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Growth management of vetiver (*Vetiveria zizanioides*) under Mediterranean conditions☆

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Abstract

In spite of the advantages of Vetiver grass in light of environmental aspects, this plant is not used in the Mediterranean region. The objectives of the present study were: (i) to elucidate growth parameters and establishment of Vetiver under Mediterranean conditions suitable for its various environmental applications; and (ii) to develop management practices for growing vetiver under Mediterranean conditions. In greenhouse experiments conducted under controlled conditions it was found that, in general, increasing the minimum/maximum temperatures to 21–29 °C significantly increased plant height. In the Mediterranean region, this range of air temperatures is obtained mainly during the summer, from June to September. For air temperatures up to 15–23 °C the effect of day length on plant height was insignificant, whereas in air temperature >15–23 °C, the plant heights under long day conditions were significantly higher than under short day. The number of sprouts per plant increased exponentially with increasing air temperature, and was not significantly affected by the day length at any air temperature range. In open fields, the heights of irrigated vetiver plants were significantly higher than those of rain-fed plants. It was concluded that, once they were established, vetiver plants could survive the dry summer of the Mediterranean region under rain-fed conditions, but they would be shorter than under irrigation. Cutting or burning of the plant foliage during the spring did not improve the survival of vetiver during the dry summer. In order to obtain fast growth of vetiver and to increase the possibility of its using the rainwater, the plants should be planted in the winter, during February and March. However, under this regime, the vetiver plant cannot be used as a soil stabilizer during the first winter, because the plant is still small. In contrast, under irrigation it is advantageous to plant vetiver at the beginning of the summer; the plant then has sufficient time to grow and develop before the beginning of the winter, so that its effect as a soil stabilizer in the following wet winter could be maximal. It was found that vetiver could grow in a wide range of substrates, such as: sandy soil, loamy sand, clay soil, crushed limestone, sandy clay loam, and tuff/peat mixture.

Keywords: Vetiver; Mediterranean region; Soil conservation; Runoff

1. Introduction

Vetiver (*Vetiveria zizanioides* (L.) Nash) is a perennial grass belonging to the Poaceae family. The South India peninsula is considered as the vetiver center of origin from where it is said to have spread over the world because of its value as a producer of an aromatic oil (Lavania, 2000). Vetiver grass has short rhizomes and a massive, finely structured root system (Fig. 1) that grows very quickly; in some applications its depth reaches 3–4 m in the first year (Truong, 2002). This deep root system makes the vetiver plant extremely drought tolerant and very difficult to dislodge when exposed to a strong water flow (Truong et al., 1995; Hengchaovanich, 1998). Likewise, the vetiver plant is also highly resistant to pests, diseases and fire (West et al., 1996; Chen, 1999). These unique physical and physiological characteristics of Vetiver give this grass distinct advantages, so that it has become known as a

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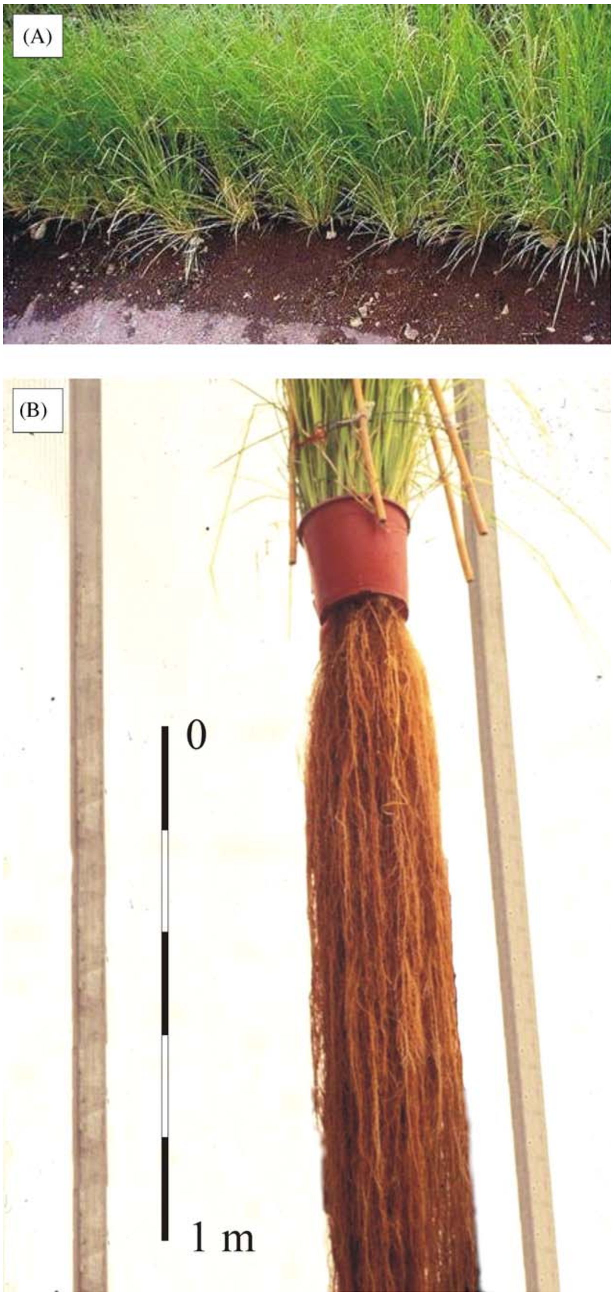

Fig. 1. Photographs of the foliage and the root system of the vetiver plant.

miracle grass plant with diverse environmental applications, including: a source of scented oil from its roots; fodder for livestock; soil and water conservation, rehabilitation, and remediation; and waste water treatment (Maffei, 2002; Lavania et al., 2004). A host of details about the potential and versatility of Vetiver grass are available at http://vetiver.org.

Surface runoff and erosion contribute widely to land degradation in many parts of the world, because of their contributions to losses of water and soil fertility, on the one hand, and their intensification of flooding and surface water pollution risks, on the other hand. Runoff occurs when the rainfall intensity exceeds the soil infiltration rate and the soil surface water holding capacity, therefore, a decrease in the infiltration rate could increase the runoff. The main factor that decreases soil infiltration under rainfall in arid and semi-arid regions is seal formation at the soil surface (Morin et al., 1981; Ben-Hur and Letey, 1989). A surface seal is thin and is characterized by greater density and lower saturated hydraulic conductivity than the underlying soil (Wakindiki and Ben-Hur, 2002a). Soil erosion processes comprise rill and interrill processes: runoff from a soil surface may concentrate into small, erodible channels known as rills or gullies, and thereby damage earth embankments and infrastructures.

Plants growing on slopes can control runoff and erosion through three main mechanisms: (i) The plant canopy can protect the soil surface from raindrop impact, thus, in turn, preventing seal formation, infiltration reduction, and soil detachment (Ben-Hur et al., 1989; Agassi and Ben-Hur, 1992). (ii) Plant roots can act as an anchor that holds the soil particles together, so limiting the risk of landslides along the slope. (iii) Rows of plants oriented perpendicularly to the slope direction can be used as semipermeable barriers that reduce the surface runoff velocity so that the amount of infiltrated water increases and the runoff and soil loss amounts decrease (Wakindiki and Ben-Hur, 2002b).

Vetiver grass has been used intensively for soil and water conservation purposes and for stabilization of steep slopes (Truong and Creighton, 1994; Xie, 1997; Hengchaovanich, 1999; Xia et al., 1999). The effects of vetiver hedges on water flooding and soil erosion were studied in Australia, where it was found that they were successful in reducing flood velocity and limiting soil movement, with the result that there was very little erosion on fallow land (Truong, 2002). Hengchaovanich and Nilaweera (1998) found that root penetration of a 2-year-old vetiver hedge with 0.15-m plant spacing could increase the shear strength of soil in the adjacent 0.5 m wide strip by 90% at 0.25 m depth and by 39% at 0.5 m depth, with gradual reduction to a 12.5% increase at 1 m.

Vetiver grass is distributed mainly in India, Southeast Asia, tropical Africa, South Africa, and Central and South America. (Greenfield, 1988; Lavania, 2000); it grows luxuriantly in well-drained sandy loam soil, in areas with an annual rainfall of 1000–2000 mm and with temperatures ranging from 21 to 44.5 °C (Maffei, 2002). When the vetiver plant is taken from its natural habitat, in which as a hydrophyte it put all its energy into seed production, and is planted in conditions ranging from the semi-arid tropics to the temperate zone, it functions like a xerophyte, putting all its energy into the deep root system necessary for survival (Greenfield, 1988). In spite of the advantages of vetiver grass, this plant is not used in the Mediterranean countries, such as Israel, which are characterized by long, dry and hot summers and short, wet and cold winters. In this region, the water is scarce and crop production relies mainly on irrigation. Therefore, the objectives of the present study were: (i) to elucidate growth parameters and establishment of vetiver under Mediterranean conditions suitable for its various environmental applications; and (ii) to develop management practices for growing vetiver under Mediterranean conditions.

2. Materials and methods

Vetiver (*V. zizanioides*, L. Nash) propagation material was imported to Israel from Reunion Island, in the Indian Ocean, and the plant has been grown in the Newe Ya'ar Research Center of the Volcani Center, Israel for 20 years. The vetiver plants that were used in the present study developed from rooted shoots that had been obtained by splitting mother plants. The following trials were conducted with these plants.

2.1. Growth in greenhouse under controlled conditions

This experiment was conducted in a greenhouse with controlled conditions (phytotron) at the Volcani Center, Bet Dagan, Israel. Rooted shoots of vetiver were planted in 2-L pots containing a mixture of tuff and peat at 1:1 (v/v) ratio, one rooted shoot per pot. The plants were irrigated to excess daily by a drip system with an application rate of $2\,\mathrm{L\,h^{-1}}$ per pot. A 5:3:8 mixture of nitrogen, phosphorus and potassium, enriched with micronutrients was applied via the irrigation water at a concentration of 0.2% (w/w). After three weeks of growing under the natural air temperature and day length, the plants were subjected to two main treatments: exposure to 10 h of light per day (short day), and exposure to 20 h of light per day (long day). Within the two main treatments, five sub-treatments included various ranges of minimum–maximum temperatures: 9–17, 12–20, 15–23, 18–26, and 21–29 °C. All the treatments included four replicates (four pots) in a randomized design. The treatments with maximum temperatures $<25\,^{\circ}\mathrm{C}$ were irrigated once daily; the treatments with the 26–28 and 29–21 °C temperature ranges were irrigated two and three times daily, respectively, because of their high transpiration. The height of the plant and the number of sprouts in each pot were determined at various times.

2.2. Irrigation and foliage treatments

This trial was conducted in an open field at Newe Ya'ar Research Center. The maximum and minimum temperatures and the rainfall depth of each rainstorm during the studied period in the experimental region are presented in Fig. 2. The soil in the experimental site was a clay soil with 63% clay (dominantly montmorillonite), 26% silt, and 11% sand. The soil contained 6.6% $CaCO_3$ and 2.4% organic matter. The mechanical composition was determined by means of a hydrometer (Day, 1956), the organic matter content was determined using the Walkley–Black method (Allison, 1965), and the $CaCO_3$ content was determined using a volumetric method (Allison and Moodie, 1965).

The plants were planted on the 4 April 2000 in a plot with two rows, 1 m apart, with four plants per metre within each row; each treatment plot was 3 m long and 2 m wide, and contained 24 plants. In order to establish the seedlings, all the plants were drip irrigated until August 2000 once a week using one emitter line in the center of each plot. The amount of irrigation water was determined according to a coefficient of 0.7 of a standard class A pan. After the 25

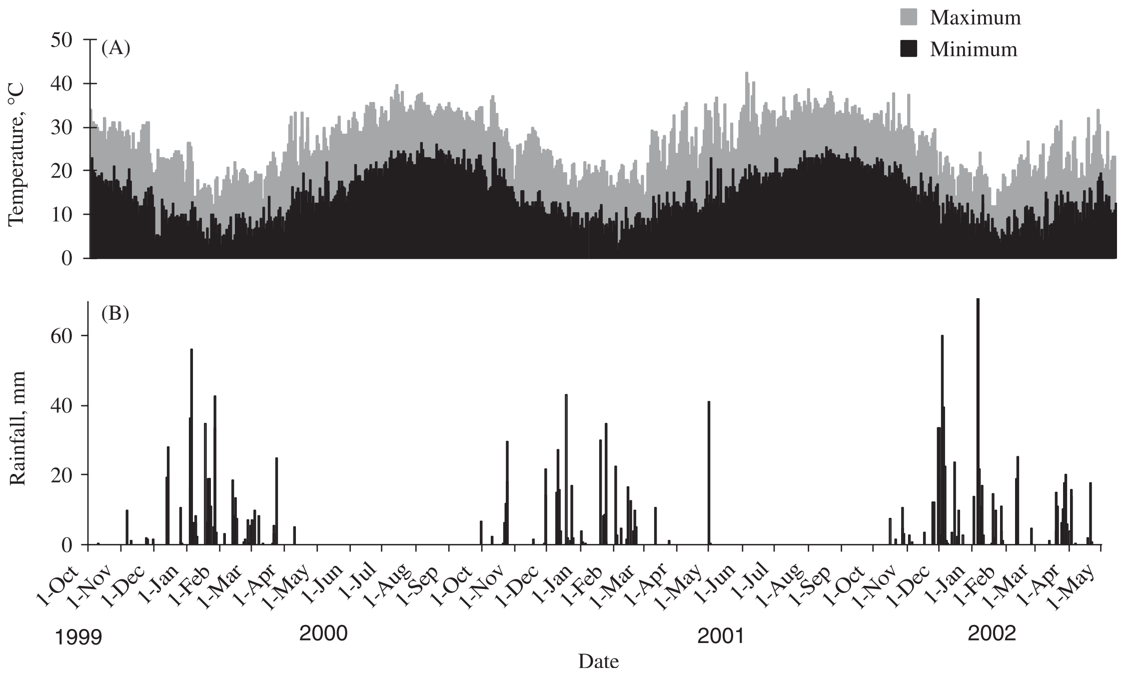

Fig. 2. Maximum and minimum temperatures and rainfall depth of each rainstorm during the studied period in the experimental region.

Table 1
General properties of the used substrate for vetiver growing

Substrate type	Soil texture	Mechanical composition (%)			Organic matter content (%)	$CaCO_3$ content (%)
		Clay	Silt	Sand		
Soil	Sand	7	0	93	0.3	0.7
Tuff	NR[a]	NR	NR	NR	NR	NR
Soil	Loamy sand	12	0	88	0.4	1.3
Soil	Clay	61	17	22	3.9	9.3
Crushed limestone	NR	NR	NR	NR	1.3	68
Soil	Sandy clay loam	21	3	76	1.9	1.8
Tuff/peat mixture, 1/1 (v/v)	NR	NR	NR	NR	48	NR

[a] NR—not relevant.

August 2000, the plants were subjected to two main treatments: irrigated and rain-fed. Each plot was divided into two equal subplots: one subplot continued to receive continuous regular irrigation (irrigated treatment); in the second, the irrigation was stopped (rain-fed treatment). On the 8 June 2001, the plants were subjected to six sub-treatments of foliage harvesting and burning; the plant foliages were cut at ~0, 0.05, 0.15, or 0.2 m above the soil surface, were completely burnt with the aid of kerosene, or were not treated (control treatment). No fertilizer was applied during the entire growing period in any of the treatments. In each subplot, the height of the four middle plants was measured at various times; the other plants served as a border. All the treatments comprised four replicates (four plots).

2.3. *Time of planting*

In order to determine the effects of the time of planting on vetiver growth under Mediterranean conditions, rooted shoots of vetiver 1 day after splitting from the mother plant were planted in each month, from October 2000 until September 2001, in an open field at the Newe Ya'ar Research Center. Twelve plants were planted in two rows, 1 m apart with four plants per metre in each row, in a plot that measured 2 × 1.5 m. At the beginning of the trial, 48 plots were designed and prepared, and at each scheduled planting time, four plots (replications) were randomly selected and planted. All the plants were irrigated according to a similar management practice to that described above for the irrigated plants in the previous trial (2.2. Irrigation and foliage treatments). During the rainy season, the amount of irrigation was reduced by the amount of rainfall. No fertilizer was given during the entire growing period. In each plot, the height of the four middle plants was measured at various times, with the other plants serving as borders.

2.4. *Growth on different substrates*

This trial was conducted in a greenhouse in Newe Ya'ar Research Center. Rooted vetiver shoots were planted on the 7 June 2001 in 10-L pots containing various substrates, with one rooted shoot per pot. The used soils were disturbed samples that were collected from the 5 to 20 cm layer in different fields. Some general properties of these substrates are presented in Table 1. Each substrate treatment was repeated four times (four pots) in a randomized design. The plants were irrigated to excess daily, by means of a drip system, using emitters with an application rate of $2\,\mathrm{L\,h^{-1}}$, with one emitter per pot. The foliage of all the plants in all the substrates was harvested twice: on the 9 September 2001 and the 6 November 2001. Until the 1st harvest, no fertilizer was added to the plants. In contrast, after the 1st harvest, a 5:3:8 mixture of nitrogen, phosphorus and potassium, enriched with micronutrients was applied to all the plants via the irrigation water, at a concentration of 0.2% (w/w). Before each harvest, the height of each plant and the number of sprouts were determined.

2.5. *Statistical analysis*

All the studies were conducted in four replicates, and the differences of the means between the studied parameters were tested by application of analysis of variance (ANOVA) as a complete randomized design. Separation of means was subjected to Tukey's honestly significant difference test (Steel and Torrie, 1981). All tests were performed at the 0.05 significance level.

3. Results and discussion

The plant height and sprouts number per plant during the vetiver growing season in the phytotron are presented in Fig. 3 for 2 day-lengths and various air temperature ranges. In most of the treatments, the plant heights increased rapidly in the first 6 weeks of growth, after which they increased gradually to a maximum value. In contrast, the number of sprouts generally increased slowly at the beginning of the growing season, and then rose exponentially in the later stages (Fig. 3). These increases in plant height and number of sprouts represent a typical growth pattern of vetiver plants. The number of sprouts

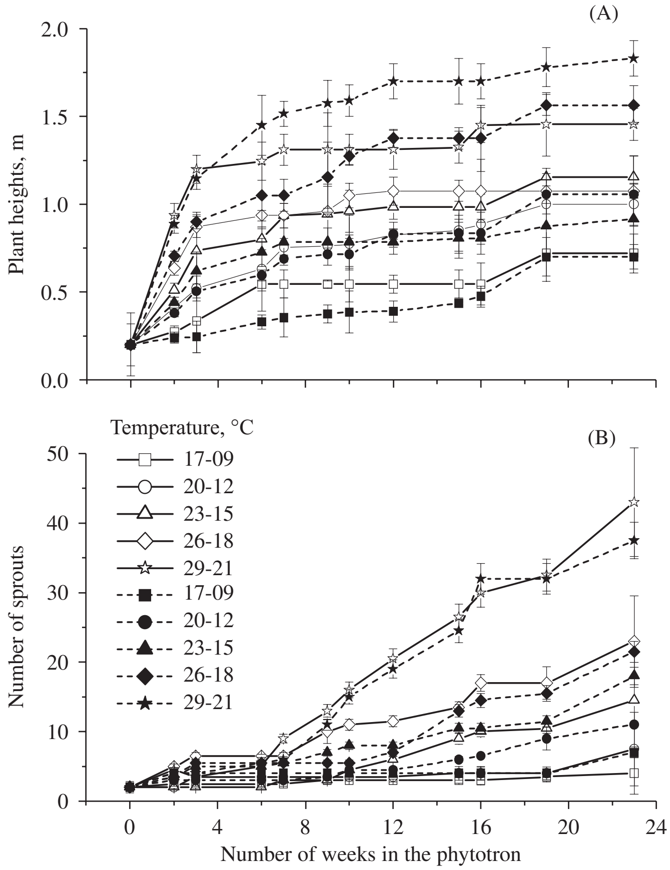

Fig. 3. Plant height and number of sprouts per plant during the vetiver growing season in the phytotron for different air-temperature ranges and long day length (solid symbols) and short day length (open symbols). Bars indicate standard deviation.

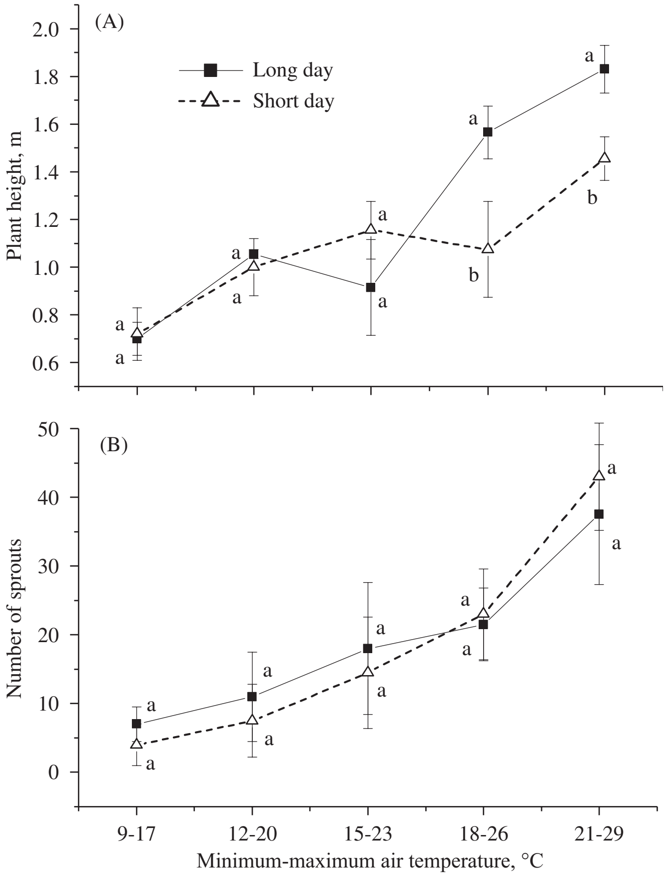

Fig. 4. Plant height and number of sprouts per plant after 24 weeks of growing, as functions of air-temperature range for 2 day lengths. Bars indicate standard deviation, and within air-temperature range, labelling of symbols with different letters indicates significant differences between long and short day treatments.

per plant (Fig. 3B) represents the horizontal growth of the plant, and could be used as an indication of the capability of the plant canopy to cover the soil surface and to protect it against raindrop impact and seal formation.

The effects of air temperature and day-length on vetiver plant growth were determined by the plant height and the number of sprouts per plant after 24 weeks of growing as presented in Fig. 4. In general, an increase of the minimum/maximum temperatures to 21–29 °C increased the plant height significantly (Fig. 3A). In the Mediterranean region, this high air-temperature range prevails mainly during the summer, from June to September (Fig. 2A). The effect of day-length on the plant height depended on the air temperature (Fig. 4A): up to 15–23 °C, the effect was insignificant, but at air-temperature ranges above 15–23 °C, the plants were significantly taller in the long-day than in the short-day treatments. The number of the sprouts per plant increased exponentially with increasing air temperature ranges, and no significant effects of day length were found in any of the examined air-temperature ranges (Fig. 4B).

The average heights of the vetiver plants growing after the various foliage treatments under irrigation and rain-fed conditions in the open field, on various dates in 2001 are presented in Fig. 5. The foliage treatments included cutting at various heights above the soil surface, and burning on the 8 June 2001. Until the 23 July 2001, the average heights of the irrigated and rain-fed plants in the control treatment (untreated foliage) were similar, at about 1.76 m (Fig. 5A), which suggests that, until the 23 July 2001 the rainfall in the winter of 2000/2001 (Fig. 2B) together with the residual water content in the soil were sufficient to support the growth of vetiver plants, so that irrigation during this time had no significant effects on the plant height. In contrast, after the 23 July 2001 the irrigated plants were significantly taller than the rain-fed ones: by the 27 November 2001 the heights of the irrigated and rain-fed plants were 2.5 and 2.0 m, respectively (Fig. 5A). It can be concluded from these results that, once established, vetiver plants can survive the dry summer in semiarid regions around the Mediterranean under rain-fed conditions, but their height will be reduced.

After the vetiver foliage had been cut or burned, the heights of the plants increased rapidly until the 23 July 2001, after which they increased gradually until they

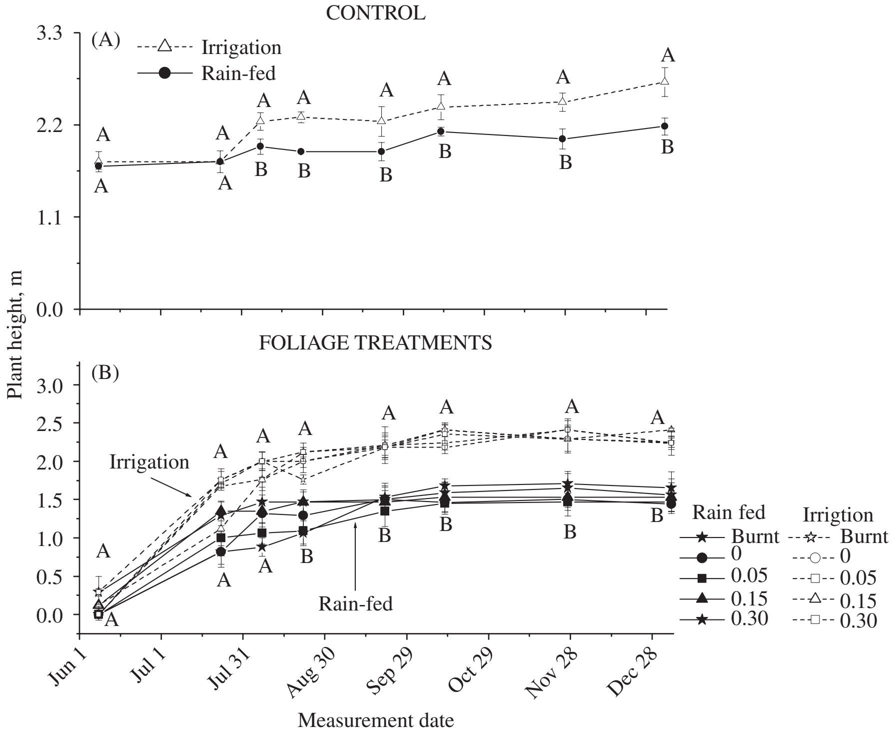

Fig. 5. Average heights of vetiver plants after various foliage treatments under irrigated and rain-fed conditions in open field at various dates in 2001. Bars indicate standard deviation; within measurement date and control and foliage treatments, labelling of symbols with different letters indicates significant differences between irrigated and rain-fed treatments.

attained their maximum values (Fig. 5B). No significant differences were found among the various foliage treatments within the rain-fed and irrigated treatments (Fig. 5B). In the light of this, the foliage treatments were considered as replicates in the statistical test of the significance of the difference in plant height between the rain-fed and irrigated treatments. In the foliage treatments, the irrigated plants were significantly taller than the rain-fed ones after the 22 August 2001 (Fig. 5B).

The heights of the irrigated plants after the various foliage treatments, were, in general, similar to those in the control treatment after the 23 July 2001 (Fig. 5), whereas the rain-fed plants after the various foliage treatments, were shorter than the controls: the average heights of the rain-fed plants in the control and the foliage treatments were 1.9 and 1.5 m, respectively (Fig. 5). Under semiarid conditions, the vetiver foliage may be cut during the spring in order to improve the survival of the plants through the dry summer. However, the present findings regarding the heights of rain-fed plants in the control and the foliage-cut treatments (Fig. 5) indicate that cutting the plant foliage during the spring did not improve the survival of vetiver during the dry summer.

The average heights of vetiver plants that had grown under irrigation in open field for 200 days after being planted on several different dates are presented in Fig. 6. These heights could be used as indicators of the growth rate of vetiver in its first year after planting. The plants that were planted during February and March were the tallest, with heights of 2.3 and 2.34 m, respectively, and those that were planted earlier than February or later than March were markedly shorter (Fig. 6). These results suggest that in order to achieve fast growth of vetiver, the plants should be planted in the winter, i.e., during February and March. Moreover, under rain-fed conditions, winter planting of vetiver increased the possibility that the plant would use

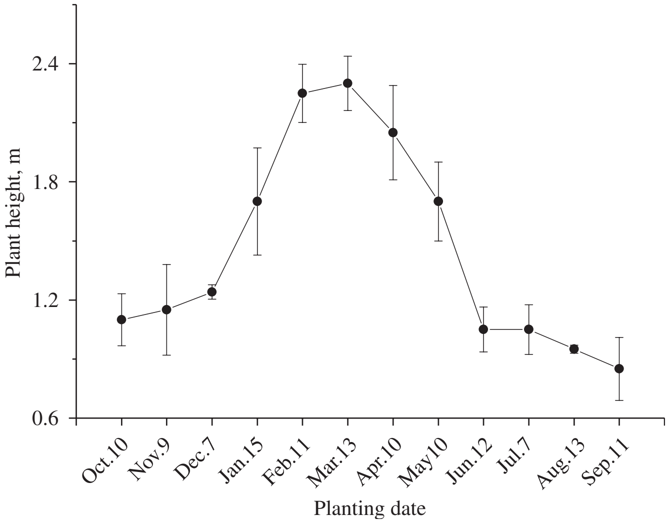

Fig. 6. Average heights, after 200 days of irrigated growth, of vetiver plants that were planted on several different dates in an open field. Bars indicate standard deviation.

the rainwater for growth and consolidation, thus, in turn, increasing its chances of survival through the dry summer. However, under this regime, the vetiver plant cannot serve as a soil stabilizer during the first winter, because the plant is still small. In contrast, for plants growing under irrigation it is advantageous to plant at the beginning of the summer. This ensures that the plant has sufficient time to grow and develop before the beginning of the winter, thus maximizing its effect as a soil stabilizer through the subsequent wet winter.

The heights and the numbers of sprouts per plant, at two harvests of vetiver plants that were grown in various substrates are presented in Fig. 7. At the 1st harvest, the heights of the plants after about 3months of growing in sandy soil, loamy sand, clay soil, crushed limestone, sandy clay loam, and a tuff/peat mixture were relatively high, and no significant differences between these substrates were found (Fig. 7A). The plants that were grown in tuff were significantly shorter than those grown in other substrates. These results indicated that with regard to plant height, vetiver could grow in a wide range of substrates, including crushed limestone.

At the 1st harvest, the number of sprouts per plant was highest—14—in the clay soil, moderate—6—in sandy soil, and low—<5—in the other substrates (Fig. 7B). No significant differences in the number of sprouts per plant between tuff, loamy sand, crushed limestone, sandy clay loam, and tuff/peat mixture were found. These results (Fig. 7A and B) suggest that, with regard to vetiver growth, the differences among the studied substrates had more pronounced effects on the number of sprouts per plant than on the plant height. The tallness and the large number of sprouts per plant of the vetiver grown in the clay soil probably resulted from the high water retention capacity and fertility of this soil.

Addition of fertilizer via the irrigation water after the first harvest did not significantly increase the height of the vetiver plants (Fig. 7A), and in the case of the plants growing in crushed limestone, addition of fertilizer significantly decreased it. In contrast, addition of fertilizer after the 1st harvest increased the number of the sprouts per plant in sandy soil, loamy sand, clay soil, and tuff/peat mixture, although this increase was significant only in the sandy soil and tuff/peat mixture. It should be noted, however, that the same irrigation and fertilization management regime was used for all the studied substrates, and it is most likely that the use of irrigation and fertilization management regimes that were more compatible with the

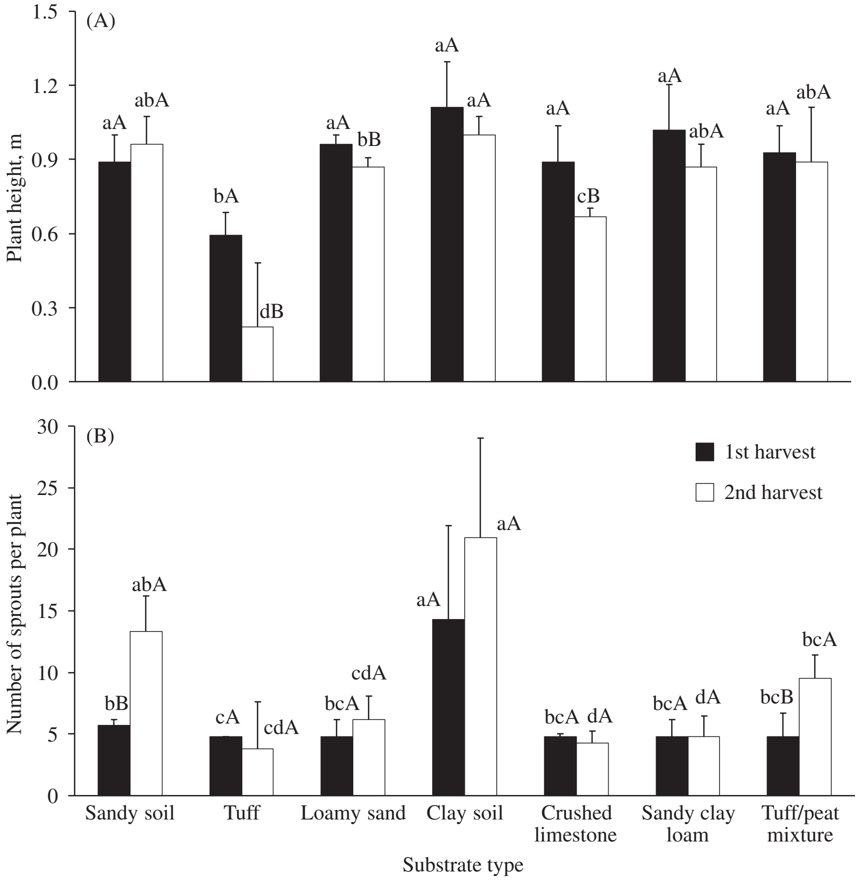

Fig. 7. Plant heights and numbers of sprouts per plant, at two harvests, of vetiver that was grown in various substrates. Bars indicate standard deviation. Values followed by different lower case letters differed significantly between substrates for each harvest; those followed by different upper case letters differed significantly between the harvests for each substrate.

chemical and physical properties of the individual substrates would considerably improve the performance of the vetiver plants in these various substrates.

4. Summary and conclusion

1. It was found that vetiver could grow in a wide range of substrates, such as: sandy soil, loamy sand, clay soil, crushed limestone, sandy clay loam, and tuff/peat mixture. The vetiver grown in clay soil was the tallest and had the largest number of sprouts per plant. This probably resulted from the high water retention capacity and fertility of this soil. It is most likely, however, that using irrigation and fertilization management regimes that are compatible with the chemical and physical properties of the individual substrates would considerably improve the performance of the vetiver plants in the other substrates.
2. In order to obtain fast growth of vetiver and to increase the possibility of its using the rainwater, the plants should be planted in the winter, during February and March. However, under this regime, the vetiver plant cannot be used as a soil stabilizer during the first winter, because the plant is still small. In contrast, under irrigation it is advantageous to plant vetiver at the beginning of the summer; the plant then has sufficient time to grow and develop before the beginning of the winter, so that its effect as a soil stabilizer in the following wet winter could be maximal.
3. Increasing the minimum/maximum temperatures to 21–29 °C significantly increased plant height. In the Mediterranean region, this range of air temperatures is obtained mainly during the summer, from June to September. For air temperatures up to 15–23 °C the effect of day length on plant height was insignificant, whereas in air temperature >15–23 °C, the plant heights under long day conditions were significantly higher than under short day conditions. The number of sprouts per plant increased exponentially with increasing air temperature, and was not significantly affected by the day length at any air temperature range.
4. Once the vetiver plants are established, they could survive the dry summer of the Mediterranean region under rain-fed conditions, but they would be shorter than under irrigation. Cutting or burning of the plant foliage during the spring do not improve the survival of vetiver during the summer.

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