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Biomass production and accumulation of nutrients in shoots of Giant Guinea sorghum plants[1]

Produção de fitomassa e acúmulo de nutrientes na parte aérea do sorgo de Guiné gigante

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Abstract - Choosing species with high phytomass production to be cropped in no tillage system is extremely important in dry winter regions. The purpose of this research was to study plant biomass production and accumulation of nutrients in shoots of Giant Guinea sorghum plants (*Sorghum bicolor* subspecies *bicolor* race Guinea) sown in different sowing dates. A randomized complete block design with six treatments and four replications was performed. Treatments consisted of six sowing dates (09/25/2000; 10/25/2000; 11/24/2000; 12/22/2000; 02/22/2001 and 04/03/2001). At flowering, dry matter production, number and diameter of stems and plant height were evaluated. Macro and micronutrient levels and accumulation were determined as well as C/N ratio. Plant cycle decreased as sowing date was delayed and, consequently, dry matter production and C/N ratio decreased as well. The opposite was observed for nutrient contents. "Giant Guinea" sorghum is sensitive to photoperiod thus late sowing reduces plant development, which leads to low biomass production and nutrient accumulation. "Giant Guinea" sorghum cultivated as cover crop is a good option when implementing no tillage system due to high dry matter production and N, P, and K recycling.

Key words - *Sorghum bicolor*. Sowing date. Cover crop. No tillage.

Resumo - A escolha de espécies com elevada produção de fitomassa para utilização como plantas de cobertura no sistema de semeadura direta é extremamente importante em regiões de inverno seco. O objetivo deste trabalho foi avaliar a produção de fitomassa e acúmulo de nutrientes na parte aérea das plantas de sorgo Guiné gigante (*Sorghum bicolor* subespécie *bicolor* raça guinea), semeados em diferentes épocas de semeadura. Foi utilizado um delineamento em blocos ao acaso, com seis tratamentos e quatro repetições. Os tratamentos foram constituídos por seis épocas de semeadura (25/09/2000; 25/10/2000; 24/11/2000; 22/12/2000; 22/02/2001 e 03/04/2001). Por ocasião do florescimento das plantas, avaliou-se a produção de matéria seca, o número e diâmetro de colmos e a altura das plantas. Também foi determinado o teor e acúmulo de macro e micronutrientes, além da relação C/N. O ciclo das plantas diminuiu com o atraso da época de semeadura, e, conseqüentemente, a produção de matéria seca e a relação C/N também foram menores. Comportamento contrário foi observado para o teor de nutrientes. O sorgo de Guiné gigante é sensível ao fotoperíodo e, portanto, semeaduras mais tardias ocasionam diminuição do crescimento das plantas, produção de biomassa e acúmulo de nutrientes. Esta espécie consiste em uma boa opção para cultivo como planta de cobertura no sistema de semeadura direta devido a alta produção de fitomassa e ciclagem de N, P e K.

Palavras-chave - *Sorghum bicolor*. Época de semeadura. Planta de cobertura. Plantio direto.

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Introduction

Cover crop species are usually aggressive and rugged because of their deep and branched root system, which are efficient to extract nutrients from deeper soil layers. Afterwards, plant decomposition releases nutrients to soil superficial layers, subsequently becoming available to succeeding crops (AMABILE et al., 2000; CRUSCIOL et al., 2005; GARCIA et al., 2008; PAVINATO; ROSOLEM, 2008).

Under no tillage system, cover crop residues that remain on soil surface may enhance water infiltration, decrease water losses through evaporation, maintain soil humidity and temperature stability, improve weed control and increase nutrient cycling effectiveness (ROSOLEM et al., 2007). Plant residues may also improve biological activity, both improving nutrient availability and maintaining/increasing the organic matter contents in soil. Soil coverage can also improve soil physical conditions (CALONEGO; ROSOLEM, 2008).

Positive effects of maintaining crop residues on soil surface are observed in time, depending on the species, decomposition rate, quantity, contact with soil, chemical composition and, especially, C/N ratio (ROSOLEM et al., 2004).

Whenever cover crops, especially grasses, are well integrated in rotation systems, they may show great potential for phytomass production and increased C/N ratio, thus ensuring soil protection for a long period of time. Therefore, characterizing species with high phytomass production for soil coverage purposes may improve establishment of no tillage system (OLIVEIRA et al., 2002).

No tillage sustainability is enhanced under crop rotation systems because of soil coverage. Alvarenga et al. (2001) reported that 6 t ha^{-1} of dry matter is considered appropriate. Consequently, an attempt was made to characterize viable species to be cropped under no tillage. To that effect, it is important for crops to be capable of extracting nutrients from soil efficiently and show slow decomposition rate, especially in tropical regions.

Sorghum is an excellent alternative for cultivation as cover crop whenever establishing no tillage system in warm and dry winter regions. This crop is resistant to drought conditions, efficiently exploiting deeper soil layers to search for available water and produces great amounts of dry phytomass (MAGALHÃES et al., 2000; MAGALHÃES et al., 2006; QUEIROZ FILHO et al., 2000). Red pool Guinea sorghum (*Sorghum bicolor* subespecies *bicolor* race *Guinea*), known as “Giant Guinea” sorghum, can be successfully cropped in rotation systems in dry winter regions. This species produces high dry matter production even under unfavorable climate conditions compared to other crops.

Although this species shows slow initial development, it has a vigorous root growth, even in compacted soils, and great dry matter production, at flowering stage (MAGALHÃES et al., 2000).

The aim of this work was to assess plant biomass production and accumulation of nutrients in shoots of Giant Guinea sorghum plants sown in six different sowing dates.

Material and methods

The experiment was carried out on a Rhodic Nitisol (FAO, 2006), in Botucatu, SP - Brazil, College of Agricultural Sciences, São Paulo State University (latitude: 22º51’ S; longitude: 48º26’ W; altitude: 786 m). According to the Koeppen classification, climate is Cwa with dry winter and hot wet summer (LOMBARDI NETO; DRUGOWICH, 1994). Rainfall and temperatures collected during the experiment are shown in Table 1.

Soil chemical analysis (RAIJ et al., 2001) of samples from the arable layer (0-20 cm) showed: soil pH ($CaCl_2$): 5.1; 24 g dm^{-3} of O.M.; 16 mg dm^{-3} of P_{resin}; 38 mmol$_c$ dm^{-3} of H+Al; 1.5, 31 and 17 mmol$_c$ dm^{-3} of K, Ca and Mg, respectively; CEC: 87 mmol$_c$ dm^{-3} and 56% of base saturation. Lime (ECC: 75%) was applied to raise base saturation up to the recommended to the sorghum crop (CANTARELLA et al., 1997) with subsequent plowing.

A randomized complete block design with six treatments and four replications was performed. Treatments consisted of six sowing dates (09/25/2000; 10/25/2000; 11/24/2000; 12/22/2000; 02/22/2001 and 04/03/2001). Each plot consisted of eight rows of plants with 20 m length and spaced 0.6 m. The six central rows were considered as harvest area (68.4 m^2), except 0.5 m of each extremity.

Sorghum bicolor subspecies *bicolor* race Guinea was used (HARLAN DE WET, 1972), which shows large open panicles, with extremely hard and vitreous grains.

One day before each sowing, soil surface was leveled, which also worked as mechanical weed control. Sowing was carried out with a 4-row seed drill to obtain 200,000 plants per ha. Fertilization at sowing consisted of 300 kg ha^{-1} of the 8-28-16 NPK formula.

Seeds were previously treated with Thiram (140 g of the active ingredient per 100 kg of seeds). For weed control, pre-emergent Atrazine + Simazine (1,500 g of the active ingredient per hectare) was applied right after sowing. Seedling emergence took place eight days after sowing.

Plant cycle was determined from seedling emergence until full flowering stage. The number of stems, plant height, and stem diameter were evaluated at

Table 1 - Accumulated rainfall, minimum and maximum temperature during "Giant Guinea" sorghum development for each sowing date

Sowing date	Rainfall (mm)	Minimum temperature (ºC)	Maximum temperature (ºC)
09/25/2000	1,181	18.9	28.8
10/25/2000	1,162	19.1	28.7
11/24/2000	1,011	19.4	28.8
12/22/2000	824	19.6	29.1
02/22/2001	275	18.6	27.5
04/03/2001	177	15.9	25.0

flowering. Plants were harvested in 2-m rows; then, the material was dried in an oven at 60 ºC and weighed. Data was transformed to kg ha^{-1}.

Plants were ground to evaluate nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn) and boron (B) levels according to Malavolta et al. (1997). Based on the results, the total amount absorbed was calculated by multiplying the nutrient levels by the weight of the dry material. Chemical analysis was carried out according to Tedesco et al. (1985) to evaluate organic carbon. Afterwards, C/N ratio in shoots was determined.

A regression analysis for randomized complete block design was performed on each characteristic evaluated through the application software Sisvar. The procedure for adjustment of response curve was performed using the same software. The response functions were chosen based on the higher coefficient of determination (R^2) and significance of regression parameters, by t test using a significant level of 5%.

Results and discussion

A summary of ANOVA results of plant cycle until full flowering stage, number of stems, plant height, stem diameter, dry matter, C/N ratio, C level, macronutrient and micronutrient levels, macronutrient and micronutrient accumulation affected by sowing date is showed in Table 2.

The vegetative stage of "Giant Guinea" sorghum plants decreased as sowing date was delayed (FIG. 1) considering the time required for plants to reach the beginning of the flowering stage. Magalhães et al. (2000) reported that sowing delays and low temperatures may decrease metabolic activities and thus plants may extend their cycle. Therefore, it can be inferred that this material is sensitive to photoperiodic variations, what was already found by Paul (1990) and Alagarswamy et al. (1998). Vegetative stage lasted approximately 180 days for plants sown in September. Nevertheless, sowing delayed to February shortened it to 70 days.

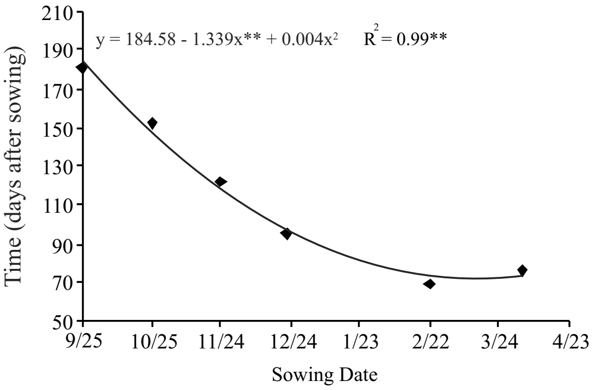

Figure 1 - Time from seedling emergence until flowering of "Giant Guinea" sorghum plants as affected by sowing date. **: significant at $p \leq 0.01$

It was observed that plants sown in September, October, November, and December of 2000 bloomed simultaneously on 03/25/2001, as a consequence of day length reduction, which was also found by Paul (1990). Shorter development period was observed for sowing in April of 2001. For this period, flowering took place 76 days after seedling emergence (DAE) and plants had already been affected by photoperiodic conditions. Also, sowing in February of 2001 decreased growth period of plants because metabolism activities were reduced by lower temperatures (TAB. 1).

The number of stems increased with sowing delay (FIG. 2A) probably because sorghum plants produced more tillers on short days and at lower temperatures (MAGALHÃES et al., 2000). Opposite behavior was found as for the number of days for plants to start the reproductive stage. Therefore, climate conditions greatly influenced plant cycle and tillering (FIG. 1 and FIG. 2A), respectively.

Table 2 - Analysis of variance of plant cycle until full flowering stage, number of stems, plant height, stem diameter, dry matter, C/N ratio, C level, macronutrient and micronutrient levels, macronutrient and micronutrient accumulation, affected by sowing date

	Plant cycle until full flowering stage	Number of stems	C level	C/N ratio	Plant height	Stem diameter	Dry matter
				F values			
Block	1.98^{ns}	0.89^{ns}	1.25^{ns}	0.93^{ns}	0.99^{ns}	1.27^{ns}	1.05^{ns}
Sowing date	25.69**	24.28**	1.18^{ns}	20.51**	287.52	13.76**	52.83**
VC%	8.78	40.96	4.55	25.60	9.11	15.37	32.48

Macronutrient levels						
	N	P	K	Ca	Mg	S
			F values			
Block	1.54^{ns}	1.47^{ns}	0.57^{ns}	0.98^{ns}	1.22^{ns}	0.42^{ns}
Sowing date	43.48**	1.92^{ns}	25.82**	6.20*	14.89**	1.77^{ns}
VC%	17.01	18.51	19.61	14.62	26.36	3.65

Micronutrient levels					
	Cu	Zn	Mn	Fe	B
		F values			
Block	0.89^{ns}	0.21^{ns}	0.33^{ns}	0.45^{ns}	0.38^{ns}
Sowing date	0.94^{ns}	15.15**	16.68**	13.91**	16.25**
VC%	24.94	19.72	13.62	25.71	43.54

Macronutrients accumulation						
	N	P	K	Ca	Mg	S
			F values			
Block	1.42^{ns}	0.67^{ns}	0.68^{ns}	0.59^{ns}	1.71^{ns}	0.83^{ns}
Sowing date	10.32**	19.30**	27.86**	21.04**	8.12*	45.67**
VC%	52.51	48.49	33.14	36.98	35.74	34.35

Micronutrients accumulation					
	Cu	Zn	Mn	Fe	B
		F values			
Block	1.24^{ns}	1.00^{ns}	1.36^{ns}	1.17^{ns}	0.91^{ns}
Sowing date	14.80**	12.41**	49.38**	7.01*	5.12*
VC%	58.89	57.63	37.93	53.60	64.14

* and ** significant at level of 5 and 1% by the F test, respectively; ns: non significant

Plant height linearly decreased with sowing delay (FIG. 2B). Plants sown in September of 2000 were 402 cm high, while plants sown in April of 2001 were 143 cm high, consisting of a reduction by 64%. Similar behavior was verified for stem diameter (FIG. 2C). Reduction of up to 85% in diameter was observed comparing the sowing dates of September of 2000 and April of 2001.

Plant height and stem diameter decreased mainly due to sorghum significant response to photoperiod. Sowing delays may cause crop growth to decrease because plants reach each development stage earlier. Thus, dry matter production decreased linearly as sowing was delayed (FIG. 2D). Nevertheless, high dry matter production was observed for all sowing dates, even in periods of low rainfall and temperature (TAB. 1). For this reason, 'Giant Guinea' sorghum is a good crop to produce phytomass in dry winter regions. Whenever sorghum is cropped in a rotation system in fallow areas, this species could provide good soil coverage and, consequently, maintain or increase soil fertility and yield of the next crop such as bean, peanut and soybean.

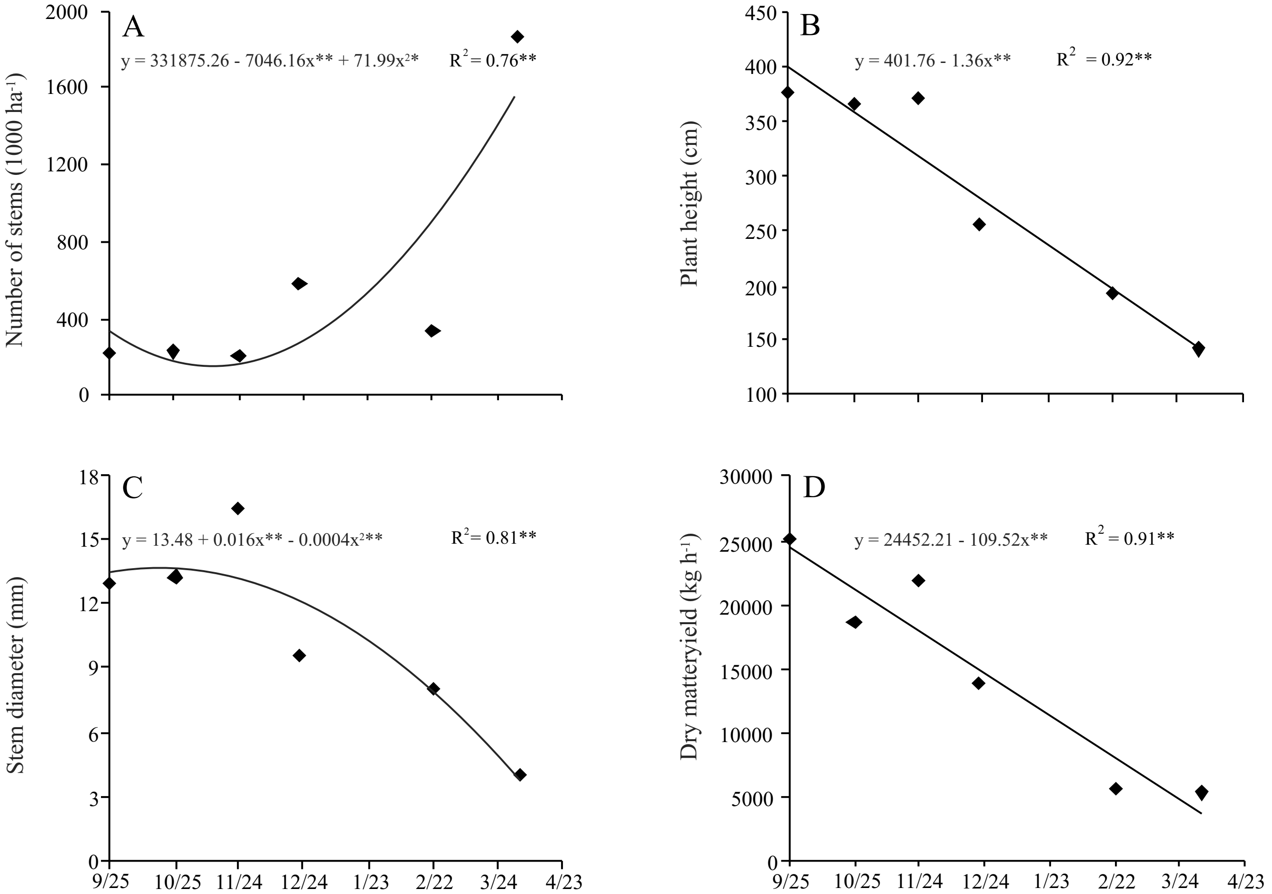

Figure 2 - Number of stems (A), plant height (B), stem diameter (C) and dry matter yield (D) of "Giant Guinea" sorghum plants as affected by sowing date. **: significant at $p \leq 0.01$

Nutritional status of soghum was greatly affected by sowing time (FIG. 3). In general, nutrient levels increased with sowing delay, except for P and S, whose concentrations were practically constant during all periods of study (FIG. 3B and 3F) respectively. Phosphorus concentrations in all periods were lower than those found by Oliveira et al. (2002), who reported P levels of 1.74 g kg^{-1} in sorghum plants 100 days after sowing. The sulfur content values were not fitted to the polynomial function, although greater throughout all sowing stages than the results obtained by Oliveira et al. (2002).

Increases in the levels of nitrogen, potassium, calcium, and magnesium were also verified as sowing was delayed (FIG. 3A, C, D and E), respectively, with linear responses for N and Mg levels, and quadratic responses for K and Ca. These results may be attributed to the dilution effect, i.e., biomass production was greater in the initial sowings (FIG. 2D), which led to smaller concentrations of these nutrients. In general, the nutrient concentrations obtained in all sowing periods were greater than the ones found by Oliveira et al. (2002), except for N. In the research mentioned, however, sorghum plants were sown in mid-November and the cycle had already completed 100 days. Santi et al. (2006) cultivated sorghum plants in nutrient solution, which showed the following ascending order of macronutrient requirement: N > K > Ca > Mg > P > S.

Considering that K levels in sorghum shoots were higher than N levels in most sowing dates (FIG. 3A and 3C), respectively, it can be inferred that this crop demands higher amounts of K for plant growth. Therefore, this species may potentially recycle this nutrient, which decreases K leaching and minimizes this problem that occurs mainly in sandy soils (WERLE et al., 2008).

Copper and carbon levels were not affected by sowing dates (FIG. 4A and 4F), respectively. On the other hand, Zn levels linearly increased with sowing delay (FIG. 4B). The opposite was observed for Mn levels (FIG. 4C). Iron and B levels (FIG. 4D and 4E), respectively increased up to a certain period of delay and

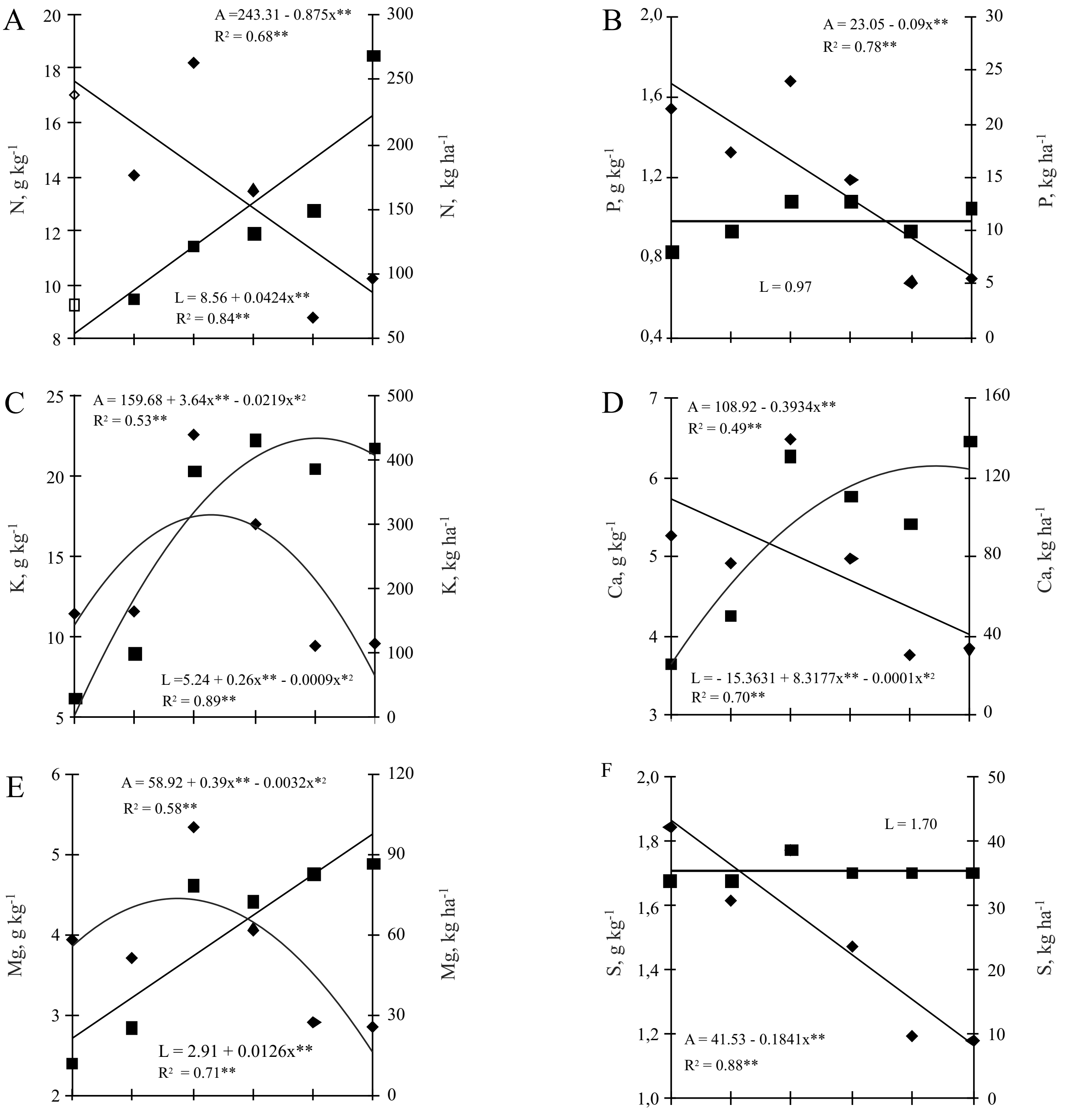

Figure 3 - Nitrogen (A), phosphorus (B), potassium (C), calcium (D), magnesium (E) and sulphur (F) levels (■) and accumulation (♦) in shoots of "Giant Guinea" sorghum plants as affected by sowing date. **: significant at $p \leq 0.01$

maximum levels were observed for sowings in January of 2001 and December of 2000, respectively.

Nutrient accumulation decreased with sowing delay, which was contrary to what happened with nutrient levels. Higher dry material production was observed for earlier sowing; so, despite lower nutrient levels, greater accumulation was found for earlier dates (FIG. 3 and 4).

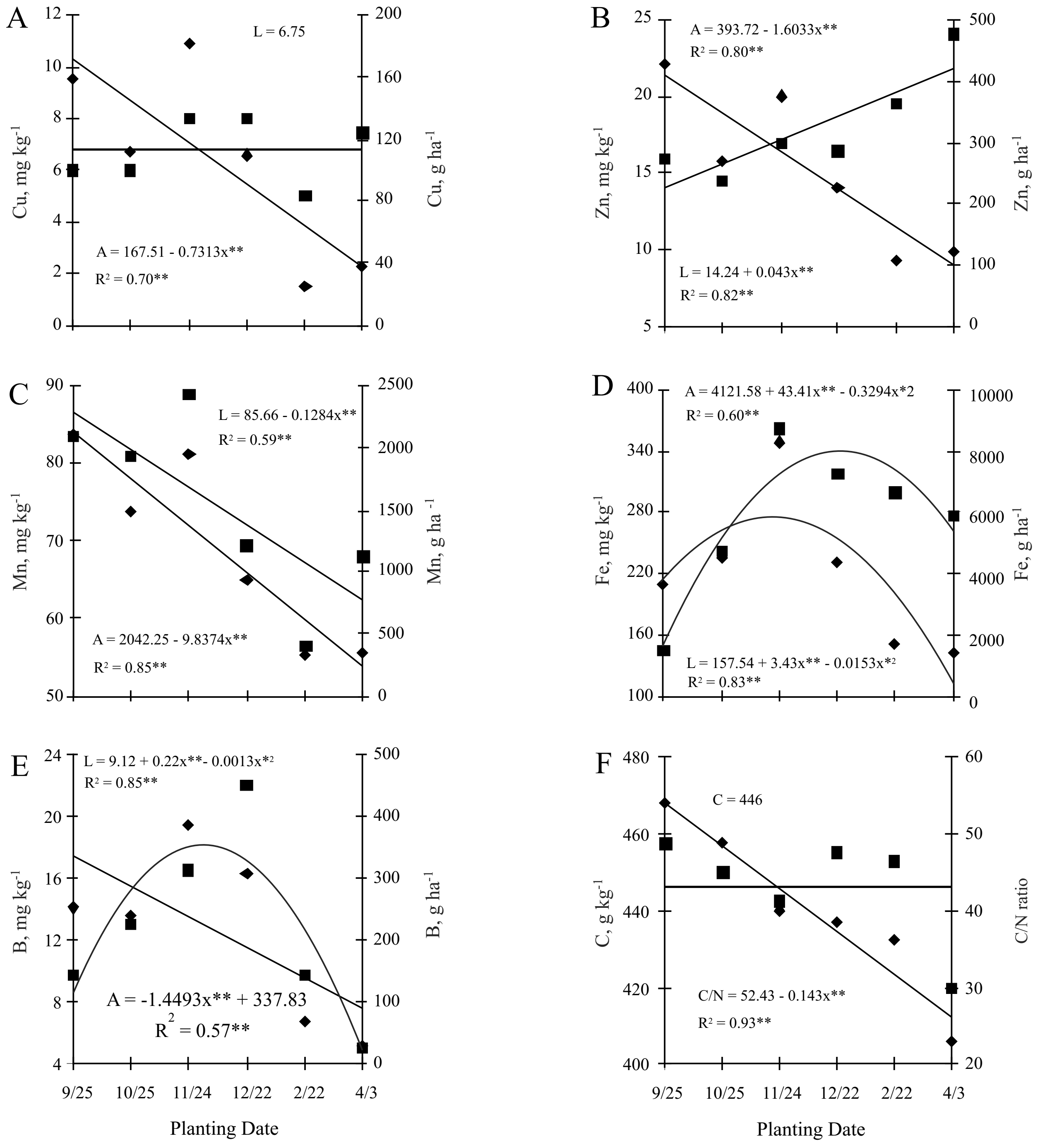

Figure 4 - Copper (A), zinc (B), manganese (C), iron (D) and boron (E) levels (■) and accumulation (♦); and carbon level and C/N ratio (F) in shoots of "Giant Guinea" sorghum plants as affected by sowing date. **: significant at $p \leq 0.01$

In most stages studied, nutrient accumulation up to the flowering stage obeyed the descending order K > N > Ca > Mg > S > P> Fe > Mn > Zn > B > Cu, corroborating results obtained by (OLIVEIRA et al., 2002), who studied sorghum. However, this contradicts results obtained by Nascimento (1988) and Santi et al (2006), who found nutrient order: N > K > Ca > Mg > S > P > Fe > B > Mn > Zn > Cu.

Dry matter production for soil coverage in no tillage system has the benefit of recycling nutrients, replacing them in upper soil layers. Therefore, sorghum sown in April of 2001 and September of 2000 saved the application of 553 and 175 kg ha^{-1} of urea for N supply, 288 and 74 kg ha^{-1} of single superphosphate for P, 331 and 126 kg ha^{-1} of KCl for K, 566 and 178 kg ha^{-1} of lime (CaO = 27%, MgO = 20%) for Ca, 491 and 146 kg ha^{-1} of lime for Mg, and 415 and 66 kg ha^{-1} of single superphosphate for S supply, respectively. The comparison between nutrient recycling and mineral fertilization is only valid to illustrate the great amount of nutrients recycled, since it does not consider the exploitation factor and nutrient availability provided by mineral fertilization.

C/N ratio linearly reduced with sowing delay (FIG. 4F), similarly to the study of Silva et al. (2009). Sowing in September resulted in a C/N ratio of 53 whereas sowing delay decreased it to 25. Variations in C/N ratio were affected by nitrogen levels, since sowing time had no effect on carbon levels (FIG. 3F). C/N ratios found in this study, except the sowing in April of 2001, were higher than those observed by Vasconcelos et al (1999). Whenever sowing took place until February of 2001, sorghum crop provided residues at flowering with higher C/N ratio, which is important to maintain residues on soil surface for longer period of time. Higher C/N ratios would result in slower residue decomposition and greater benefits to soil and to the next crop (ALVARENGA et al., 2001).

Conclusions

1. Giant Guinea sorghum shows sensitivity to photoperiodism; therefore, late sowing adversely affects plant development, resulting in lower biomass production and lower accumulation of nutrients;
2. This plant is a good option as a cover crop to implement the no-till system due to its capacity to produce dry matter and recycle N, P, and K.

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