Above-ground phytomass and below-ground biomass production of *Salvia verbenaca* Linné

Production de phytomasse et biomasse racinaire chez Salvia verbenaca *Linné*

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Abstract

Salvia verbenaca *L. is a ruderal herbaceous plant, very common in the Mediterranean region. Its flowers are prized for their appearance, and it displays a high degree of adaptability in relation to habitat sites with a paucity of resources.*

The objective of this study was to obtain data about the production of phytomass and root biomass, with a view to the probable use of this species in urban green spaces. A two-year field experiment was undertaken, comprising four treatments of eight randomly selected plots, four being used in each year. This species was manual seed broadcast at the following densities: 20 000, 15 000, 10 000 and 5 000 viable seeds m^{2}.

The production of phytomass and root biomass was assessed through periodic collections, during the seasonal cycle of the species under study. In the first year there appears to have been a tendency for an increase in seed density to cause an increase in phytomass production. In the second year, by which time the plants had settled, when seed density rose from 5 000 to 10 000, a slight increase in phytomass production occurred. However, when the seed density rose from 10 000 to 20 000 seeds m -2, a decrease in phytomass production was observed. Root biomass, in the first year, had minimum value in January and a maximum value in June-July. In the second year, the highest values were observed in May. The relationship between above and below ground biomass, for the first-year experiment, decreased over the cutting dates. However, an inverse behaviour occurred in the second year. Although the values of the phytomass obtained did not reveal statistically significant differences between treatments, when the plants were found already established, they appeared to indicate that densities of seeding between 5 000 and 10 000 m^{2} *could be more advantageous.*

Key-words

Phytomass, seed density, root biomass, shoot/root ratio.

Résumé

Salvia verbenaca *L. est une herbacée rudérale très commune dans la région méditerranéenne. Ses fleurs sont très prisées pour des raisons esthétiques. Cette espèce présente un degré d'adaptation important pour des habitats pauvres en ressources. L'objectif de cette étude a consisté à analyser la production de la phytomasse et de la biomasse racinaire dans l'optique d'utiliser cette espèce dans les espaces verts des villes. Durant deux ans, une expérience a été réalisée, comprenant quatre traitements avec huit plots aléatoires ; quatre plots étant utilisés chaque année. Les graines ont été semées selon les densités suivantes : 20 000, 15 000, 10 000 et 5 000 graines/m*^{2}.

La production de la phytomasse et de la biomasse racinaires a été mesurée suite à des récoltes périodiques pendant la durée du cycle saisonnier. Dans la première année, il semble que l'augmentation de la densité des semis a conduit à un accroissement de la production de phytomasse.

Dans la deuxième année, lorsque la plante était déjà installée, l'augmentation de la densité des graines de 5 000 à 10 000 a entraîné une légère croissance de la production de phytomasse. Cependant, lorsque la densité des graines a augmenté de 10 000 à 20 000 graines/m^{2}*, une réduction de la production de phytomasse a été observée. Dans la première année, la biomasse racinaire a présenté une valeur minimum en janvier et une valeur maximum en juin-juillet. Dans la deuxième année, les valeurs les plus hautes ont été observées en mai. La relation entre la phytomasse et la biomasse racinaire, pour la première année, diminue au fil des dates de coupe. Cependant, un phénomène inverse s'est produit au cours de la deuxième année. Bien que les valeurs de la phytomasse n'aient pas révélé de différences significatives entre les traitements, lorsque les plantes sont déjà établies, elles indiquent que les densités de graines comprises entre 5 000 et 10 000/m*^{2} *pourraient être plus avantageuses.*

Mots-clés

Phytomasse, densité des graines, biomasse racinaire, ratio tige/racine.

Introduction

The importance of studying spontaneous herbaceous species from the point of view of their use in urban green spaces has been approached by various authors, due to the difficulty that certain exotic species have in adapting to places with a paucity of resources, and thus making them unable to survive in adverse conditions. (Cole & Keen, 1976; Wells, 1987; Brown, 1989; Clément, 1990).

The spatial and temporal distribution of photosynthesis-active organs plays an important role in determining the quantity of sunlight which is captured by the plant, thus contributing towards an increase in the quantity of elements assimilated (Norman & Campbell, 1992).

Root biomass, expressed in dry weight, reflects the effort of the plant to distribute the products of photosynthesis. The thickest roots have a greater capacity for penetrating more compact soils, are more durable and contribute over the long term to the development of the root system (Oliveira *et al.*, 2000).

The partial or total removal of the aerial part of the plant is invariably followed by compensatory growth, that is, distributed assimilated elements or reserves of carbohydrates in the root system are channelled towards the formation of leaf tissue, and away from root formation, in such a way that the equilibrium between the two systems is restored (Troughton, 1977).

There is an interactive relationship between aerial and root biomass, which is reflected in the level of distribution of photosynthesised products between the above and below ground systems, which have simultaneously different and complementary functions. While the aerial part of the plant depends on the absorption capacity of the root system for its growth, the root system needs the carbohydrates produced by the organs of photosynthesis. Thus, there is an interdependent relationship between them (Troughton, 1977; Bohm, 1979 *cit. in* Oliveira, 1988; Klepper, 1991).

In zones with a Mediterranean climate, the amount and timing of rainfall is often the limiting factor in the choice of species, the choice being those preferring dry land to meadowland, having originating in the different climatic conditions of the Mediterranean. Thus, the objective of this study was to evaluate the production of phytomass and root biomass, using four densities of seeding, with a view to the probable use of the species under study in urban green spaces.

Materials and methods

Salvia verbenaca (Labiatae) is a herbaceous plant, growing on uncultivated land, which is very commonly found in the Mediterranean region, Southern and Western Europe and Northern Scotland (Tutin *et al.*, 1972). It produces lilac flowers, with spring blooming (March to April). The aerial part of the plant ages and dies in early summer. After the fall of the first autumn rains, the vegetative stage begins, with the emergence of the first leaves.

Study site

The study was carried out at the University of Évora in the Alentejo region of Portugal (38° 32' N; 8° 01' W; 200 m altitude). The soils were classified as alfisoils (SSS, 1992) or luvisoils according to the FAO/UNESCO (1988).

The climate is an oceanic Mediterranean pluvial-seasonal bio-climate (MPO), according to Rivas Martínez (1995). Figure 1 shows climate data for the study period

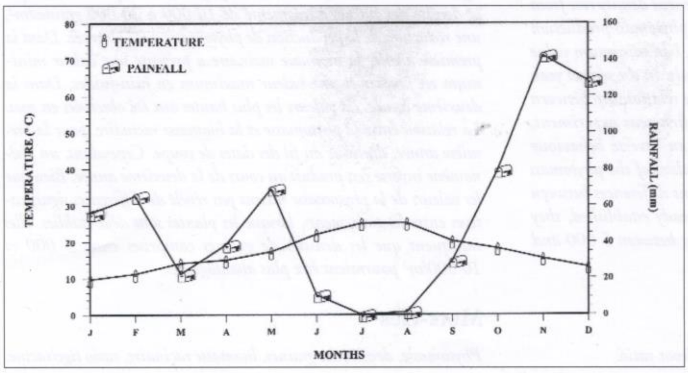

Figure 1. Thermo-pluviometric chart referring to Évora-Malagueira Meteorological Station (1993-1995).

(1993 to 1995). A two-year field experiment was performed comprising four treatments of eight randomly selected plots, four being used in each year. Each plot, sited 30 cm apart, had an area of 1 m^2. Seeding was carried out by manual seed broadcast, using the following densities: 20 000, 15 000, 10 000 and 5 000 viable seeds (Germination capacity: 65 %; Degree of purity: 99 %; Field losses: 78.7 %; Weight of 1,000 seeds: 2.643 g). Seed densities were selected in accordance with the work carried out by Harper & Gajic, 1961; Ross & Harper, 1972; Sheldon, 1974; Weaver & Cavers, 1979; Gross & Werner, 1982; Shaw & Antonovics, 1986. The study was performed in field conditions. In the first year, only four plots were used. The other four were used in the second year, when plants were already settled. At the end of the first year, when the plants reached the stage of senescence, the above-ground material was removed.

Determination of phytomass

Sampling sites with an area of 625 cm^2 (25 cm x 25 cm) were randomly selected in each plot. A border of 15 cm width was set between each site. Phytomass was divided into vegetative, support and reproductive structures. The dry matter weight was recorded from the samples which were oven-dried at 80 °C until constant weight was achieved, after approximately 48 hours (Milner & Hughes, 1968). The dry weight of the structures, which included some ash, was related to soil surface unit. Total phytomass was obtained from the sum of the weight of all the structures, and calculated per soil surface unit.

Determination of root biomass

At the site where the above-ground material of plants was removed, four soil samples per layer were extracted using a hand auger, comprising a cylindrical tube 10 cm long, with an inside diameter of 7 cm (Oliveira *et al.*, 2000).

Roots were extracted from the soil sample by a hydro-pneumatic elutriation system (Smucker *et al.*, 1982; Oliveira *et al.*, 2000).

Soil samples, containing roots for each depth and each sampling event, were placed in individual plastic bags, which were labelled and frozen awaiting laboratory treatment (Oliveira *et al.*, 2000).

The root dry weight was recorded for root samples, which were oven-dried at 70 °C until there was no further change in weight, after approximately 48 hours (Böhm, 1979; Schuurman & Goedewaagen, 1971 *cit. in* Oliveira *et al.*, 2000).

In accordance with Gregory (1988) and Oliveira *et al.* (2000) among others, the root dry weight was related to soil volume unit.

The relationship between above and below ground biomass

In order to evaluate the relationship between above and below ground biomass, the shoot-root ratio was estimated (Böhm, 1979; Pagès *et al.*, 2000; Atkinson, 2000).

Data Analysis

The data recorded were analysed by descriptive statistics and analysis of variance (ANOVA), followed by comparison of means among treatments, using Newman/Keul's test.

RESULTS AND DISCUSSION

Phytomass production

The mean values of phytomass dry weight, in the first year of the study, varied from 141.9±79.9 $g.m^{-2}$ (seed density 5 000) to 189.6±89.6 $g.m^{-2}$ (seed density 20 000).

Table 1 shows that there was a tendency for an increase in phytomass up until June (223 days after seeding), when production peaked. In the second year (table 2), there was a tendency for production to peak in May, 212 days after the emergence of the first leaves. Average annual values varied from 502.3±230.7 $g.m^{-2}$ (seed density 20 000) to 554.3±290.1 $g.m^{-2}$ (seed density 10 000). Thus, in the first year, there seems to have been a tendency for the increase in seed density to cause an increase in phytomass production. In the second year, a time by which the plants had settled, when seed density rose from 5 000 to 10 000, an increase in phytomass production occurred. However, when the seed density rose from 15 000 to 20 000, a decrease in phytomass production was observed. According to Harper (1961), the above ground weight of the plant may not initially be influenced by seed density but, at high seed densities, the competition between individual plants leads to a reduction in individual plant weight. The behaviour of the species observed in this study may be explained by competition being less when there are fewer plants per soil surface unit, with these plants taking the opportunity to increase phytomass production.

Cutting date	Treatments Sv 20 000	Sv 15 000	Sv 10 000	Sv 5 000
17/01/94	51.0 ± 7.6 c	54.7 ± 7.4 c	37.3 ± 11.0 b	18.6 ± 6.8 a
07/03/94	199.7 ± 99.6 b	134.9 ± 31.8 ab	143.6 ± 34.8 ab	80.9 ± 5.3 a
11/04/94	176.3 ± 58.9 a	154.7 ± 24.8 a	192.2 ± 35.8 a	156.8 ± 38.6 a
09/05/94	224.4 ± 61.3 a	155.6 ± 25.4 a	158.9 ± 23.1 a	169.6 ± 25.3 a
06/06/94	271.4 ± 30.4 a	222.9 ± 29.7 a	240.9 ± 51.3 a	270.6 ± 14.7 a
11/07/94	223.0 ± 81.5 a	165.4 ± 19.5 a	185.9 ± 46.9 a	170.7 ± 18.0 a
Annual average	189.6 ± 89.6 b	148.0 ± 55.3 a	156.9 ± 70.8 a	141.9 ± 79.9 a

Different letters note significant differences (P<0,05).

Table 1. Salvia verbenaca *L. (Sv) total average dry weight of phytomass (g.m*$^{-2}$*), for periodic cuttings and treatments.*

Cutting date	Treatments Sv 20 000	Sv 15 000	Sv 10 000	Sv 5 000
19/12/94	234.4 ± 63.5 b	145.3 ± 63.6 a	159.9 ± 80.9 a	190.0 ± 48.0 a
31/03/95	509.0 ± 211.3 a	698.6 ± 185.8 a	490.9 ± 73.0 a	655.0 ± 118.8 a
23/05/95	702.3 ± 89.4 a	751.2 ± 179.2 a	815.5 ± 183.6 a	655.0 ± 253.7 a
10/07/95	590.4 ± 228.8 a	468.8 ± 166.9 a	754.9 ± 139.9 a	729.1 ± 307.5 a
Annual average	502.3 ± 230.7 a	515.3 ± 283.7 a	554.3 ± 290.1 a	552.5 ± 288.2 a

Different letters note significant differences (P<0,05).

Table 2. Salvia verbenaca *L. (Sv) average dry weight of root biomass (g.cm*$^{-2}$*), for periodic cuttings and treatments.*

The result seems to be in accordance with Harper (1961), who states that the characteristic behaviour of the development of phytomass production, as a function of an increase in seed density, has a linear pattern as it increases up to a certain density, and remains constant with the increase in seed densities, although, in some cases, there is a real loss of production at higher densities.

The pattern of phytomass development, with maximum values in the blooming season, bears out some of the results obtained in this study, and variations are thought to result from the floristic composition of the respective natural meadows (Tappeiner & Cernusca, 1996, 1998; Anten & Hirose, 1999; Zeller *et al.*, 2000).

Root biomass

Table 3 shows root distribution expressed as dry root weight in the first year, with values which tend to increase as cutting dates progress, with a minimum value in January, at the beginning of the vegetative stage (83 days after seeding), and a maximum value in June-July, 223 and 258 days after seeding.

Although phytomass production peaked in June, there seems to have been no increase in dry root weight. Average dry root weight varied from 0.45±0.45 mg.cm^{-3} (seed density 5 000) to 0.54 ± 0.58 mg.cm^{-3} (seed density 20 000).

Table 4 shows dry-root-weight development in the second year, revealing a tendency for the highest values

Table 3. Salvia verbenaca *L. (Sv) average dry weight of root bomass (mg.m*$^{-3}$*), for periodic cuttings and treatments.*

	Treatments			
Cutting date	Sv $_{20000}$	Sv $_{15\,000}$	Sv $_{10\,000}$	Sv $_{5\,000}$
17/01/94	0.14 ± 0.04 a	0.12 ± 0.03 a	0.12 ± 0.02 a	0.05 ± 0.01 b
07/03/94	0.24 ± 0.19 a	0.24 ± 0.19 a	0.28 ± 0.19 a	0.15 ± 0.12 a
11/04/94	0.42 ± 0.39 a	0.43 ± 0.35 a	0.48 ± 0.42 a	0.36 ± 0.26 a
09/05/94	0.58 ± 0.50 a	0.52 ± 0.43 a	0.52 ± 0.41 a	0.50 ± 0.45 a
06/06/94	0.58 ± 0.58 a	0.55 ± 0.58 a	0.57 ± 0.60 a	0.65 ± 0.49 a
11/07/94	0.75 ± 0.80 a	0.60 ± 0.65 a	0.70 ± 0.63 a	0.47 ± 0.53 a
Annual average	0.54 ± 0.58 a	0.49 ± 0.50 a	0.53 ± 0.51 a	0.45 ± 0.45 a

Different letters note significant differences (P<0,05).

Table 4. Salvia verbenaca *L. (Sv) average dry weight of root bomass (mg.m*$^{-3}$*), for periodic cuttings and treatments.*

	Treatments			
Cutting date	Sv $_{20000}$	Sv $_{15\,000}$	Sv $_{10\,000}$	Sv $_{5\,000}$
19/12/94	0.35 ± 0.21 a	0.27 ± 0.19 a	0.31 ± 0.25 a	0.29 ± 0.24 b
31/03/95	0.35 ± 0.26 a	0.57 ± 0.41 a	0.47 ± 0.41 a	0.34 ± 0.37 a
23/05/95	0.53 ± 0.53 a	0.55 ± 0.54 a	0.55 ± 0.58 a	0.48 ± 0.55 a
10/07/95	0.28 ± 0.25 a	0.47 ± 0.45 a	0.75 ± 0.87 a	0.40 ± 0.49 a
Annual average	0.38 ± 0.34 a	0.47 ± 0.42 a	0.52 ± 0.59 a	0.38 ± 0.43 a

Different letters note significant differences (P<0,05).

Table 5. Shoot and root ratio (s/r) of Salvia verbenaca *L. (Sv), for periodic cuttings and treatments.*

	Treatments			
Cutting date	Sv $_{20000}$	Sv $_{15\,000}$	Sv $_{10\,000}$	Sv $_{5\,000}$
17/01/94	3.58	4.44	3.20	3.63
07/03/94	4.13	2.77	2.58	2.65
11/04/94	1.38	1.19	1.33	1.44
09/05/94	0.96	0.74	0.76	0.85
06/06/94	0.92	0.80	0.84	0.81
11/07/94	0,59	0.55	0.48	0.71
Annual average	1.93 ± 1.52	1.75 ± 1.55	1.53 ± 1.10	1.68 ± 1.20

Different letters note significant differences (P<0,05).

	Treatments			
Cutting date	Sv $_{20\,000}$	Sv $_{15\,000}$	Sv $_{10\,000}$	Sv $_{5\,000}$
19/12/94	1.32	1.08	1.02	1.31
31/03/95	2.92	2.44	2.10	3.78
23/05/95	2.64	2.72	2.97	2.72
10/07/95	3.12	1.99	2.01	3.60
Annual average	2.50 ± 0.81	2.06 ± 0.72	2.02 ± 0.80	2.85 ± 1.13

Different letters note significant differences (P<0,05).

Table 6. Shoot and root ratio (s/r) of Salvia verbenaca *L. (Sv), for periodic cuttings and treatments.*

to occur in May, coinciding with the peak of phytomass production (212 days after emergence). However, there seems to have been an evident decrease in dry root weight from May. Average dry root weight varied from 0.38 ± 0.34 mg.cm^{-3} (seed density 20 000) to 0.52 ± 0.59 mg.cm^{-3} (seed density 10 000).

The above and below ground biomass relationship

The changes in the relative growth of the aerial part and root part of the plants can be interpreted as a strategy adopted by plants for adaptation to the environment. Thus, it makes sense to treat the plant as a "whole", and assume that the aerial and root systems are interdependent (Oliveira, 1988)

The relationship between the dry weights of the aerial and root part of the plant (shoot/root) is shown in table 5 (first year) and table 6 (second year).

There seems, therefore, to have been a tendency for s/r values to decrease over the range of cutting dates, there tending to be a maximum in January, at the beginning of the vegetative stage (83 days after seeding), and a minimum in July, at the senescence stage (258 days after seeding). The second year produced a reversal in this pattern of behaviour for s/r values, mainly caused by the predominance of the aerial part of the plant over the root part (table 6).

Average s/r values varied from 2.02±0.80 (seed density 10 000) to 2.85±1.13 (seed density 5 000). The range of values recorded for each treatment and for each cutting date seems to be in accordance with Oliveira (1988) and Klepper (1991). These researchers described the relationship between the weights of the aerial and root parts of plant as being similar for plants of the same species, although there are variations between species and within each species, in accordance with environmental conditions, plant age and different phenological stages.

During each year of the study, the variations recorded in the values of this relationship could have resulted from a variation in environmental conditions, on which the activity of the root part and the aerial part of the plant depends, as well as depending on plant development stages. Brown and Scott (1984, *cit. in* Oliveira, 1988) state that a higher level of growth of the root part as compared with the aerial part could appear prejudicial to the dispersion of metabolites used for increasing the area of photosynthesis. However, Russel (1977 *cit. in* Oliveira, 1988) states that in heterogeneous environments such as soil, in which there is a considerable variation in environmental conditions over time and between different layers or horizons, plant productivity could depend on the development of a root system which allows plants to weather adverse periods. This could explain the results obtained in the first year of the experiment; from May there seems to have been a tendency for a decrease in the s/r ratio. Nonetheless, Barbour (1973 *cit. in* Oliveira, 1988) states that, for perennial species and in arid conditions, r/s ratios lower than 1 are rarely found. Kuiper (1992), commenting on the change in the supply of nutrients, refers to s/r values for *Plantago major* ssp. *major* and ssp. *pleiosperma*, which vary from 0.9 to 2.3.

According to Brouwer (1983, *cit. in* Klepper, 1991), the interdependency of the root and aerial parts of the plant is expressed by a functional equilibrium, and there is a tendency for each species to possess a characteristic r/s relationship. However, Brouwer (1966 *cit. in* Davidson, 1969) states that the r/s relationship is similar for plants of a certain species subject to similar environmental conditions, although it is sensitive to environmental variations and can change with plant ageing.

Troughton and Luckwill (1960 *cit. in* Davidson, 1969) suggest that plants have the capacity for adjusting the r/s ratio in accordance with the characteristics of the environment in which they are growing.

According to Davidson (1969), a plant constitutes a "whole", although the absorption of water and nutrients is carried out by the roots in distinct edaphic conditions from those in which photosynthesis occurs. As the difference of temperature between leaves and roots changes, there seems to be a tendency for the plant to compensate for this by means of changes in root activity, increasing or decreasing the relative size of the root system. In field conditions, according to Davidson, there is great degree of disparity between root activity and photosynthesis activity as days decrease in length and summer progresses towards winter, in which the drop in soil temperature is higher than the drop in air temperature, and thus root growth is limited. This may provide a possible explanation for the seasonal variation of the patterns of growth observed in this study.

When either the root or the aerial part of the plant is removed, a compensatory process is activated in the plant which restores the s/r ratio which is characteristic of the species. Brouwer and De Wit (1969 *cit. in* Klepper, 1991) state that when they removed half of the aerial part of bean plants they found that, later, the growth of the aerial part was faster than that of the roots until the initial r/s ratio was attained. This could contribute to an understanding of the evolution of the s/r relationship in the second year of this study, by virtue of the fact that, at the end of the first year, the aerial part of the plants on the plots which were the object of study in the second year was removed in its entirety.

CONCLUSION

The levels of production for each of the two years of the study were not compared statistically, because the first year was for seeding. However it was an evidently lower level of production in the first year. In the second year, by which time the plants had settled, there seems to have been a tendency for the increase in seed density to cause a decrease in phytomass production. This behaviour may be explained by possible competition between individuals, at high seed densities.

Assuming the above and below ground system interdependency, shoot/root ratio provided some indications as to the changes occurring in growth in these systems. In the first year of the study, s/r values progressively decreased throughout the cutting dates, which could be interpreted as a greater increase in the below ground than in the above ground system. In the second year, the opposite occurred. Probably, due to the low levels of precipitation, which occurred in the first year of the study, root system development predominated, allowing deeper soil layers to be explored. In the second year, the plants produced more aboveground biomass, probably using the reserves stored in the root system. Nonetheless, the removal of the entirety of the aboveground biomass of the existing plants, at the end of the first year, after senescence, could also have contributed to the plants attempting to adjust in the following year to the s/r relationship, which is characteristic of the species.

The results seem to indicate that biomass production was more sensitive to environmental or seasonal changes than to seed densities.

Nowadays, in Portugal, the seeds from wild plants are collected by hand in its habitat. Timing seed collection is one of the most crucial and difficult steps in the process as flowers and fruits are produced in succession. Thus, the seed collector has either to select only mature seeds or to wait until the whole inflorescence will be ripen, losing seeds from the earliest ripened fruits. Therefore, this is an expensive method of obtaining large quantities of seeds.

Although the values of the phytomass obtained did not reveal statistically significant differences between treatments, when the plants were found already established, they appeared to indicate that densities of seeding between 5 000 and 10 000 m^{-2} could be more advantageous, reducing seed collection.

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