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The effect of sowing date and late season drought on growth and development of bambara groundnut (Vigna subterranea (L.) Verdc) landraces under field conditions in Botswana

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Abstract A field experiment was conducted to investigate the effect of sowing date and late season drought on the growth and development of bambara groundnut (*Vigna subterranea* (L.) Verdc). The experiment was conducted at the Botswana College of Agriculture, Gaborone, Botswana. Two landraces were grown under three sowing dates and two water regimes; rain fed and irrigation. The two landraces were Dip C (from hot, dry environment/ Botswana) and Uniswa Red (from cool, wet environment/ Swaziland). For the rainfed treatment, irrigation was terminated approximately at pod filling (63 DAS). There was a reduction in development, growth and yield. The effect of sowing date on leaf number was significant. The four treatments mean of leaf number of leaves declined from 62 per plant in the first sowing date (D1) to 52 leaves per plant in the second sowing date (D2) and 46 leaves per plant in the third sowing date (D3). The effect of sowing date on pod number was significant ($P< 0.05$) with pod number reaching 20 pods per plant in D1and only 2 pods per plant in D3.The landraces varied in their response to temperature and drought stress with respect to growth and development. The landraces used different mechanisms to resist drought and temperature stress, that include reduction in leaf number and dry matter and avoidance through faster growth rate.
Keywords: Bambara groundnut, drought, heat, legume, yield.

تأثير موسم الزرع والجفاف على نمو وتطور نبات البمبارا في بوتسوانا

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الملخص أجريت تجربة لدراسة تأثير وقت الزرع والجفاف على نمو وتطور نبات البامبارا (Vigna subterranea (L.) Verdc) . أجريت التجربة في كلية بوتسوانا للزراعة، غابروني، بوتسوانا. تم تنمية صنفين من البامبارا بثلاث تواريخ مختلفة ونظامي ري مختلفين، نطام ري بالمطر ونظام ري يدوي. الصنفين كانا ديبسي ،من بيئة حارة وجافة (بوتسوانا) و يونيسوا ريد، من بيئة باردة ورطبة (سوازيلاند). تم ايقاف الري في معاملة الري اليدوي بعد 63 يوم من الزرع. حدث انخفاض في النمو والتطور والانتاج. كان تأثير تاريخ الزرع معنوياً على عدد الأوراق، متوسط عدد الاوراق للأربع معاملات انحدر من 62 ورقة للنبات في تاريخ الزرع الاول إلى 52 ورق للنبات في تاريخ الزرع الثاني ثم 46 في تاريخ الزرع الثالث. تأثير موسم الزرع كان معنويا على عدد القرنات (البذور مع الغلاف) حيث وصل إلى 20 قرنة للنبات في أول تاريخ للزرع وانخفض إلى قرنتين للنبات في ثالث تاريخ للزرع. اختلف الصنفان في استجابتهما للظروف المناخية مع تغير وقت الزرع وكذلك الجفاف. ظهر هذا الاختلاف في تقليل عدد الأوراق والمادة الجافة واختلاف دورة الحياة بين الصنفين.

كلمات المفتاحية: البمبارا الفول السوداني ، الجفاف ، الحرارة ، البقول ، المحصول.

Introduction

Crop improvement targets include increased yield, disease and drought resistance and improved quality. To achieve the main objective of yield increase and stability, crop improvement should be applied in areas which suffer from food shortage, like Africa and some places in Asia, where certain crops have the ability to stand the harsh conditions like drought and heat. In these conditions concentrating on a crop that can be drought and heat tolerant, and at the same time has a high nutritional value has been very important. Although over 10000 plant species have been cultivated over time, globally, 90% of the world food needs is provided by 15 plant species and eight animal species [1]. This makes it necessary to expand the number of food plants which are cultivated by small holder farmers in the marginal areas, and to investigate the possibility whether it is manageable to elevate the breeding status similar to ones which have been used as main sources of food [1]. Bambara groundnut is well-known in sub-Saharan Africa, but is little known or sometimes unknown in other parts of the world. The crop belongs to the family leguminosae. The crop is bunch type, leaves are trifoliate. Pods are on the soil surface or immediately under the surface. A pod contains 1-2 seeds, but most landraces have a single-seeded pod. The crop is known to be pest resistant; it buries its pods in the soil, which makes them safe from damage by flying insects that usually destroy pulses like cowpeas and beans [2]. Bambara groundnut is essentially grown for human consumption, the seed considered as a complete food because of the high nutritional value [3]. One of the most important characteristics of bambara groundnut is its ability to produce some yield in soils which are too poor for cultivation of other, more favoured, species such as groundnut [3]. Growth and development of bambara groundnut varies according to landraces and environmental conditions. In a field study in Ivory Coast, bambara groundnut produced 4.8 t ha^{-1} [4]. Because this crop grows in semi-arid areas and gives higher yield under drought compared to the other species, it is very important to conduct trials using this crop in semi-arid zones along with studies in the controlled environments. Soil moisture deficit has a huge effect on total dry matter (TDM) production in bambara groundnut. Mwale et al. [5] reported a reduction of 50% in accumulated total dry matter under drought. Collinson et al. [6] reported that TDM ranged from 2.5 to 9.3 t h $^{-1}$ under droughted and irrigated treatments respectively. Pod number per plant was reduced by 43% due to drought while the harvest index (HI) was not affected by drought [5] . Shamudzarira [7] reported a pod yield of 450 g m^{-2} under irrigation and a yield of 25 g m^{-2} in bambara groundnut droughted from establishment. The overall objective of this study was to investigate the effects of drought and temperature stress on the growth and development of three landraces of bambara groundnut. The study was designed to investigate the differences in the drought and heat tolerance and partitioning efficiency of bambara groundnut landraces. This study was part of the experiments run by the BAMLINK project at its partner location in Botswana. The measurements were conducted at Notwane Farm, Botswana College of Agriculture, Gaborone, Botswana

Field site, experiment preparation and sowing: The field experiment (2007-2008) was designed to examine two landraces with two water regimes; rainfed and irrigated, and 3 dates of sowing; December 21, January 18, and February 18. The experiment was designed as split-split plot (sowing dates as the main plot, water treatment on the sub-plots, and landraces on the sub-sub plots). Plots were hand-planted**,** and, except for the December 21 sowing in which two seeds were planted per station, in all other sowing dates, seeds were sown at double spacing (10cm) along the row and all plots were thinned to 1 plant per station at 25 DAS. The soil was dug over and leveled to make a fine seedbed . The gross sub-sub plot size was 4 x 3.5 m that gave 320 plants per sub-subplot. At 25 DAS the plants were thinned to 20 plants in each row to give a plant population of 160 plants in each subplot with an equivalent plant density of 11 plant m^{-2}. Adjacent sub-sub plots were spaced 1m apart, in addition to two border rows of plants to minimize lateral infiltration of water from irrigated plots to moisture stressed plots. At planting, all plots were fertilized with a basal application of single super phosphate at the rate of 25 kg P ha^{-1}. For the first date of sowing only, two Neutron probe access tubes were installed in each sub-subplot, one between rows and one within the row. All plots were irrigated using trickle tape. The irrigation for the rainfed treatment was terminated at 63 DAS.

Plant materials: Two landraces were examined, Uniswa Red and Dip C. The seeds used in this experiment were collected from previous field experiments in Botswana.

Irrigation: All plots were irrigated from first day of sowing to 90% of field capacity using a trickle irrigation system which was terminated from the rainfed treatment at 63 DAS

Measurements

Soil moisture content: Soil moisture content in the soil profile was monitored using Neutron Probe (CPN, Model 503). Measurements were taken weekly starting from 40 DAS. The Neutron probe measured the soil moisture at 0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm. The sum of readings represents the total amount of water in each location. Each sub-subplot had two access tubes; the average of readings represents the mean amount of water in each subplot.

Before starting the measurements, the probe was calibrated for the experimental site at the same soil type.

Growth analysis: Sequential growth analysis at 25, 45, 60, 89, 105, 112, 120 DAS was carried out on 5 adjacent plants per sub-subplot, which were taken from one row. Every growth analysis was carried out on a different row. No plants were collected from the two end rows in each subplot to avoid edge effects, nor the central area where final harvest was taking place. Leaves and pods were counted at each growth analysis. Leaf, stem and pod dry weight was obtained after oven-drying at 80^{o}C for 48h. For the yield measurement, the plants from the two central rows were collected (3.4m^{2}) and the number of plants was recorded, pods were air-dried on a greenhouse floor for at least one week and weighed.

Climatic factors: Air temperature, and rainfall were recorded hourly by an automatic weather station installed at the experimental site.

Data Analysis: All the results were analysed statistically using the software package Genstat 12th edition (Lawes Agriculture Trust, Rothamsted Experimental Station, UK) by analysis of variance, the difference was considered significant when probability was equal or less than 0.05.

Results

Temperature and rainfall: In D1, maximum temperature ranged between 22^{o}C and 36^{o}C and the minimum between 9^{o}C and 21 ^{o}C. The daily mean ranged between 14 ^{o}C and 26^{o}C. The maximum temperature ranged between 14^{o}C and 33^{o}C, and the minimum between 3^{o}C and 20^{o}C during D2. The daily mean ranged between 14^{o}C and 25^{o}C. For D3, the maximum temperature ranged between 14 and 33^{o}C, and the minimum between 2 and 20^{o}C , and the daily mean between 15^{o}C and 26^{o}C. The total amount of rain was 410, 326 and 247 mm, for D1, D2 and D3, respectively**.**

Soil moisture: Soil moisture was measured for D1 only. Figure 1 shows the trend of total soil moisture in each treatment. There was no clear trend in the soil moisture content. The highest soil moisture content was in Dip C plot (269 mm) at 90 DAS in the rain fed treatment following 89 mm rainfall on 86 DAS, and the lowest was 129 mm in Uniswa Red soil, irrigation treatment at 81 DAS. There was a fluctuation in the moisture content, but the difference between the treatments was very small.

Growth and development

Leaf appearance: Figure 2 shows the number of leaves of Uniswa Red and Dip C plotted against days after sowing for three dates of sowing. At D1 and D2, Dip C gave high number of leaves in both irrigated and rain fed treatment, but it produced fewer leaves in the rain fed treatment at D3. The two landraces showed a decrease in leaf number with delay in sowing.

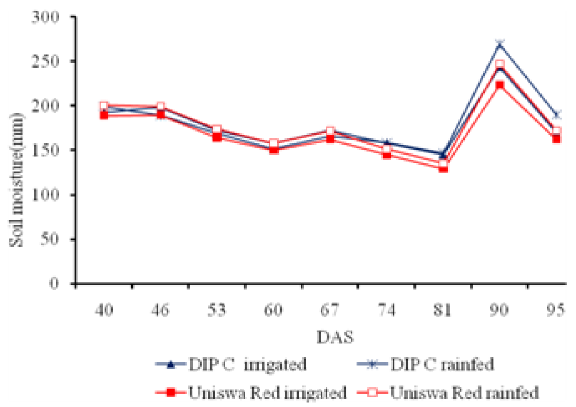

Figure 1 Changes in the mean soil moisture content (mm) per treatment throughout the soil profile with time during the experiment of two bambara groundnut landraces (Dip C and Uniswa Red) grown in Notwane Farm, Botswana College of Agriculture. 2007-2008 (First date of sowing).

Pod number: The pod number produced by Dip C and Uniswa Red throughout the three dates of sowing is presented in Figure 3. The effect of sowing date was significant (P< 0.05) with pod number reaching 20 pods per plant in D1and only 2 pods per plant in D3.

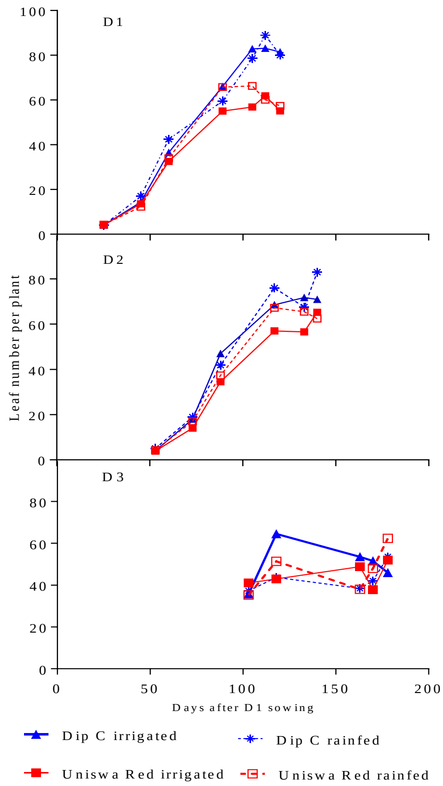

Figure 2 The effect of soil moisture and sowing date on the leaf number of two bambara groundnut landraces (Dip C and Uniswa Red) grown at three dates of sowing in Notwane Farm, Botswana College of Agriculture. 2007-2008.

Total dry matter: Total dry matter (TDM) accumulation for each landrace and each treatment is shown in Figure 4.

The statistical analysis showed no significant interaction effect of the landrace, sowing date and temperature (P>0.05). TDM accumulated in D1, was significantly higher than TDM accumulated in D3. In D1, the amount of accumulated TDM started to decline from 105 DAS.

Pod dry matter: Figure 5 shows the pod dry matter (PDM) accumulation throughout three sowing dates in Dip C and Uniswa Red. The accumulated pod dry matter in the D**2** was higher than the accumulated PDM in D1 and D**3** (P<0.001).

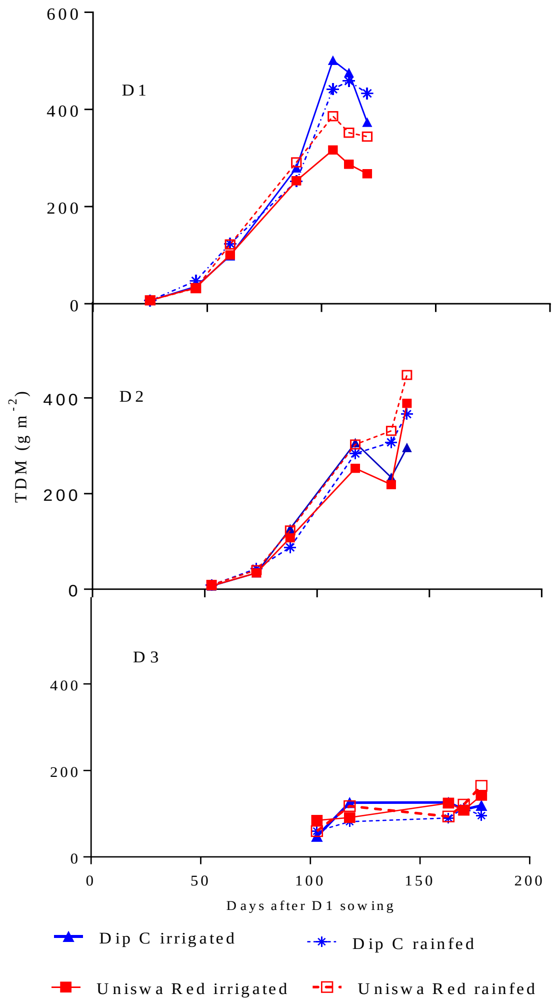

Figure 4 The effect of soil moisture and sowing date on the total dry matter production of two bambara groundnut landraces (Dip C and Uniswa Red) grown at three dates of sowing in Notwane Farm, Botswana College of Agriculture. 2007-2008.

Yield and yield component: Table 1 shows yield, TDM, and harvest index (HI) of the three dates of sowing. The highest yield (97.6 g m^{-2}) was produced by Uniswa Red in D1, and the lowest was given by Dip C in the rainfed treatment sown on D3. The yield differed significantly between the landraces and the sowing date (P<0.05).

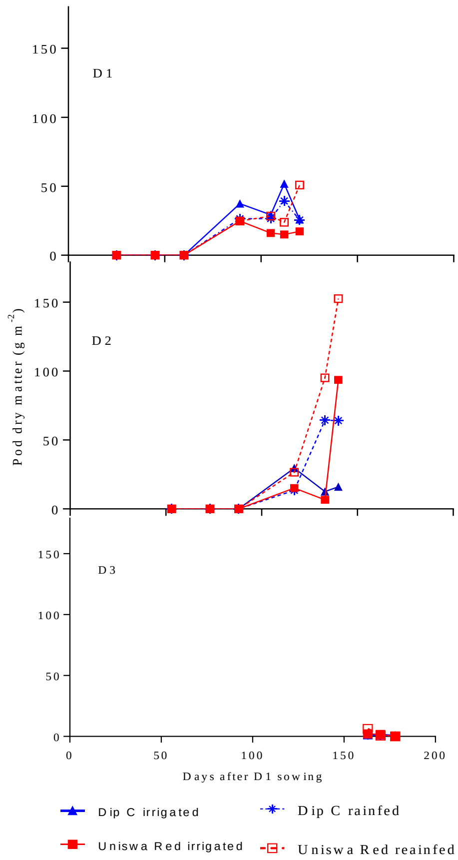

Figure 5 The effect of soil moisture and sowing date on the pod dry matter production of two bambara groundnut landraces (Dip C and Uniswa Red) grown at three dates of sowing in Notwane Farm, Botswana College of Agriculture. 2007-2008.

Table 1 Yield components and yield (gm^{-2}) (from final harvest) among two landraces of bambara groundnut (Dip C and Uniswa Red) grown in Notwane Farm, Botswana College of Agriculture at three dates of sowing; the first date (D1), the second date (D2) and the third date (D3) under two water regimes; irrigation (irr) and rainfed (rf) during the experiment of 2007-2008.

	Treatment	Seed yield gm^{-2}	HI	TDM gm^{-2}	Pod yield gm^{-2}
D1	Dip C irr	83.3	0.32	373.7	119.3
	Dip C rf	53.5	0.17	433.2	74.5
	UNI irr	94.9	0.5	267.9	134.9
	UNI rf	97.6	0.37	344.3	128.6
D2	Dip C irr	13.8	0.06	296.4	19.8
	Dip C rf	59.8	0.25	366.1	93.8
	UNI irr	18.4	0.07	388.5	26.4
	UNI rf	95.1	0.4	331.3	129.1
D3	Dip C irr	1.3	0.03	119.2	3.3
	Dip C rf	2.5	0.04	95.3	4
	UNI irr	3.6	0.04	142.2	5.6
	UNI rf	5.9	0.07	164.6	11.9

ns for not significant, * for P≤ 0.05, ** for P≤0.01 and *** for P≤0.001

Discussion: The experiment was set to impose drought expecting that the amount of rain would be sufficiently small to expose crops to water stress, but the amount of rain during the experiment was higher than expected (sum of 456 mm from December to May in 2008). Opposite to rainfall, the temperature between December and March was as high as expected and the effect of temperature was clear from the high vegetative production at the first sowing date (D1), and it was as cold as expected by the end of the season in the third sowing date (D3) when the temperature went down to 9°C. The unusual amount of rainfall during the growing season did not give a chance for the interaction effect between temperature and water stress, and the only effect existed was the temperature stress. Although the soil moisture content was not measured for the rest of sowing dates, because of high rainfall, it can be assumed that soil moisture was not a limiting factor. Sowing date had a significant effect on leaf number. The leaf number decreased from maximum of 88 at D1 to maximum of 64 at D3. In a study by Linneman [8] on the effect of photoperiod on three bambara groundnut landraces collected from Nigeria, she found that the rate of leaf appearance was similar for all the daylength regimes up to 52 DAS when all treatments had started to flower. From then on, the rate of leaf appearance decreased under 10 h d^{-1} photoperiod while the other treatments continued to produce one leaf per day, and plants at photoperiods 12, 12.5, 13 and 14 h d^{-1} reduced leaf production from 80-100 DAS while plants at 16 h photoperiod maintained producing one leaf per day until 129 DAS. Photoperiod in the present study might also play a role in reducing the leaf number where it decreased from 14.5 h d^{-1} in D1 to 10.5 hd^{-1} in D3. The effect of sowing date on leaf number was significant in both field experiments. The number of leaves declined from maximum of 84 per plant in D1 to 71 leaves per plant in D2 and 60 leaves per plant in D3. The effect of sowing date on leaf area of mungbean was reported by author in [9] who reported a decline in leaf area from 1465 cm^{-2} in D1 (third week of June) to 1141 cm^{-2} in D3 (third week of July). Mwale et al. [5] reported that TDM of bambara groundnut of 650 g m^{-2} at optimum temperature and non-limiting soil moisture and Shamudzarira [7] reported values of 850 g m^{-2} for Dip C under non-limiting soil moisture. These values are higher than the values obtained in this study (598 g m^{-2}). However, the values obtained in the present study are higher than the values reported from a field study in Tanzania [10]. Exposing plants to cold temperature stress during reproductive stages causes a reduction in the metabolic rates leading to low yields. Functional abnormalities in reproductive organs might be caused by cold stress, leading to failure of fertilization or causing premature abortion of seeds [11]. The effect of cold stress was clear in D3 through the reduction in dry matter and pod production. The results of the present study are consistent with the findings of [12] which reported in a study on six sowing dates of bambara groundnut in Swaziland a decline in yield dry matter of 75 % between the first sowing date (the hottest) and the last sowing date (the coldest) [12]. The yield of the first sowing date was 157% more than the yield produced under the third sowing date. In the present study, D3 produced 50% of D1 yield. The highest grain yield reported in [13] of faba bean was 136.9 g m^{-2} which is higher than the highest yield of 119 g m^{-2} obtained in the present field study. Dip C and Uniswa Red behaved similarly in response of HI to sowing date. Delay in sowing reduced the growth, development, yield and harvest index in bambara groundnut. Throughout the three dates of sowing, Uniswa Red had higher yield and HI than Dip C.

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