2: Air temperatures (min, max) for the period 1997-2000 in the field trial in Italy

Field experiment in Italy: The experimental field was established in Sicily, Catania plain (Primosole area, 37°25' Lat. N, 15°30' Long. E) on vertic xerofluvents soil with a Field

Capacity (FC) 32% cm^3/cm^3, Wilting Point (WP) 11% cm^3/cm^3, using rooted stem cuttings deriving from plants of a local clone collected in Fondachello area, the widest and strongest clone found nearby Catania. The propagation material used in the trial was constituted by portions of the stem with a single node.

2.2 Experimental designs and details of the experiment

Water was applied by a drip irrigation system at frequent intervals during the drought period (May – September). Immediately after planting and during the first growing period, plants were supplied by sufficient amounts of water, in order to achieve high establishment success for all the treatments. Irrigation was differentiated during the second and subsequent years.
The establishment year (1997) is excluded from the results, because the applications of irrigation and nitrogen fertilization were uniform in all plots. Additionally, during the establishment year growth and yielding capacity of the crop is anticipated to be very low. The experimental designs and other details of the experiments are presented in Table 1.

Table 1: Description of field trials

Sites	Experimental design	Meteorological data	Growth data	Yield data
Central Greece	3x2 factorial in a randomized complete block design, with 3 replicates. The factors are: Water treatments: I_0=dry control, I_1=100% of ET max and I_2=100% of ET max Nitrogen fertilization: N_0=40 and N_1=120 kg/ha. Plot size: 8x9 m^2 Plant density: 80x50 cm	– Air temperature (min, max, mean) – Precipitation – Global radiation – PAR – Net radiation over plant canopy – Wind speed (at 2 and 6m) – Evaporation from class ‘A’ pan	– Height of plants – Shoots per m^2 – Shoot diameter – No. of nodes – LAI <u>Frequency:</u> At monthly intervals <u>Sample:</u> 3 plants per plot	– Fresh and dry matter yields – Yield components <u>Frequency</u>: At monthly intervals Sample: 3 plants per plot, and <u>Frequency</u>: At final harvest <u>Sample</u>: Area of experimental value/plot
South Italy	Split plot design with 3 replicates. The factors are: Water treatments: I_0=dry control, I_1= 50% of ET max and I_2=100% of ET max Nitrogen fertilization: N_0=0, N_1=60 kg/ha and N_2=120 kg/ha. Plot size: 8x5.6 m^2 Plant density: 80x50 cm	– Air temperature (min, max, mean) – PAR – Precipitation – Global radiation – Evaporation from class ‘A’ pan	– Height of plants – Plants and shoots per m^2 – Shoot diameter – Visible leaves per shoot – Leaf length – LAI <u>Frequency</u>: At monthly intervals <u>Sample</u>: 3 plants per plot	– Fresh and dry matter yields – Yield components <u>Frequency</u>: At monthly intervals <u>Sample</u>: 3 plants per plot <u>Frequency</u>: At final harvest <u>Sample</u>: Area of experimental value/plot

2.3 Measurements

In both trials the meteorological variables were recorded using an automatic weather station CR10 Campbell). During each growing period meteorological data were recorded on a ¼ of a minute basis (wind speed, air temperature, air humidity, rainfall, photosynthetic active radiation, global radiation, net radiation above crop canopy, evaporation from class ‘A’ pan). Temperature and rainfall are reported in fig. 1 and 2.

Soil moisture content was measured weekly, from May to September, using a neutron scattering device. At the beginning of each year, aluminium tubes were installed at a depth of 180 cm. Readings were taken at 20 cm intervals, from 20 cm to 180 cm and converted to volumetric soil water content with a calibration equation that was determined at the experimental site. The surface 20 cm was sampled and oven dried, to detect soil water content. Evapotranspiration for each growing period was calculated as the change in soil water during the growing period, plus the rainfalls.

At the end of each growing period (February) final harvest of the aerial part of plants was carried out. At the final harvest a total area of $20m^2$ was harvested for fresh and dry matter estimations. The harvested material was then separated into stem and leaf fraction in order to estimate relative fresh and dry matter. The samples were weighed fresh and then they were oven dried at 80^oC until constant weight. Dry samples were milled and prepared for chemical analyses.

Analysis of variance was carried out using the STATGRAPHICS PLUS ver. 2.1 program and, in case of significance at p=0.05 level, the LSD multiple range tests were used to separate treatment means.

3. RESULTS

3.1 Meteorological data

The meteorological data were typical of the Mediterranean environment in both trials. In Vagia, along each growing period, the minimum temperatures increased linearly from -5^0C in March (-2^0C in 1999) to 21^0C in June-August, while the maximum temperatures raised from 4^0C in March to over 40^0C in July-August, every year (fig 1). Almost no rainfall was measured over the summer months, that is from June up to September, with an exception in year 1999, when 35.2 mm were fallen during the last four days of July.

In Catania, along the growing season the minimum temperature increased linearly from 5°C in March to almost 20°C over the months of June, July, August and September; the maximum temperature increased from 18°C in March to over 40°C July. No rainfalls were measured on summer period, while some rains were observed at the end of August, in September and October (fig. 2).

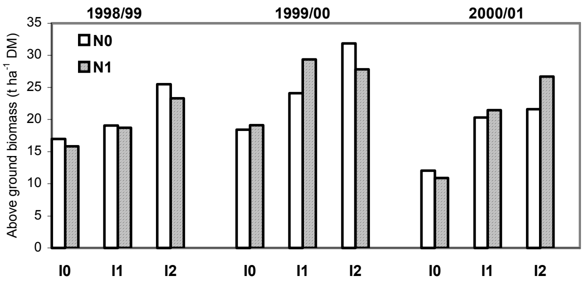
3.2 Biomass productivity

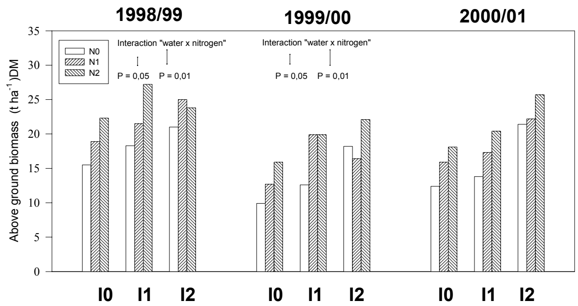
Field experiment in Greece:
The plant yielded from 11.5 to 29.9 t/ha and moisture content ranged from 50.4 to 56.6 %, depending the treatments and the years. The estimated dry matter yields averaged over all treatments were 19.9, 25.1 and 18.8 t/ha for the three years (fig 3).

Performing the analysis of variance, at the 0.05 p-level, on the estimated yields of the aerial parts of the plant, it was noticed that only water treatments had a significant impact on the dry matter. The significant differences were depicted between I_0 and I_2, while yields recorded in the I_1 and I_2 treatments did not differ statistically. The same remarks applied also for the stem dry matter, as stems fractions contributed approximately 90% (88-91%) on the dry matter.
In the best conditions of water and nitrogen treatments the crop yielded 23.28, 27.84 and

26.7 t/ha in the three subsequent years, though in 1999 the highest yields (31.9 t/ha) were achieved by the I_2N_0 treatment. The relevant yields for the worst conditions were 17.0, 18.4 and 12.7 t/ha. Nitrogen fertilization did not have any clear effect on biomass production.

Comparing the yields of all years, it was revealed that total dry matter in the I_0 treatment was nearly the same in all years, except of the third year, when a reduction in yields was recorded in all treatments. Dry matter yields in the I_2 treatment exhibited a lower increase from the first to the second year, compared to the respective percentages in the I_1 treatment. These remarks lead to the conclusion that the highly irrigated Arundo plants may reach high yields from the first year (after establishment). The stable yields recorded in the low irrigated treatment in all three years may indicate that these are the maximum yields to be anticipated under water-limited conditions.





Figures 3, 4: Dry matter yields for all water and nitrogen treatments in the three subsequent years in the field experiments in Greece (left) and Italy (right).

Field experiment in Italy:
The dry biomass yield, in the average of the studied factors, resulted equal to 21.5, 16.4 and 18.6 t/ha for the subsequent three years.

The dry biomass yield was affected by soil water availability and nitrogen fertilisation in all the three years. In the best conditions of water and nitrogen the crop produced 23.8, 22.1 and 25.7 t/ha in the subsequent three years. It is worth to be noted that in conditions of absence of water and nitrogen fertilisation the crop produced 15.5, 9.9 and 12.4 t/ha in the three years. The significance of the interaction in the first and second year allows to highlight that high yield can be also obtained with half of ETm restoration with high dose of nitrogen fertiliser. In the I_1N_2 treatment yields of 27.2, 19.9 and 20.4 t/ha, respectively the 114%, 90% and 79,5% of the I_2N_2 treatment, were observed in the three years.

Among the yield components, the stem weight resulted strictly related to the dry biomass yield and therefore affected by the studied factors. The stem weight increased significantly both with the increasing of soil water content and nitrogen supply. In the best experimental conditions (I_2N_2) the weight of a stem resulted equal to 139.3, 141.2 and 151.1 g in the subsequent three years, whereas in the worst conditions (I_0N_0) were 74.9, 76.4 and 94.4 g in the same period. The significance of the interaction in the second and third year confirm that in I_1 treatment (50% of Etm restoration) combined with N_1 and N_2 treatment (60 and 120 Kg/ha of N) the stem weights were comparable to those of the best conditions.

Comparisons of both field experiments

Comparing the yields of the first, second and third years, it was revealed that total dry matter in the I_0 treatment ranged from 10 to 21 t/ha, depending more on the treatment applied than the experimental site. I_2 treatment ensured high dry matter yields from as early as the first year, which reached 20-25 t/ha in both fields. These yields remained the same in all years in the Greek trial, while in the Italian one a decrease (15-20 t/ha depending on the nitrogen treatment) was noticed in the second year, which however applied to all treatments.

3.3 Soil moisture

In the field experiment at Vagia, soil moisture content varied considerably with irrigation rates. Soil moisture in the highly irrigated plots (I_2) was the highest, but always lower than Field Capacity. Soil moisture of the dry treatment (I_0) was stable during the growing period at a level near to 21% cm^3/cm^3. As observed also in the previous growing period, soil moisture content never dropped below 21% cm^3/cm^3, while the Wilting Point was 18% cm^3/cm^3. Apparently, the root system crop could not extract more water from the soil and stopped his growth and evapotranspiration.

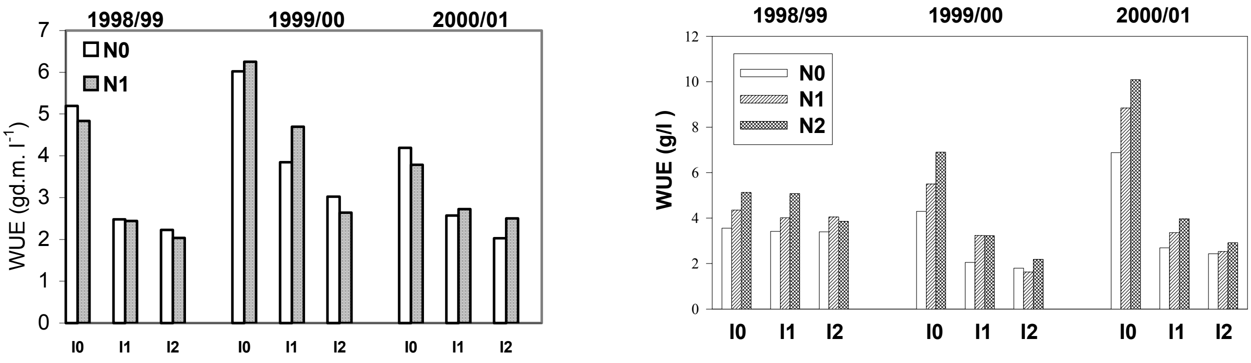
In Catania the measurements of soil moisture at different soil depth have shown that the crop was able to uptake, at the end of the season, all the available water in the soil up to 160 cm. The soil layers resulted, at the end of the season, under the wilting point, in the I_0 treatment, up to 120, 80 and 80 cm of depth in the three subsequent years; in the I_1 treatment until 140, 120 and 100 cm of depth; in the I_2 treatment 160, 160 and 180 cm of depth. This led to the consideration that the crop was perhaps able to uptake water at deeper layers. This result may give on idea of how deep were the roots in the three treatments. The amount of water used by the crop was computed in both experiments taking into account the irrigation, the rainfall and the water stored in the soil (Table 2).

Table 2: Water used by the crop in relation to the water treatments (mm/year).

Treatment	*Year*	Water used (mm/year)	
		Vagia	Catania
I_0	1998	327.3	434.8
	1999	305.8	230.8
	2000	287.7	179.8
	Mean	*306.9*	*281.8*
I_1	1998	768.7	535.0
	1999	625.8	615.2
	2000	789.2	515.2
	Mean	*727.9*	*555.1*
I_2	1998	1144.6	671.1
	1999	1055.4	1009.6
	2000	1066.9	879.6
	Mean	*1088.9*	*835.4*

3.4 Water use efficiency

In the best growing conditions (full irrigation and 120 kg N/ha), the water use efficiency (WUE) was almost similar in both localities and ranged between 2 and 3 g d.m./l. With the reduction of the water consumed by the crop the WUE tended to increase attaining at maximum values of 6 g d.m./l in Vagia and 10 g d.m./l in Catania. The reduction of nitrogen fertilisation determined a generally small reduction of WUE in Catania, whereas did not affected WUE in Vagia.



Figures 5, 6: Water use efficiency (WUE) in the trial in Greece (left) and Italy (right).

4. CONCLUSIONS

Generally, the irrigated plants had a tendency to show better growth and yield performance. In conditions of low soil water availability the plant was able to improve the water use efficiency and maintain a high level of production, to a certain extent similar to that of the well watered plots (I_2). This means that *A. donax* could be successfully grown under moderate irrigation. It is also worth to be noted that *Arundo donax* was able to make useful use, at least in the conditions of Catania, of the nitrogen fertilisation, showing also the good capacity of the crop to catch the nitrogen in the soil. This allows retaining that the crop may avoid nitrate leaching in the subsoil. Taking also into consideration the good capacity of the crop to preserve soil erosion in slope, attributed to its perennial behaviour and the lack of pesticides for its cultivation, it can be pointed out that *Arundo donax* represent an environmentally friendly crop for the Mediterranean environment.

5. ACKNOWLEDGEMENTS

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