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Intercropping corn and kudzu in a rotation system with soybean

Núbia Maria Correia[1*], Bruno Daniel[2] and Marcela Basile Leite[2]

*[1]Departamento de Fitossanidade, Universidade Estadual Paulista "Julio de Mesquita Filho", Via de Acesso Prof. Paulo Donato Castellane, s/n., 14884-900, Jaboticabal, São Paulo, Brazil. [2]Curso de Agronomia, Universidade Estadual Paulista "Julio de Mesquita Filho", Jaboticabal, São Paulo, Brazil. *Author for correspondence. E-mail: correianm@fcav.unesp.br*

ABSTRACT. The objective of this study was to evaluate the effects of sowing procedures and the seed sowing rate of kudzu (*Pueraria phaseoloides* cv. 'Comum') in corn on corn plant development, forage dry matter production, weed infestation and soybean plant development and yield. The kudzu seeds were either broadcasted over the terrain or sown in furrows (in the main plots) at rates, in both cases, of 400, 800, 1200 and 1600 points of cultural value (on the subplots). Singly cultivated corn was considered the control treatment. Intercropping did not cause corn plant development to show any significant difference compared with that of the singly cultivated corn plants. When sown in furrows, the number and dry matter contents of the kudzu plants were higher than sowing by broadcasting. The number of plants and the dry matter of the plants increased with the number of seeds. Prior to sowing soybean, the incidence of weeds decreased as the number of kudzu seeds at sowing increased. The intercropping of corn with kudzu benefited soybean plant population, plant height, and grain yield in comparison with the single cultivating of corn in the previous year.

Keywords: *Glycine max*, *Pueraria phaseoloides*, *Zea mays,* integrated crop-livestock, no-tillage system.

Cultivo consorciado de milho com puerária em um sistema de rotação com soja

RESUMO. Objetivou-se com esse trabalho avaliar os efeitos dos métodos de semeadura e das quantidades de sementes de puerária (*Pueraria phaseoloides* cv. Comum) em consórcio com a cultura do milho no desenvolvimento do milho, na produção de matéria seca da forrageira, na infestação de plantas daninhas e no desenvolvimento e produção da cultura da soja em rotação. Foram estudadas duas formas de semeadura (a lanço e em linha) de puerária nas parcelas, quatro quantidades de sementes (400, 800, 1200 e 1600 pontos de valor cultural) nas subparcelas e uma testemunha, representada pelo monocultivo de milho. O consórcio não afetou o desenvolvimento do milho comparado ao milho solteiro. Nos tratamentos semeados em linha houve maior densidade de plantas e acúmulo de massa de puerária do que nos tratamentos semeados a lanço. O número de plantas e a matéria seca da parte aérea da forrageira aumentaram com o aumento da quantidade de sementes. Antecedendo à semeadura da soja, a ocorrência de plantas daninhas reduziu com o aumento da densidade de semeadura da forrageira. O consórcio de milho com puerária beneficiou a população de plantas, a altura de plantas e a produção de grãos de soja comparado ao monocultivo de milho no ano anterior.

Palavras-chave: *Glycine max*, *Pueraria phaseoloides*, *Zea mays,* integração lavoura-pecuária, semeadura direta.

Introduction

Among the main obstacles to the success of the no-tillage system in most parts of the State of São Paulo and Central Brazil is the low production of straw during the Fall/Winter and Winter/Spring periods. This low production of straw is essentially due to prolonged dry spells, which usually take place during these periods in Brazil. As a consequence, several of these areas remain in a fallow condition for up to seven months, which poses serious difficulties for the success of the no-tillage system (BARDUCCI et al., 2009). A solution for this problem would be the intercropping of plant species such as cereals and pastures, which allow the establishment of pastures after harvest of cereal crops and, simultaneously, additional feed for livestock in the dry season. At the same time, the process of cultivation improves the physical and chemical properties of the soil and also increases the amount of straw needed for the no-tillage system of cultivating intercropping species. The corn plant, because of its height, with ears at high positions, is appropriate for intercropping because these characteristics make the harvesting of the intercropped forage plants easier (ALVARENGA et al., 2006).

Plants of the genus *Urochloa* are the most used for intercropping with corn, but other forage species, such as those of tropical kudzu (*Pueraria*

phaseoloides), may be used for the same reason. Kudzu is advantageous compared with other grasses because it is capable of fixing atmospheric N in the plant, thus improving the nutritional value of the feed consumed by livestock. Kudzu, a member of the Fabaceae family, is a perennial plant that originated from Asia. Kudzu has thin, flexible, and hairy stems that are easily rooted when touching the soil (SEPROTEC, 2010). Kudzu is well adapted to poor and acidic soils, showing a good competition capacity when growing close to weeds. It is also well adapted to grow in shaded areas, making it a good alternative to soil cover plants in association with rubber trees and American oil palm (EMBRAPA, 1999; MONTEIRO et al., 2009).

Cereal species and forage plant intercropping systems have consistently been found to be highly beneficial both for soil characteristics and plant yields. One of these desirable consortia is that between corn and kudzu plants. Nonetheless, the intercropping arrangement of plants of these species need to be more clearly understood with respect to, for example, sowing procedures. The broadcasting of seeds or sowing in furrows with nitrogenous fertilizer being side dressed is a simple technique that can easily be put into effect by the average farmer. However, the amount of seeds to be sown is to be calculated in consideration of each sowing modality and the seeds' cultural value. To facilitate the diffusion of information, the values should be presented in points of cultural value (PCV = quantity of seeds x cultural value). This calculation is particularly important in regions such as that of the Northeast of the State of São Paulo, where the common water deficit during the Fall/Winter period makes it difficult to establish field crops.

The present study was thus undertaken based on the assumptions that kudzu and corn intercropping is 1) not harmful to the development of the corn plant, 2) capable of reducing weed infestation, 3) capable of providing the adequate amount of straw for the subsequent sowing of soybean, and 4) capable of improving the productive performance of soybean plants. The objective of this study was to evaluate the effects of sowing methods and the amount of kudzu seeds in corn intercropping on maize development, kudzu biomass and weed infestation, and the development and production of the soybean crop in rotation.

Material and Methods

The experiment was carried out in the field from December 2008 to April 2010 at Paulista State University (UNESP) at its campus in Jaboticabal, State of São Paulo, Brazil. The local altitude is 605 m above sea level, the latitude is 21º 15'17'' South, and the longitude is 48º 19'20'' West. According to the Köeppen classification, the climate of the region is the Aw type and is characterized by a rainy Summer and a dry Winter.

Intercropping and its effects on a corn crop and weeds were evaluated from December 2008 to October 2009. The soybean crop in rotation with the intercropping system was evaluated from December 2009 to April 2010. Table 1 shows the data concerning the maximum and minimum temperatures, air relative humidity and precipitation during the period from December 2008 to April 2010.

Table 1. Mean monthly values of maximum and minimum air temperatures, air relative humidity, and total monthly rain during the months from December 2008 to April 2010.

Year	Month	Air temperature (ºC)		Air relative humidity (%)	Rain (mm)
		Maximum	Minimum		
2008	December	31.0	19.1	77.0	278.9
2009	January	29.7	19.8	80.4	238.0
	January	31.2	20.6	80.9	190.6
	February	31.0	20.2	80.4	217.9
	March	29.5	17.2	74.9	70.8
	May	28.4	15.5	75.9	26.6
	June	25.0	12.2	76.5	51.9
	July	27.6	14.4	74.6	25.5
	August	28.0	14.6	66.3	133.1
	September	29.7	17.8	74.0	132.4
	October	30.8	18.1	72.8	101.9
	November	32.1	21.0	74.8	163.3
	December	29.8	20.5	81.8	383.7
2010	January	30.4	20.8	82.2	240.7
	January	32.2	20.4	76.6	150.7
	February	31.4	20.0	77.6	183.0
	March	29.2	17.1	74.6	95.5

Source: Agroclimatological Station of the Department of Exact Sciences, FCAV/UNESP, 1.0 km distant from the experimental area.

The experiment was set up in the field according to a randomized complete block design with four repetitions in a split-plot arrangement. The kudzu seeds were either broadcasted over the terrain or sown in furrows (in the main plots) at rates, in both cases, of 400, 800, 1200 and 1600 points of cultural value (on the subplots). The check treatment for these sowing procedures consisted of plots in which corn was singly cultivated.

The kudzu seeds used to sow the experiment had a germination of 60% and a purity of 98%, so that its cultural value was 58.8%.

The plot size was 3.6 m wide by 32 m long, and the subplots were 3.6 m wide and 8 m long. The area located in each plot from which the data were collected was formed by two 6-m-long lines, totaling 10.8 m^2.

DKB 350 YG corn hybrid seeds were sown on December 18, 2008, under conventional soil tillage. The distance between rows was 0.9 m, with 6 seeds per meter sown at a depth of 5 cm. A formulated fertilizer (8-24-12) was applied to the soil at a rate of 450 kg ha^{-1} in the sowing furrows.

Before sowing, the seeds were treated with insecticides (deltamethrin and pirimifos-metil, 0.001 mg plus 0.02 mg kg^{-1} of seeds) and fungicides (fludioxonil and metalaxyl, 0.038 mg plus 0.015 mg kg^{-1} of seeds).

For weed control, the post-emergence herbicides nicosulforon (40 g ha^{-1}) and 2.4-D (806 g ha^{-1}) were applied 18 days after the sowing of corn (DAS_C).

At 22 DAS_C, the corn plants received a side-dressed dose of 75 kg ha^{-1} of N provided by ammonium sulfate fertilizer. Kudzu seeds were sown simultaneously with the fertilizer application according to the procedures and rates specified in this study.

The fertilizer was distributed without incorporation along a straight line with the assistance of manual equipment. To have the fertilizer incorporated into the soil as thoroughly as when distributed in the field by mechanical equipment, a superficial (up to 3 cm deep) row was opened in the center between two neighboring planting lines, and the fertilizer was placed in that row. When the seeds were sown in furrows, the kudzu seeds were manually sown over the fertilizer. When broadcasted over the terrain, the kudzu seeds were manually spread between the corn rows in the corresponding plots before the fertilizer was side dressed.

The height and the dry matter of the corn plants were determined 31 and 33 days after the sowing of kudzu (DAS_K), respectively. Grain yield, the number of plants per plot, and the number of ears per plant and by plot were evaluated at the end of the crop cycle (April 10, 2009).

The number of kudzu plants was evaluated at 32 DAS_K and again before the corn harvest (86 DAS_K). This counting was done in two 0.45-m^2 areas randomly picked in each of the sub-plots. At grain harvest and at 315 DAS_K (November 20, 2009), 26 days before soybean sowing, the shoots of the plants were harvested from two 0.45-m^2 areas taken randomly from each sub-plot to determine the shoot dry matter.

At the end of the corn crop, weeds from two 0.45-m^2 areas within each sub-plot had their shoots harvested and their dry matter content evaluated. At 317 DAS_K (November 22, 2009), that is, 28 days before soybean sowing, the weeds were visually evaluated, and the various degrees of infestation were expressed as a percentage, in which zero indicated the absence of plant cover and 100 indicated that the area was completely covered by plants.

Fifteen days prior to and the day of soybean sowing, the weeds and fodder plants of the experimental area were desiccated using 1.30 kg ha^{-1} of glyphosate acid equivalent in the first application and 0.975 kg ha^{-1} in the second application.

Based on the results of the soil chemical analysis, the soil received a dose of 245 kg ha^{-1} of the formula 0-20-20 placed on the bottom of the furrows.

Soybean seeds of the cultivar NK 7059 RR (V-Max RR) were sown on December 12, 2009, according to a no-tillage system at a depth of 5 cm and 45 cm between rows at a rate of 21.4 seeds per meter of row. Before being sown, the seeds were submitted to treatment with carbendazim and imidacloprid (0.5 mg plus 1.2 g kg^{-1} of seeds) for the protection of the plants' initial growth and as inoculants (*Bradyrhizobium elkanii* at a rate of 3.5 mL kg^{-1} of soybean seeds with 5 x 10^9 viable cells mL^{-1}).

The experiment was set up with the same plot (sowing procedure) and sub-plot (seed quantities) arrangement that had been used in the experiment of the previous year. The plot size was 3.6 m wide and 32 m long, and the sub-plots were 3.6 m of wide and 8 m long with 3 central 6-m-long lines as the area in which the data were to be collected. The five soybean rows were sown in the central part of the plot, occupying a width of 2.25 m.

The herbicides glyphosate (0.975 kg ha^{-1}) and chlorimuron-ethyl (20 g ha^{-1}) were applied 31 days after soybean sowing (DAS_S), when the soybean plants had their fourth trifoliated leaves fully expanded and when the weed plants had 2 to 10 definitive leaves (the dicotyledonous) and up to 4 tillers (the grasses).

At 31 DASs, the number of weeds in two randomly chosen 0.225-m^2 areas in the sub-plot area was counted. The shoot of each weed was cut off and dried in an oven to a constant weight.

At 39 DAS_S, the number of soybean plants in each sub-plot was counted, and this value was used to calculate the number of plants per hectare. At 75 DAS_S, the plant height and dry matter were determined. Grain yield and the weight of 100 grains were determined at the end of the crop cycle.

The data obtained in both phases of the experiment were submitted to an analysis of variance and the F test. The seed amounts were submitted to regression analysis when the chosen data adjustment model was that of the largest determination coefficient and, more importantly, that of its significance ($p < 0.01$ and $p < 0.05$) in the F test. To evaluate the performance of the single cultivation in comparison with sowing procedures and sowing rates, the degrees of freedom of the treatments were determined in accordance with an orthogonal contrast of interest. The check treatment was compared with the convenient intercropping treatments. Each contrast was analyzed by means of the F test, accepting or rejecting the null hypothesis $H_0 (Y = 0)$.

Results and discussion

The interaction between the sowing procedure and sowing rate was not significant for any evaluated characteristics.

The sowing procedure had an effect on corn grain yield: the highest production was verified when the kudzu seeds had been broadcasted (Table 2). However, the analyses of the orthogonal contrasts showed that the corn yield when kudzu had been sown in furrows (8.979.95 kg ha^{-1}) was statistically similar to that of the singly cultivated corn (9.490.33 kg ha^{-1}). The higher yield observed when the kudzu seeds were broadcasted might be due to the lower kudzu plant number, which represented a lesser degree of competition for the natural resources needed by the corn plants to grow and produce.

Table 2. Grain yield of corn intercropped with kudzu sown either in furrows or broadcasted.

Sowing procedure	Grain yield (kg ha^{-1})
Broadcast	9710.36 a[(1)]
In furrows	8979.95 b
DMS	263.47

[(1)]Means followed by the same letter do not differ at the 5% level of probability according to F test.

The further evaluated characteristics of the corn (plant height, shoot dry matter, plant population and number of ears per plant and per plot) were not affected by the isolated factors. Based on the contrast analyses, the treatments of intercropping with broadcast sowing and sowing in furrows did not differ from the control monoculture of corn.

Freitas et al. (2005a and b) report that *Urochloa brizantha* intercropped with silage corn did not cause any significant modification in the amount of both fresh and dry weight of the corn plants independently of the method of sowing and the weed plant management. Borghi and Crusciol (2007), studying in corn plant rows 0.45 or 0.90 m apart one from another, intercropped *U. brizantha* by sowing the seeds on the corn rows, between the rows, or simultaneously on and between the rows. They observed that the corn yield was significantly affected only when the spacing between corn rows was 0.45 m and when the *B. brizantha* seeds had been sown both on and between the corn rows.

Heinrichs et al. (2005), intercropping corn with jack bean (*Canavalia ensiformis* L.), pigeon pea (*Cajanus cajan*, L.), dwarf mucuna (*Mucuna deeringiana* (Bort.) Merr), and crotalaria (*Crotalaria spectabilis*, Roth), observed no significant effect on corn yield in the first year, but in the second year, the corn yield was significantly higher when the intercropping had been with jack bean. This result was probably due to the higher green matter produced by jack beans in the first year, which resulted in higher levels of available nutrients in the soil for the second-year corn plants.

The sowing procedures had a significant effect on the numbers of plants at 32 and 86 days after kudzu sowing (DAS_K) and on the kudzu shoot dry matter yield at 86 DAS_K (Table 3). At 32 and 86 DAS_K, there was greater number of kudzu plants on the furrows of the sowing treatment; consequently, at 86 DAS_K, the plants of this treatment accumulated more shoot dry matter.

Table 3. Kudzu plant numbers 32 and 86 days after in furrow or broadcasted sowing of kudzu (DAS_K) seeds in an intercropping with corn and kudzu shoot dry matter 86 DAS_K.

Sowing procedure	Number of plants m^{-2}		Dry matter
	32 DAS_K	86 DAS_K	(g m^{-2}) - 86 DAS_K
Broadcast	23.01 b[(1)]	40.42 b	7.82 b
In furrows	47.57 a	104.31 a	15.55 a
DMS	12.63	27.94	4.52

[(1)]Means followed by the same letter do not differ at the 5% level of probability according to F test.

The seed sowing rate significantly influenced the shoot dry matter at 86 and 315 DAS_K (Figure 1A and B) and the number of plants at 32 and 86 DAS_K (Figure 2). The number of plants (at 32 and 86 DAS_K) and the shoot dry matter (at 86 and 315

DAS_K) increased linearly with an increase in the quantity of kudzu seeds sown in the plots (Figures 1 and 2). These findings showed that sowing 1600 points of cultural value (PCV) of kudzu seeds led to an increase in the density and biomass accumulation.

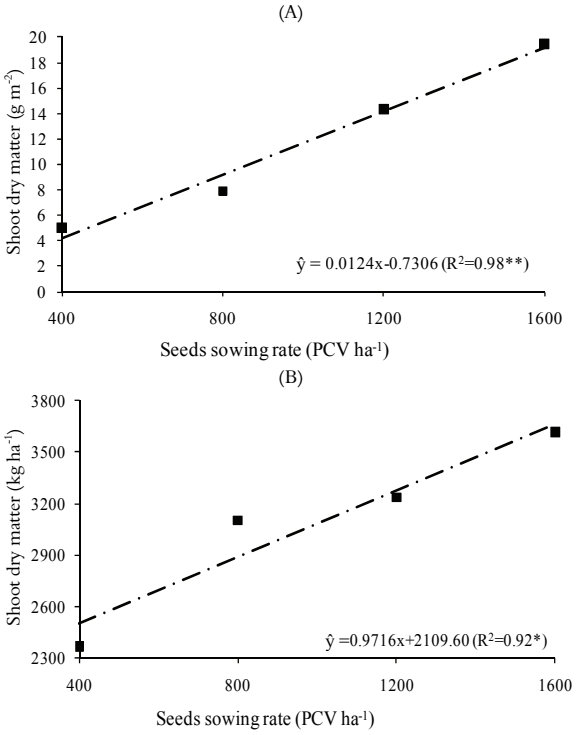

Figure 1. Kudzu shoot dry matter 86 (A) and 315 (B) days after kudzu seeds were sown at different sowing rates in an intercropping with corn.

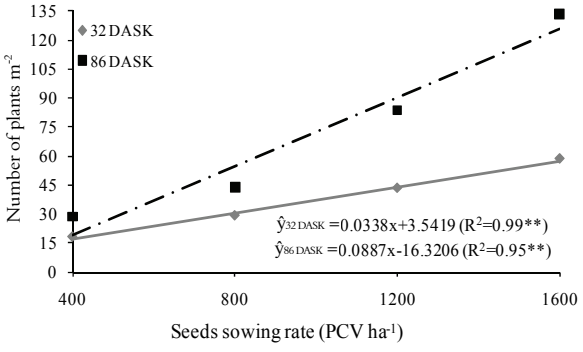

Figure 2. Number of kudzu plants intercropped with corn 32 and 86 days after sowing kudzu seeds at different sowing rates.

Freitas et al. (2005a e b), working with corn intercropped with *U. brizantha*, verified that the highest production of *U. brizantha* dry matter took place when this species' seeds had been sown in lines between the corn plant rows and that the lowest production was verified when the forage seeds had been broadcasted 30 days after corn sowing. In both sowing procedures, the amount of sown seeds was 380 PCV. The procedure by which the *U. brizantha* seeds are broadcasted among corn plant rows 30 days after corn sowing is the most adopted in Brazil (FREITAS et al., 2005a e b) because farmers consider this procedure the easiest and most practical for the intercropping of these species.

The dry matter of weeds was not significantly affected by the studied treatments. However, the degree of weed infestation 317 DAS_K was significantly influenced by the sowing rate (Figure 3). The orthogonal contrasting of the treatments showed that the intercropping treatments did not differ from the treatment in which corn was singly cultivated.

The observations made at 317 DAS_K showed a linear reduction in weed infestation as the kudzu seed sowing rate increased (Figure 3). This result is probably a consequence of the fact that the higher the sowing rate is, the faster and better the soil is covered by kudzu plants, which are thus rendered more capable of suppressing the growth of the weeds.

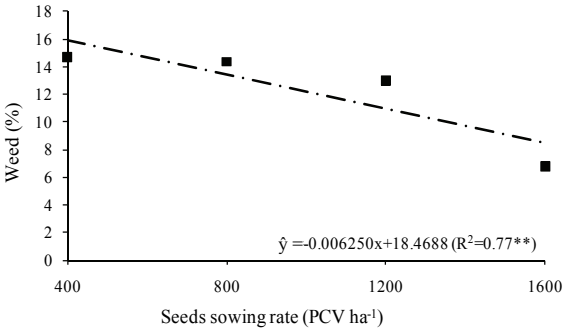

Figure 3. Weed infestation in intercropped corn and kudzu 317 days after sowing kudzu seeds at different sowing rates.

Results reported by Heinrichs et al. (2005) show that the intercropping of corn and jack bean (*Canavalia ensiformis*) led to a significant reduction in the level of weed infestation, probably because of a suppressing allelopathic effect by the jack bean plant. Nevertheless, when the intercropping was with dwarf mucuna (*Mucuna deeringiana*), pigeon pea (*Cajanus cajan*) and crotalaria (*Crotalaria spectabilis*), the authors observed no such effect. But, Linhares et al. (2009) reported that the intercropping of corn with gliciridia (*Gliciridia sepium)*, a perennial species of the Fabaceae family that displays known allelopathic properties, had no effect on weed plant population.

In the soybean crop, the kudzu sowing procedure in rotation with the corn-kudzu intercropping had a significant effect on the number of weeds (Table 4). When the kudzu was broadcasted, the number of weeds was 425.55

plants m^{-2}, whereas when the kudzu was sown in furrows, the number was 401.29 plants m^{-2}.

The soybean plants, while in rotation with the corn-kudzu intercropping, had their population, height, and grain yield significantly affected by the kudzu seed sowing rate (Figure 4). The soybean plant population and grain yield increased linearly with the increase of the sowing rate. For plant height, the best fitting was verified to be the polynomial, with the lowest mean resulting from the use of kudzu sown at a rate of 400 points of cultural value.

The analysis by contrast showed that the soybean plants growing in plots in which the previous crop was singly cultivated corn had a lower dry matter content than those grown in plots in which the corn had previously been intercropped with kudzu sown by broadcasting. The corn and kudzu intercropping, independently of the sowing procedure and of the sowing rate, benefitted the plant population and the height and grain yield of soybean in the first year of the experiment compared with the maize monoculture control plot.

Table 4. Results of F test by way of orthogonal contrast analyses of the sowing procedure of kudzu (in furrows or broadcasted), seeds sowing rate of kudzu (400, 800, 1200 and 1600 points of cultural value - PCV) and corn monoculture, beyond of the average values of the characteristics evaluated in the weed (number of plants, shoot dry matter and dry matter plant^{-1}) and in the soybean crop (plant population ha^{-1}, shoot dry matter, height, 100 grain weight and e grain yield) grown in rotation to kudzu and corn intercropping.

Variation causes		Weed			Soybean				
		Number of plants m^{-2}	Dry matter (g m^{-2})	Dry matter plant^{-1}	Plant population ha^{-1}	Dry matter (g planta^{-1})	Height (cm)	100 grain weight (g)	Grain yield (kg ha^{-1})
Corn monoc. x broadcast		0.05	0.43	0.03	6.43*	5.01*	7.20*	1.82	6.22*
Corn monoc.x in furrows		0.03	0.30	0.01	13.92**	3.32	4.88*	0.87	7.04*
Corn monoc. x 400 PCV		0.04	1.33	0.11	4.86*	2.81	5.60*	0.24	3.96*
Corn monoc. x 800 PCV		1.44	0.05	0.15	5.17*	3.75	6.17*	0.08	4.54*
Corn monoc. x 1200 PCV		1.69	0.33	0.11	19.03**	5.29	9.06**	0.06	9.80**
Corn monoc. x 1600 PCV		0.03	0.44	0.13	14.82**	3.06	5.69*	0.44	8.96**
Treatments					Average values				
Sowing	Broadcast	425.56	49.40	0.12	349382.72	24.36	49.01	14.18	3002.50
	In furrows	401.30	50.40	0.13	389506.17	22.54	47.88	13.81	3059.76
Rates	400 PVC	422.96	45.68	0.11	332098.77	23.34	44.82	13.19	2532.38
	800 PVC	344.07	53.50	0.15	340740.74	23.54	49.69	13.66	2950.57
	1200 PVC	485.19	50.57	0.11	411111.11	24.03	51.19	13.64	3347.96
	1600 PVC	401.48	49,86	0.13	393827.16	22.88	48.08	13.89	3293.62
Corn monoculture		411.85	55.47	0.14	274197.53	14.57	42.60	13.48	2303.60

*Significant at 5% probability by the F test of the analyses of variance.

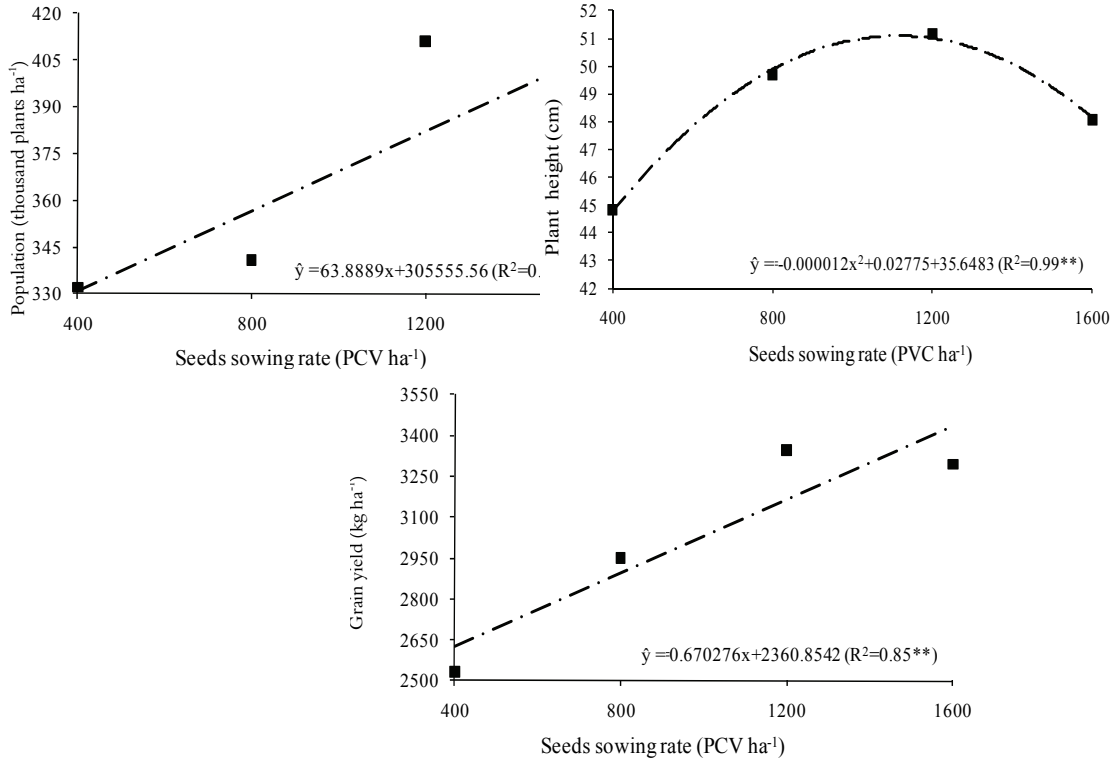

Figure 4. Soybean plant population, plant height and grain yield rotating with intercropped corn and kudzu sown at different sowing rate.

Pacheco et al. (2009) reported no significant difference in plant population, the number of pods with 2 or 3 grains or the mass of 1,000 grains in soybean plants rotated with several plant species. However, when grain yield of soybean plants growing in rotation with *U. ruziziensis* was compared with that of soybean plants growing in soil previously submitted to fallow, the results showed the grain yield of the former to be significantly higher than that of the latter. Correia and Durigan (2006) reported that the rotation of soybean with *U. brizantha* (in the two years of the experiment) and with *Eleusine coracana* (only in the second year of the experiment) resulted in higher grain yield, higher dry weight of aerial parts, and taller plants. Nunes et al. (2006) verified that rotating beans with *Panicum maximum* cv. Mombaça, *U. decumbens*, and *Panicum maximum* cv. Tanzania resulted in heavier grains (determined by the weight of 100 grains) and higher grain yield.

Conclusion

The intercropping of corn with kudzu sown either in furrows or by broadcasting has no negative effect on corn plant performance.

The seed sowing rate of 1600 points of cultural value, either in furrows or broadcasted, permits the kudzu plants to reach the maximum straw production.

The incidence of weeds is reduced by increasing the kudzu sowing rate, particularly when the kudzu seeds are sown in furrows.

The intercropping of corn with kudzu benefited soybean plant population, plant height, and grain yield in comparison with the single cultivating of corn in the previous year.

Acknowledgements

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