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Full length Research paper

Crop Diversification to Enhance No-Till System in the Brazilian Savannah

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Agricultural systems in the Brazilian Savannah have been dominated by monoculture of soybeans [*Glycine max* (L.) Merrill]. Diversification would provide positive attributes including high carbon sequestration, soil quality, disease control, water use efficiency, and producer income. The objective of this work, conducted in savannah farm for two years on Ferralsol, was to evaluate grain and forage species, relay cropped on no-till soybeans at reproduction and drill planted after soybean harvest. Seeds of the C4 plant species and cultivars, grain amaranth (*Amaranthus cruentus*) cv. "BRS Alegria", finger millet (*Eleusinecoracana*), pearl millet (*Pennisetum glaucum*) cv. "BN 2", *Sorghum bicolor* cv. "BR 501" (grain), *S. bicolor* cv. "AG 2501" (forage) and the perennial grasses *Urochloa brizantha* cv. "Marandu", *U. brizantha* cv. "Xaraés" and *U. ruziziensis*, were spread over soybean at the R5, R6 and R7 reproductive sub-periods, in three densities. Rainfall data were collected and used to relate with crop performance. Plant number and height, dry matter yield and soil shading rate defined crop response to canopy shade at early growth. Pearl millet, forage sorghum, finger millet, grain sorghum, the pasture species and grain amaranth ranked for dry matter yield, between 6.5 and 2.7 Mg ha^{-1}, proportional to soil shading. Biomass obtained from sowing at R6 and R7, 30-50 days before harvest, utilized residual moisture for carbon sequestration and soil protection, causing no interference in soybean yield. Poor performance on drilling after soybean harvest was related to drought stress. It is concludedthat continuous soil cover in no-till system is achievable by crop species seed broadcasted over soybeans at the reproductive phase. Performance of monocots was ascribed to their tillering and exponential growth under direct sunlight. In dicotyledonous grain amaranth stand is attainable by adjusting sowing density. The effective use of residual moisture stimulate studies on shade tolerance at early growth and water use, including innovative, small-seeded, crops such as quinoa, buckwheat, sesame, tef and kenaf. On-farm relay cropping experiments shall lead to pursuit of technology, associating commercial production and soil quality on sustainable basis.

Key-Words: soybean, relay cropping, over sowing, yield, soil cover, canopy shade

INTRODUCTION

The Brazilian Savannah has become a major grain producer, based on advances in soil science and crop breeding (Spehar et al., 2011). However, to a large proportion, soils have been degraded since the last 30 years, dominated by continuous monoculture of soybean [*Glycine max* (L.) Merrill]. Soybean has covered 70 % of the grain crop area, with deficient soil and plant management (Spehar et al., 2011). No-till has become a practice to conserve the soil but repeated crops, increasing weeds and spontaneous plants from harvest seed loss, has caused plant mineral nutrition unbalance and synergized diseases and pests outbreaks (Spehar 2009).

In large savannah farming areas land remain idle in long dry season leaving the soil unprotected or weed infested. A second crop often is not feasible, due to moisture scarcity by the concentrated rainfall in short

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period (Spehar and Trecenti 2011). In view of this, prevailing monoculture in the savannah agricultural scenario shall, in the long run, become unsustainable, compromising technological advances hardly acquired since last century.

Occupied area in the savannahs represents about 90 10^6 ha on grain crop and pasture in some level of degradation and soil organic matter (SOM) loss. Permanent soil cover should increase carbon (C) sequestration, even in no-till, materializing the production potential on sustainable basis (Bayer et al., 2000).No-till cropping has shown to enhance carbon in soil by root decomposition, conditioning nutrient retention and plant growth (Mazzlli et al., 2015).Recovery of organic matter in tropical soils under no-till has shown direct relation with C balance, which is governed by the quantity and quality of crop residues (Bayer et al., 2006). Diversified cropping could reverse the trend of SOM loss, by the volume of C retained in biomass, reaching a positive net balance (Sage and Zhu 2011). Hence, there is need to develop cropping systems leaving large amount of residue on soils for its protection in dry season and subsequent conversion into SOM.

Relay cropping could be an alternative to the savannahs, for no-till crop diversification using residual moisture. However, its use has been restricted to few crops in areas of extended rainfall period (Pacheco et al., 2009). New cropping options should be studied to compose diversified biomass and positively synergize production systems (Spehar and Trecenti 2011).

This on-farm experiment aimed at evaluating plant establishment, biomass production and soil covering by monocots and dicotyledonous grain amaranth relay cropped after spreading seeds over soybeans at reproductive sub periods. Moreover, It was hoped to identify potentialities and limitations of diversified relay cropping to improve no-till, by direct interaction with farmers.

MATERIALS AND METHODS

Farm physiographic characteristics and soil analysis

The experiment was conducted in Dom Bosco Farm located at BR 251 (Brasília-Unaí road) Km 14, (16º 14’ S latitude, 47º 27’ W longitude and 967 m altitude), on a typical savannah landscape plateau, in two successive crop seasons. The climate is classified as Aw (Köppen), of well-defined rainy season from October to April, 1,400-1,600 mm precipitation, and dry autumn-winter, each lasting six months. The farm is located in catchment area. In absence of soil compaction, excess rainfall water infiltrates, stores in aquifers, and springs out on slopes, forming major South American river basins. Average temperature 23 ^{0}C in summer and 20 ^{0}C in winter, poses no limitation for plant growth, if water is available. The soil, representing major savannah groups, is a dystrophic, clayey, dark-red Ferralsol. It was limed and fertilized to suit cropping demand added by gypsum to mobilize calcium in soil, creating conditions for root growth in the profile (Ritchey et al., 1980; Santos et al., 2008). Soil chemical analysis, from samples collected at 0-20 cm depth, before the experiment, revealed pH (H_2O) 6.5, OM 4.3 dag kg^{-1}; P 12.1, K 420, S 4.9, B 0.4, Zn 6.3, Fe 54, Mn 19.9 and Cu 0.8 mg dm^{-3}; Ca 3.4, Mg 15, Al 0, (H^+ + Al^{3+}) 25 and CEC, 85 mmol$_c$ dm^{-3}; and 71dag kg^{-1} total base saturation.

Farm cropping systems and the experiment

Cultivation was maintained under no till for 13-14 years prior to the experiment. Intercropped maize and *Urochloabrizantha* pasture preceded soybean. In each experimental season, after pasture desiccation using 2.5 L ha^{-1} glyphosate [N-(phosphonomethyl) glycine)], 1,500 degree-days maturity group soybean, cv MG/BR-46 Conquista, was direct drilled in first week of November. Row spacing of 0.5 m and 16 viable seeds m^{-1} resulted in a population density of 320 10^3 plants ha^{-1}. Maintenance fertilization was 400 kg ha^{-1} formulated containing N and P_2O_5 (5-37-0), added by 9.0 Ca, 4.0 S, 0.13 B, 0.2 Zn and 0.07 Cu, in dag kg^{-1}. Potassium in the form of KCl was broadcast applied 35 days after emergence at the rate of 150 kg ha^{-1}. Post-emergence broad leaf herbicides lactofen {(+)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate} + chlorimuron { [[[[(4-chloro-6 methoxypyrimidin-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl] benzoic acid ethyl ester}, 0.5 L + 30 g ha^{-1}, and narrow leaf haloxyfop-p-methyl{methyl(R)-2-[4-(3-chloro-5-trifluoromethyl-2-pyridyloxy)phenoxy]propionate}0.4 L ha^{-1}, were used on weed control.

Experimental design, sowing dates, treatments, rainfall and crop residue

The experimental design was a split-split-plot randomized complete blocs in three replications. Spreading seed dates were the plots, crop species and cultivars the subplots and seed densities the sub subplots. Dates corresponded to the soybean R5, R6 and R7 reproductive sub periods described by Fehr and Caviness 1977. Sowing was carried out before rain forecast, within five-day intervals between 01-05 (R5) and 15-20 (R6) for February, and March 01-05 (R7). The sub subplots were 5m wide by 10m long, comprising 50m^2. Seeds were hand thrown over soybeans, within each sub subplot, starting from low to high density, keeping the pattern for homogenous distribution in the area. The treatments, species and cultivars, were as follows: grain amaranth (*Amaranthus cruentus*) cv. “BRS Alegria”, finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*) cv. “BN 2”, *Sorghum bicolor* cv.

"BR 501" (grain), *S. bicolor* cv. "AG 2501" (forage) and the perennial grasses *Urochloa brizantha* cv. "Marandu", *U. brizantha* cv. "Xaraés" and *U. ruziziensis*. Treatments were sown at densities of 2, 3 and 4 times the recommended for drill, corresponding to 2.5, 8.5, 17.5, 8.5, 17.5, 4.0, 4.0 and 4.0 kg ha^{-1}, corrected to 100% germination and vigor (Trecenti, 2005). A fourth sowing was made by seed drilling on furrows, 0.5 m spaced and 0.03 m depth, on the last week of March, after soybean harvest, to compare with relay cropping. During the experiment, data on rainfall were collected, grouped by five-day intervals and monthly, to relate with crop establishment, growth, dry matter yield and soil shading. Residues from previous crops remaining on soil were collected in four 1.0 m^2 random samples, dried and converted in Mg ha^{-1}, to evaluate effect on plant establishment.

Soybean performance, relay cropping evaluation and statistics

Soybean grain yield, in Mg ha^{-1}, was evaluated at physiological maturity, by harvesting six random samples consisting of four rows each, 2m long and 4.0 m^2, collected at high seeding density and adjacent to experiment, to evaluate relay cropping effects on the soybean.

Agronomic evaluation for each season was based on four 1.0 m^2 random samples collected per sub subplot, using a metal frame split into two L-shaped parts. Before harvest, at the end of May, data were collected on number of plants m^{-2}, average tiller number $plant^{-1}$ for the monocot species and plant height. Harvested material was kept in ventilated plastic bags at 40 ^{0}C and 15 % air moisture to reach constant weigh and converted into Mg ha^{-1}. Soil shading rate (%) per sub-subplot was evaluated by photographs taken in three shots, before the plants were harvested, using a tripod built on rigid PVC to include 1 m^2 (Ziviani et al., 2009). The pictures were edited and submitted to digital classification, using ENVI ™ program (Excelis, Colorado Springs, CO, USA) and shading (%) was transformed using Arc Sine. Analyses of variances for dry matter yield and soil shading, to assess time of sowing and density effects, used SISVAR software, version 5.0 (Ferreira, 2014). Means were compared by Tukey test.

RESULTS

Rainfall in the growing period for crop seasons, plant number and height, and tiller number for monocotyledonous species are presented in Fig. 1 – 4. The means for dry matter yield and soil shading rate of species and cultivars, across sowing dates and densities are compared in Table 1 – 2. Comparison of relay cropping from seed spreading at reproduction sub periods and drill planting after harvest of soybeans are presented in Table 3.

Rainfall in the growing period

Rainfall was 435 mm and 764.3 mm for crop seasons, between February and May (Fig. 1). Five-day period, accumulated monthly and the total precipitation had considerable volume differences in the two seasons, although rain distribution allowed broadcasting seeds in the pre-defined periods. Water supply by rain and the residue in soil from January supplied plant demand at germination and early growth. In March sowing first crop season, plants were exposed to water deficit, when balance between March and May was below necessary for plant growth, reproduction and dry matter yield. In second crop season, there was excess water from rainfall between January and March, a possible cause of mineral nutrient dilution and leaching.

Germination, plant survival and growth

Canopy shading had negative effects on crops seeded over soybean at R5reproductive sub period, indicated by low plant population in the annual species, in spite of water availability (Figure 1 and Figure 2). Even though the stand was reduced, plants were taller than the ones in the two succeeding sowing dates, while plant height for the same date did not vary significantly across densities (Figure 3). In the annual monocot species, tiller number was inversely proportional to plant population density (Fig4). High tiller number at low plant density was related to less competition for moisture and nutrients, after soybean harvest, when plants were exposed to full sunlight. High tiller number of pearl and finger millets, at high seeding density, contributed to significant dry matter yield at R5, when seedlings were exposed to canopy shading. The perennial forage species did not germinate at early soybean reproduction but, at the R6and R7sub periods, the number of plants was related to the effect of light on germination, survival and growth. Dry matter yield was a function of number of tillers per plant, especially *U. ruziziensis*, similar to annual species, but occurring late in plant growth. At R6and R7 reproductive sub periods, finger millet, pearl millet, both forage and grain sorghum, grain amaranth and perennial forages had plant population and dry matter yield proportional to sowing density.

Soybean yield and crop dry matter production in broadcast seeding

Seedlings of broadcast sown crops, growing simultaneously to soybeans at reproduction, did not cause reduction in grain yield. Comparisons with plots in adjacent areas to the experiment indicated no competition by seedling growth, even at high population

Table1: Dry matter yield for eight species and cultivars relay cropped from spreading seeds over soybean at reproductive sub periods (R) and three densities (D) in crop seasons 1 and 2

Species/Cultivar	**Dry Matter Yield (Mg ha)**																	
	R5						R6						R7					
	D1		D2		D3		D1		D2		D3		D1		D2		D3	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Grain amaranth	06cB	10cB	07cB	15bB	11cB	15bC	04dC	08cC	10cC	15bC	17bC	27aC	07cE	09bE	08cE	12cD	15bD	21aC
E coracana	05eB	08eB	14dB	17dB	16dB	20dC	31cA	34cA	45bA	49bA	56aA	60aA	43bA	35cB	49bA	44bB	44bA	56bA
P millet BN 2	25dA	28dA	38cA	41bA	58aA	61aA	27dA	36bA	50bA	60aA	60aA	65aA	31cB	43bA	39bB	58aA	43bA	62aA
Forage sorghum	01fB	02fC	09eB	11eB	19dB	25dB	26dA	36cA	47bA	55aA	55aA	60aA	21dC	34cB	21dC	36cC	32cB	56aA
Grain sorghum	01fB	04fC	10eB	14dB	21cB	30bB	17cB	22cB	20cB	40aB	32bB	44aB	19cC	27bC	25bC	32bC	29bB	39aB
U ruziziensis	0	0	0	0	0	0	0	11dC	0	19cC	0	34aC	15cD	18cD	20cC	28bC	26bB	36aB
*U br*izantha M	0	0	0	0	0	0	0	08dC	0	15bC	0	25aC	12cD	06dE	15bD	11cD	15bD	24aC
U brizantha X	0	0	0	0	0	0	0	06cC	0	14bC	0	25aC	12bD	08cE	16bD	13bD	22aC	23aC

Means followed by same upper case letter in column and lower case letter in line are not different (Tukey, P < 005)

Table 2: Soil shading at harvest for eight species and cultivars relay cropped from spreading seeds over soybean at reproductive sub periods (R) and three densities (D) in second crop season

Species/Cultivar	Soil Shading (%)								
	R_5			R_6			R_7		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
Grain amaranth cv. BRS Alegria	6dC	8dC	21cC	10dC	18cC	41bC	28cC	37bC	57aB
Eleusine coracana	15eB	23eB	34dB	60cA	74bA	82aA	67cB	78bA	91aA
Pearl millet cv. BN 2	22eA	41dA	60cA	35dB	57cB	77bA	82aA	85aA	87aA
Forage sorghum cv. AG 2501	1fD	9eC	16eC	29dB	56bB	65bB	31dC	51cB	79aA
Grain sorghum cv. BR 501	1fD	6fC	15eC	17dC	23dC	47bC	34cC	52bB	64aB
Urochloa ruziziensis	0	0	0	0	0	0	27bC	32bC	45aC
U brizantha cv. Marandu	0	0	0	0	0	0	12bD	19aD	23aD
U brizantha cv. Xaraés	0	0	0	0	0	0	10cD	20bD	27aD

Means followed by same upper case letter in column and lower case letter in line are not different (Tukey, P < 005)

Table 3: Comparison of dry matter yield for eight species and cultivars relay cropped from spreading seeds on soybean at reproduction and drill planted (DP) after soybean harvest

Species/Cultivar	Dry Matter (Mg ha^{-1})		
	Relay (1)	Drill(2)	(BS – DP)
Eleusine coracana	60a	08	52
Pearl millet cv BN 2	65a	14	51
Forage sorghum cv. AG 2501	60a	14	46
Grain sorghum cv. BR 501	44b	10	34
Urochloa ruziziensis	36b	04	32
Grain amaranth cv. BRS Alegria	27c	04	23
U brizantha cv. Marandu	25c	04	21
U brizantha cv. Xaraés	25c	04	21

Dry matter yield at high seeding density (2) Planting at end of March after soybean harvest, mean for first and second seasons Means followed by same letter in the column are not different (Tukey, P < 005)

density. The mean grain yield values obtained in the two seasons were 3.1 and 3.4 Mg ha^{-1}, approaching productivity estimates by the farmer, before soybean was combine harvested.

After testing the variances, means for dry matter yields were compared by treatment and within treatment, across sowing period and densities (Table 1).

At R5-D3, pearl millet dry matter yields were statistically similar to sowing at R6and R7, when significant yield was obtained for millets and forage sorghum at intermediate (D2) and high (D3) densities, reaching maximum values. Grain amaranth and grain sorghum had the lowest yields in the rank for annuals (Table 1).

These differences were associated to short plant cycle in amaranth and low tiller number in grain sorghum.

At early March sowing (R7), all species germinated, established and had proportionally high dry matter yield. In first crop season, yield reduction for the same sowing period resulted from moisture stress affecting plant growth late in season.

Soil crop residue and treatment shading rate

Residue from previous crops reduced population density and resulted uneven plant distribution in the area, compensated by tillers in monocots, a limiting factor to dicotyledonous grain amaranth.

The amount of crop residue covering the ground was 5.3 and 6.2 Mg ha^{-1}, in the two seasons and could become an obstacle to relay cropping in no-till.

Analysis of variance for soil shading rate (%) allowed comparing means within treatment and across sowing period and densities. Shading, measured only in second season, increased in proportion to broadcast seeding density.

Finger millet, pearl millet and forage sorghum soil shading values were 91, 87 and 87, followed by grain sorghum 64, grain amaranth 57, *U ruziziensis* 45, *U. brizantha* cv. “Xaraés” 27, and *U. brizantha* cv. “Marandu” 23, associated to respective highest dry matter in Mg ha^{-1} (Table 1 and Table 2). At high broadcast seed density, crop shading protected the soil in dry season for most treatments, at end of May evaluation.

Relay and drill planted crop performance

The compared treatment means for dry matter yield, of relay cropping and drilled seeds at the end of March, presented large differences between the two sowings (Table 3).

Pearl millet, finger millet and forage sorghum, followed by grain sorghum, *U. ruziziensis*, grain amaranth, *U. brizantha* cv. Marandu and *U. brizantha* cv. Xaraes had respective dry matter yields of 6.5, 6.0, 6.0, 4.4, 3.6, 2.7, 2.5 and 2.5 Mg ha^{-1}, at R6 and R7 high density broadcast seeded over soybeans.

Drill planted after soybean harvest had low plant emergence, growth and dry matter yield for all treatments, relating to severe water stress at the end of rainy season.

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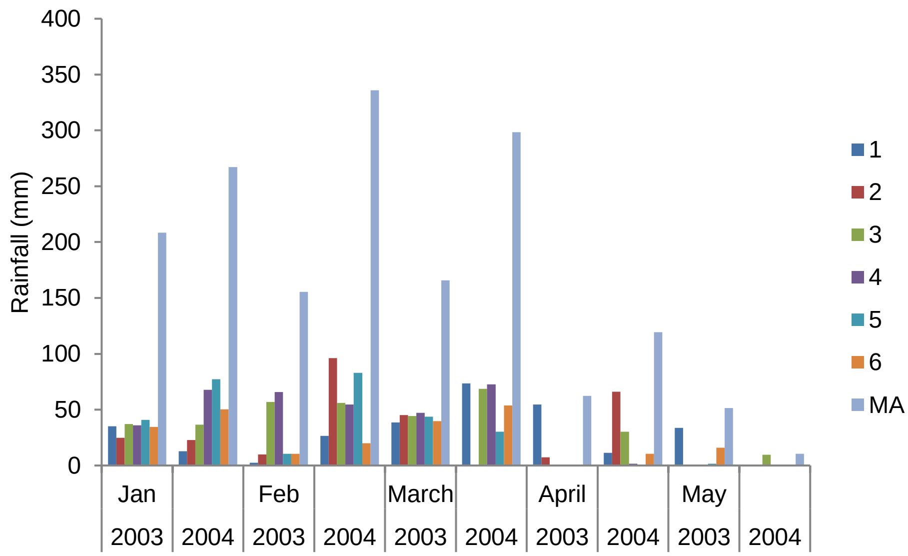

Figure 1: Rainfall, five-day (1-5) and monthly accumulated (MA), between January and May for two crop seasons Dom Bosco Farm, Cristalina, GO, Brazil

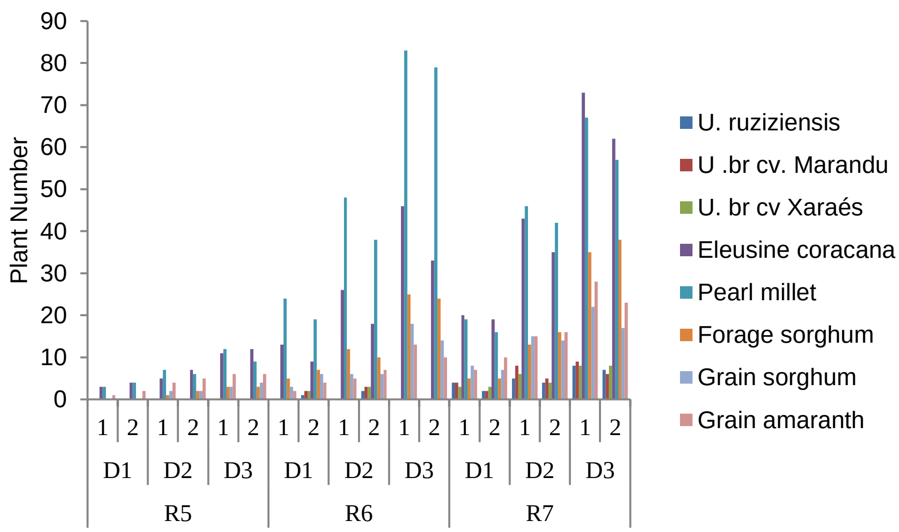

Figure 2: Plant number m^{-2} at harvest of relay cropping from spreading seeds over soybean at reproductive sub periods (R) in three densities (D) and crop seasons 1 and 2

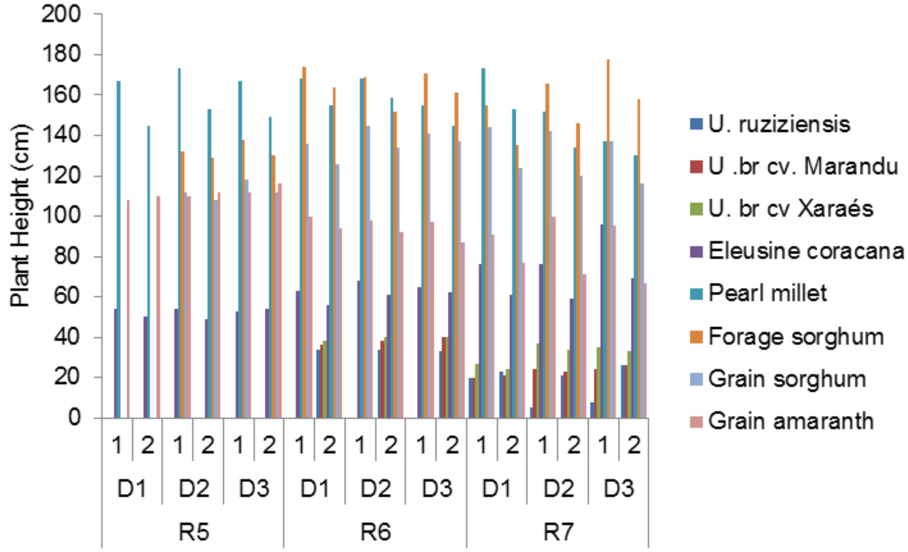

Figure 3: Plant height at harvest of relay cropping from spreading seeds over soybean at reproductive sub periods (R) in three densities (D) and two crop seasons 1 and 2

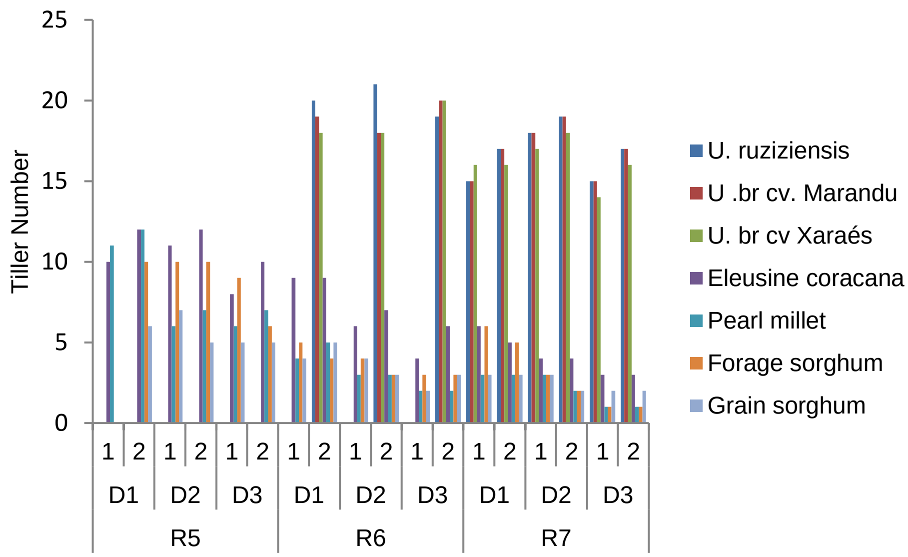

Figure 4: Plant tiller number of monocots at harvest of relay cropping from spreading seeds over soybean at reproductive sub periods (R) in three densities (D) and two crop seasons (1 and 2)

DISCUSSION

The discussion has focused on the response of crop species and cultivars to residual moisture from broadcast seeding over soybean at reproduction. The effectiveness of relay cropping was measured by population density, plant growth, dry matter yield and soil shading in savannah environment, alternated by rainy and dry periods. Based on the measurements, inferences were made on crop establishment and growth, when water is available but plants are exposed to soybean canopy shading at germination and seedling. How top-of-soil crop residue from continuous no-till could cause limitation in relay cropping and the possibilities to overcome the setback. On-farm innovative experimentation was envisioned as strong possibility to diversify production and biomass input, perfecting no-till system on sustainable basis.

Soybean yield and shade effect, sowing date and seed density on relay cropping

Relay cropping small seeded species has shown as alternative to biomass input in no-till, using available moisture. Seed germination and early plant growth simultaneously with soybean at pod filling reproductive period, caused no competition measured by grain yield at physiological maturity. The efficiency of relay cropping, demonstrated by plant population, tiller number, dry matter yield and soil shading, was attained at considerably higher seed densities than drill planting. Dates for spreading seeds over soybeans were synchronized with pod filling sub periods (Fehr and Caviness 1977), when plant canopy progressively opened to light penetration. Therefore, seedling exposure to full sunlight, after soybean harvest, resulted in substantial plant growth and dry matter yield, typical of C4 species (Sage and Zhu, 2011). Mean temperature in dry season (autumn-winter), only a few degrees lower than the one in spring-summer, did not interfere in plant growth. Although germination and early growth happened under soybean shade, species and cultivars were more exposed to water stress, causing negative effect in late sowing.

Plant growth and yield were related to population density and tillers for monocots in absence of water stress. In first seasons, yield was affected by low rainfall precipitation and, consequently, low moisture residue at R7, early March seeding. Therefore, plant performance for seeding at R6 soybean reproduction sub period was a direct response to water availability. Dry matter yields were equivalent to the obtained by forage and grain species, succeeding summer crops and intercrop cultivated in rain fed favored areas (Crusciol et al., 2012; Zhang et al., 2008).

Grain amaranth dry matter yields were lower than the annual monocots in the three sowing periods and associated with absence of tillers and short plant cycle. Cultivar BRS Alegria, in the low latitude savannah takes 500 degree days form emergence to flowering and 1080 degree days from emergence to physiological maturity. Stress intensity and length has shown to reduce plant growth at the short vegetative period before flowering with consequent low dry matter and grain yield (Spehar, 2007).

The perennial forage grasses *Urochloa ruziziensis*; *U. brizantha* cv. Marandu and *U. brizantha* cv. Xaraés responded proportionally to seed density at R6 and R7 in first season and at R7 in second. Low population for all broadcast seeding densities was probably caused by shading, reduced N near the soil surface (Zimmer et al., 1986) and amount of crop residues limiting seed contact with soil. Moreover, lack of nitrogen has shown to reduce leaf elongation and tiller number in perennial forage species (Paciullo et al., 2010). Added by excess water in second season, diluting nutrients, the reduced *Urochloa* spp. germination was a result of combined effects. These effects also retarded seedling growth and tiller initiation, extending plant lag phase. It must be considered, however, species and cultivars were evaluated 90-120 days after sowing, a short period for perennials. Dry matter yield was below reported for conventional pasture establishment (Paciullo et al., 2010) and could be related to the seedling long lag phase. Exponential growth and tiller formation explained the high dry matter accumulation of surviving plants late in season, similar to maize – pasture intercropping (Crusciol et al., 2012). In addition, pasture species yielded 3.0-4.0 Mg ha^{-1} dry matter when evaluated at 210 days after emergence (Gazola et al., 2013). Therefore, this experiment illustrated how perennial pastures could cover the ground in dry season, using soil moisture to provide forage when it is most needed.

The annual monocots tolerance to soybean canopy shade, notably the millets and forage sorghum, was related to more rapid germination, tiller formation and exponential growth than pasture species, overcoming the critical plant seedling phase (Paciullo et al., 2010). They added biomass faster than perennials, reaching a maximum value in a relatively short time.

Soil crop residue effect on annual monocots and grain amaranth

Residue from previous crop, although beneficial to no-till, prevented seed contact with soil, limiting seed germination and crop establishment. Tiller number compensated for poor germination (Kim et al., 2010), explaining dry matter yield of pearl millet broadcast seeded on soybeans at R5 reproductive sub period, and all annual monocots at R6 and R7.

Poor performance of grain amaranth at R5 resulted from low number of plants. At R6 and R7, for high seeding rate, population density increased but was unevenly distributed in the area, affected by top-of-soil crop residue. One characteristic of grain amaranth that could be used to overcome stand failure is the small seed size and weight; each seed weighs only 0.001 g. Germination in no-till could be improved by adjusting seed density to reach suitable stand for competitive grain yield and soil protecting biomass (Spehar, 2007).

Biomass, soil shading and cropping effect

Significant biomass, expressed by dry matter yield, at intermediate to final soybean pod filling sub periods, demonstrated the viability of soil protecting crops (Pacheco et al., 2009). Soil shading rate by crops was related to population density and growth, similar to obtained in common beans (Ziviani et al., 2009). From high seeding density at R6 and R7, the canopy for finger millet, pearl millet and forage sorghum provided near 100 % ground cover, followed by grain sorghum and grain amaranth. The benefit of crop cover in dry season, when SOM could lose even in no-till due to sunlight exposure, is measurable by reduced soil bulk density and increased water infiltration (Bharati et al., 2002).

C4 plants produce abundant crop residue as shown by sugar cane straw remaining after harvest, to improve soil physical and chemical properties (Segnini et al., 2013). The species and cultivars employed here were chosen for efficient sunlight use, drought tolerance and high biomass accumulation to protect the soil (Sage and Zhu 2011). The monocots and grain amaranth growth, dry matter yield and soil protection opened possibilities to other small seed species as quinoa, sesame, buckwheat, tef and kenaf (Spehar and Rocha 2010; Spehar and Trecenti 2011). However, sensitivity to shade at early growth, more evident in grain amaranth and perennial forages, suggests evaluation of plant response should be conducted in controlled environment before including them in relay cropping experiments.

Relay cropping and no-till production system enhancement

This farm experiment demonstrated effectiveness of water use by crops broadcast seeded over soybean at reproductive phase. Relay cropping, established 30-50 days before soybean harvest, could contribute to soil structuring by permanent plant and root growth (Costa et al., 2009).

Soil physical conditions, measured elsewhere, could benefit from extensive root system (Bharti et al., 2002; Samarajeewa et al., 2006), especially in perennial crop growth even in dry season (Pacheco et al., 2009). Another consequence of continuous cropping could be water conservation, avoiding runoff or evaporation to atmosphere. It should contribute to maintaining the savannah water cycle, immobilizing C and nutrients that are gradually released back to soil, depending on biomass composition (Kladivko, 2001; Spehar and Trecenti 2011).

Crop innovation to diversify savannah agriculture, under concentrated rain fall should improve SOM and cation exchange capacity, from biomass decomposition (Bayer et al., 2000; Segnini et al., 2013). SOM is expected to increase above the original levels in native areas, as in the fringe between Amazon and savannah, after amending soil fertility for grain crops (Maia et al., 2010; Santos et al., 2008). Therefore, unconventional cropping could associate agricultural production and biomass input by botanically diverse crops, to improve nutrient cycling (Boer et al., 2007). Crop diversity, emulating naturally life-rich savannah biome, should lead into more balanced plant nutrition and improved crop protection, impacting positively farmers' income. We have shown the potential of small seeded species broadcast sown to compose no-till production systems although stand was not always uniform. Tiller formation compensated for low population density in monocots, but was a limiting factor to dicotyledonous species. In practice, broadcast seeding in no-till depends on assessing the amount of top-of-soil crop residue to adjust density. Alternatively, to overcome uneven plant distribution setback, there is need to develop mechanisms to place seeds on soil surface during soybean reproduction. On-farm relay cropping experiment in tropical savannah has raised possibilities and limitations, stimulating studies to encompass particularities of soil, climate and crop species, for no-till enhancement and sustainable resource utilization.

CONCLUSION

Continuous soil cover in no-till system is achievable by crop species seed broadcasted over soybeans at the reproductive phase. Performance of monocots is ascribed to their tiller formation and exponential growth under direct sunlight. In dicotyledonous grain amaranth stand is attainable by adjusting sowing density.The effective use of residual moisture, without competing with soybean, stimulate studies on shade tolerance and water use by other innovative, small-seeded crops such as quinoa, buckwheat, sesame, tef and kenaf. On-farm replicated relay cropping experiments shall lead to pursuit of technology, associating commercial production and soil quality on sustainable basis.

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