Leaf area expansion and dry matter accumulation during establishment of broad bean and sorghum at different temperatures and soil water contents in two types of soil in mediterranean Portugal

J.A.Andrade[1*], F.G. Abreu[2]

[1]*Departamento de Geociências, Universidade de Évora- Colégio Luís António Verney,, Rua Romão Ramalho nº59, 7000-671 Évora, Portugal, Tel. nº 266745300, Fax. Nº 266-74539. e-mail: zalex@uevora.pt*
[2]*Departamento de Ciências do Ambiente, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal*

1. INTRODUCTION

Crop establishment is a major factor determining crop productivity in the field and is strongly controlled by soil temperature and soil moisture. Extremes variations of soil temperature near the surface of bare soils and quick changes of soil water content due to irregular rainfall and high evaporative demand are typical of Mediterranean climate. These characteristics lead generally to poor crop establishment (Abreu, 1987).

Leaf area is responsible for total interception of solar radiation during the early development of any crop. The accumulation of dry matter is the ultimate measure of the plant performance. During establishment, seedlings require high rates of leaf area expansion, root development and dry matter accumulation to become quickly independent of the limited seed reserves.

The aim of this study was to evaluate the influence of the temperature and soil moisture on the leaf area expansion and the accumulation of dry matter during the establishment of sorghum (*Sorghum vulgare* L.) and broad bean (*Vicia faba* L.), in a Luvisol and a Vertisol.

2. MATERIALS AND METHODS

The field experiments were located in Monte dos Álamos, Évora (lat.: 38º30'N; long.: 7º45'W) and in Tapada da Ajuda, Lisboa (lat.: 38º42'N; long. 9º11'W). The soils were a Luvisol (Évora) and a Vertisol (Lisboa). The former is loam-sand textured, with a bulk density of 1.48 in the upper layer (0 - 20 cm depth); the Vertisol is loam-clay textured, with a bulk density of 1.22 in its upper layer (0 - 15 cm depth). The soil water content at 1.5 MPa was 0.10 $cm^3\ cm^{-3}$ in the upper layer of Luvisol and 0.26 $cm^3\ cm^{-3}$ in the Vertisol; the water content at 30 kPa was 0.23 $cm^3\ cm^{-3}$ in the Luvisol and 0.42 $cm^3\ cm^{-3}$ in the Vertisol.

In both soils, temperature was measured with copper-constantan (Type T) thermocouples at 2 and 4 cm depth. Air temperature was measured with a ventilated psychrometer. A CR 10 data logger (C*ampbell Scientific, Inc*.) was used for data acquisition and logging. Average air and soil temperatures were recorded hourly and daily. Soil water contents were measured every 2-3 days by the gravimetric method down to 10 cm depth.

Seeds of broad bean and sorghum were supplied by the University of Évora. Seeds were sown 2-3 cm depth. Twenty seeds of sorghum per square meter were sown in rows 40 cm apart; eighty seeds of broad bean per square meter were sown in rows 20 cm apart. In each experiment, 4 m^2 of broad beans and 10 m^2 of sorghum were used. Several experiments were performed along the year to obtain different mean temperatures and soil water contents in both soils.

The length and width of each fully unfolded leaf (or leaflet) were measured every 3 days on ten different seedlings. Leaf area was calculated using regression equations incorporating the product of length and maximum width (Andrade, 2001). The above ground material of five seedlings of both crops were collected randomly every six days, oven-dried at 65ºC to constant weight and weighted with an electronic precision balance. Establishment was considered successful, and the experiments were ended, when half of the seedlings presented five fully unfolded leaves.

The concept of a constant thermal time (Monteith, 1977; Mohamed *et al*., 1988) was used to analyse leaf area expansion and the accumulation of dry matter along the establishment of both crops. On each soil, temperature at 2 cm depth was accumulated above the base estimated for leaf production of each crop (Andrade, 2001); for broad bean only, air temperature was used for accumulation after emergence. Temperature was accumulated from sowing.

3. RESULTS

Leaf growth

Fig. 1 shows the time course of leaf area per plant of broad bean and sorghum for various mean temperatures computed from sowing. Leaf growth during the establishment of both crops was approximately linear (Fig. 1). For mean temperatures ranging from 10-11ºC to about 17ºC, no significant differences were found between time course of the leaf area of broad bean for soil water contents ranged from about 60% of soil Available Capacity (A.C.) to soil Field Capacity (F.C.). Very low soil water contents (less than 30-40% of A.C.), usually associated to high temperatures, limited or even interrupted leaf expansion of sorghum in both soils. Leaf growth of sorghum was also retarded when seedlings were submitted to low temperatures (hourly temperatures lower than T_{base}). Over a range of non-limiting soil water contents, the greatest leaf areas at establishment (fifth leaf stage) of broad bean and sorghum were measured in the Vertisol: leaf area per seedling at establishment of broad bean was ranged from 74.1±15.01cm^2 to 109.2±25.71 cm^2 in the Luvisol and from 87.8±22.03 cm^2 to 150.2±38.84 cm^2 in the Vertisol; at favourable soil temperatures (from about 19ºC to about 26ºC) and moisture conditions, leaf area per seedling at establishment of sorghum was ranged from 13.8±6.74 cm^2 to 17.0±15.37 cm^2 in the Luvisol and from 13.4±4.24 cm^2 to 28.5±9.25 cm^2 in the Vertisol.

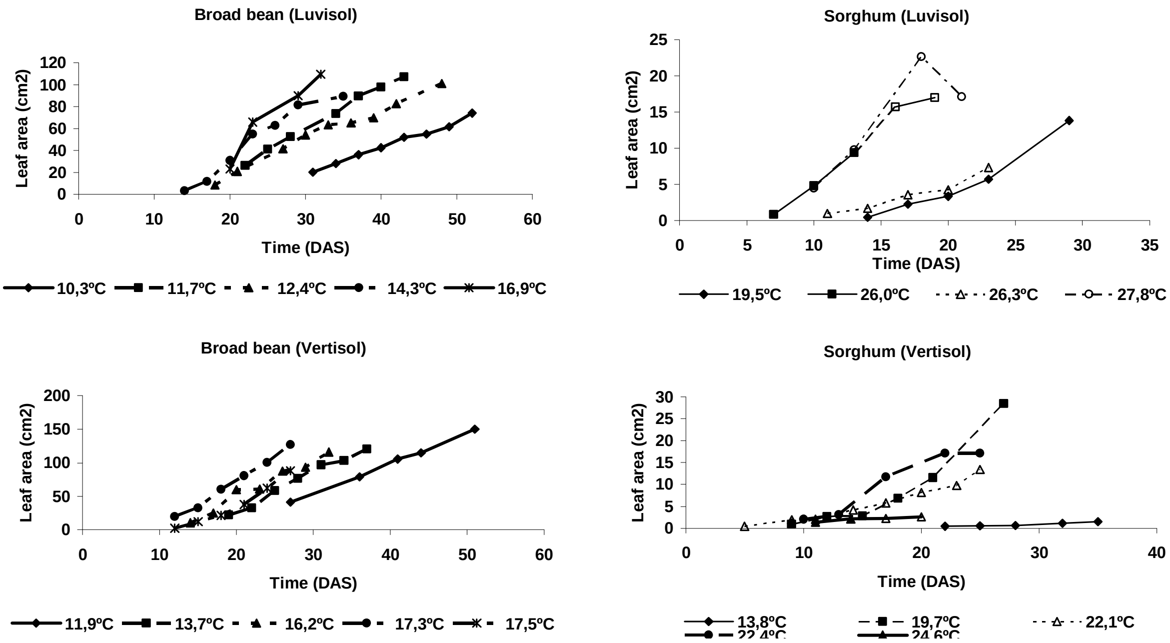

Fig. 1 - Time course of leaf area development of seedlings of broad bean and sorghum grown in the Luvisol and the Vertisol, for different experiments (each of them is identified by their mean temperatures). Note: values affected by soil water contents lower than 50% of A.C. are represented by no coloured markers.

At favourable soil moisture and soil/air temperature conditions, leaf area of both crops increased linearly (*P<0.05) with the accumulated temperature (Fig. 2). This allows us to define "thermal rates of leaf expansion" (cm^2/ºCd) as the slope of this linear relationship and the "thermal time required to the start of leaf expansion" (ºCd) as the interception on the X-axis. Leaf expansion of broad bean (Fig. 2a) in the Vertisol (*P<0.05) was faster than in the Luvisol (thermal rates of foliar expansion were, respectively, 0.47 cm^2/ºCd and 0.33 cm^2/ºCd). On the other hand, leaf expansion of sorghum (Fig. 2b) in the Luvisol was faster (*P<0.05) than in the Vertisol (thermal rates of foliar expansion were, respectively, 0.10 cm^2/ºCd and 0.09 cm^2/ºCd). Thermal time required to start of leaf expansion was greater in the broad bean (about 190ºCd) than for the sorghum (about 80ºCd) and for each crop it was not affected (*P<0.05) by the type of soil.

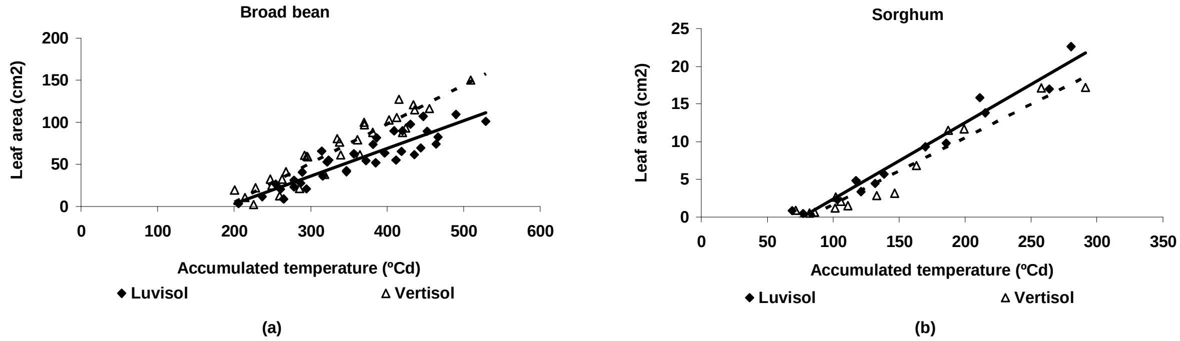

Fig. 2 – Leaf area and accumulated temperature for seedlings grown in the Luvisol and the Vertisol at favourable soil moisture conditions: (a) broad bean; (b) sorghum

Accumulation of dry matter

At soil water contents higher than 30% of A.C. (moist conditions) and for mean soil temperature higher than 15ºC, the accumulation of dry matter during the establishment of sorghum increased exponentially (*P<0.05) with the accumulated temperature in both soils (Fig. 3a). Whenever soil water contents ranged from 50% of available capacity to field capacity (moist conditions), the accumulation of dry matter during the establishment of broad bean over the accumulated temperature (Fig. 3b) can also be described by a exponential curve (*P<0.05). The accumulation of dry matter of broad bean in the Vertisol was significantly faster (*P<0.05) than in the Luvisol; no significant differences were found on seedling dry matter of sorghum (*P<0.05) in both soils. Very low soil water contents during the establishment of sorghum (dry conditions) reduced dry matter accumulation, mainly if occurred before the emergence. Soil moisture higher than F.C. (wet soil) seems to affect the rate of dry matter accumulation of the broad bean (Fig. 3b).

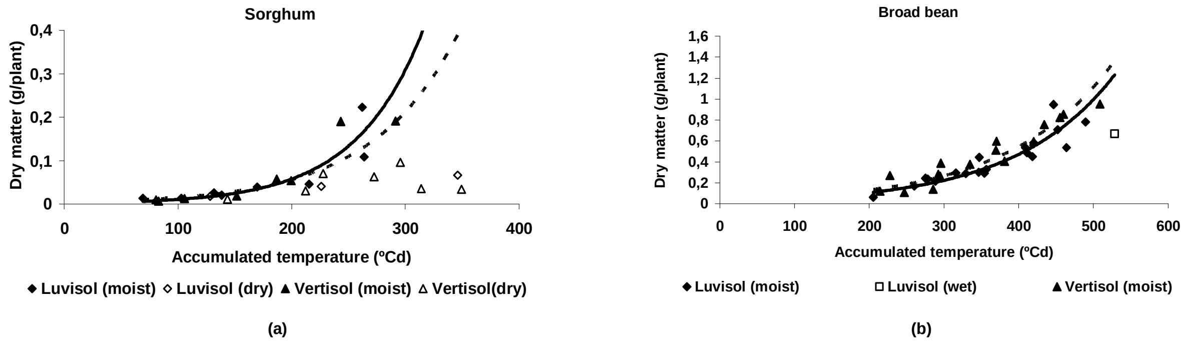

Fig. 3 – Dry mass and accumulated temperature for seedlings grown in the Luvisol and the vertisol: (a) sorghum; (b) broad bean

At favourable soil thermal and moisture conditions, dry matter at fifth leaf stage of sorghum ranged from 0.11±0.122g to 0.223±0.231g. Dry matter at establishment of broad bean ranged from 0.53±0.146g to 0.95±0.236g in the Luvisol and from 0.59±0,237g to 0.95±0,262g in the Vertisol. The highest soil water content (above F.C.) did not influence apparently the final performance of dry matter accumulation of broad bean.

4. DISCUSSION

The results are an example of the usefulness of thermal time concept for the analysis of plant responses to a relatively wide range of temperature. Over a range of non-limiting soil water contents, it was possible to define a constant “thermal rate of leaf expansion” for both crops.

Although the negatives effects of soil water deficiency are visible on leaf growth of the sorghum, the smallest leaf growths do not correspond always to lowest soil water contents. Probably, time courses of seedlings in chronic soil moisture stress are different from those of seedlings that are subject to a transitory of stress (Larcher, 1977).

The results show that different rates of leaf expansion of broad bean and sorghum and different rates of dry matter accumulation of broad bean were found in the two types of soil. Taking into account the results found in Andrade (2001) we must note that the differences for the emergence were more expressive than those found for leaf growth or dry matter accumulation and that the influence of the soil on the establishment may vary according to the stage of development (e.g., Vertisol was more favourable for the emergence of sorghum, but the Luvisol guaranteed better conditions in the subsequent stages). In addition to the influence of soil thermal regime or soil moisture variations we must consider important factors as the contact seed-soil at the germination (Bewley and Black, 1994), the mechanical resistance at the elongation of seedling up to soil surface (Bresson, 1995) or the photosynthetic rates after emergence (Abreu, 1987).

In mediterranean type climates meteorological extremes of low rainfall associated to high temperatures are expected to be more frequent on the wake of global climate change, reducing crop establishment and productivity. This trend claim a more rigorous knowledge of suitable ranges of soil water contents and soil temperatures for each stage of development, pre- or pos-emergence. For example, eventual changes of sowing-time can be performing with more accuracy or crop selection can be more sensible.

5. CONCLUSIONS

In moist soils, leaf area of both species increased linearly with accumulated temperature and dry matter increased exponentially with accumulated temperature. Low soil water during establishment reduced leaf expansion and dry matter accumulation of both crops, mainly if it occurred before seedling emergence. The type of the soil influences significantly the thermal rates of foliar expansion of both species and dry matter accumulation of broad bean. The knowledge of soil moisture and soil thermal requirements as well as the type of the soil may modify agronomic issues as crop selection and sowing-time.

REFERENCES

Abreu, F.G.. 1987. *Influence of atmospheric saturation deficit on early growth of groundnut.* Ph. D. Thesis. Nottingham University

Andrade, J.. 2001: Temperatura do solo (e análise de Fourier), humidade do solo e desenvolvimento inicial de várias culturas em solos Pmg e Cb. (Ph. D. Thesis). Universidade de Évora, Évora.

Bewley, J.D. & Black, M.. 1994. *Seeds. Physiology of development and germination*. 2ed. Plenum Press. New York and London

Bresson, L.M.. 1995. A review of physical management for crusting control in Australian cropping systems research opportunities. *Austr..J.Soil Res*., 33:195-209

Larcher, W.. 1977. Ecofisiologia vegetal*, Omega. Barcelona*

Mohamed, H. A., Clark, J. L. & Ong, C. K.. 1988: Genotypic differences in the temperature responses of tropical crops. II. Seedling emergence and leaf growth of groundnut (*Arachis hypogea L.*) and pearl millet (*Pennisetum typhoides S. & H*). Journal of Experimental Botany, 39: 1129-1135.

Monteith, J.L. 1977: Climate. *In Alvim, P.T. & Kozlowsky, T.T. (eds) Ecophysiology of tropical crops*, pp. 1-25. Academic Press, New York, USA