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Upland rice intercropped with green manures and its impact on the succession with common bean

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Abstract

The aim of this work was to verify the possibility of intercropping rice with green manures, as well as the impact of the dry biomass yield of these intercropping systems on common bean in succession, evaluating the agronomic and qualitative performance of grains from both crops. The experiment was conducted in Southeastern Brazil in the years 2018 and 2019, with succession of rice (spring/summer) and common bean (autumn/winter). The treatments were composed of cropping systems with rice as a sole crop and intercropped with forage peanut, calopo, *Crotalaria breviflora*, *Crotalaria spectabilis*, stylo, jack bean and dwarf pigeon pea. No intercropping increased the system's yield compared to sole-crop rice, but intercropping of rice with forage peanut and stylo promoted grain yield and quality similar to those of sole-crop rice. Intercropping with *C. breviflora* affected the agronomic and qualitative performance of rice. Common bean yield after rice intercropped with dwarf pigeon pea, *C. spectabilis* and *C. breviflora* was similar in yield after sole-crop rice, while the other intercrops reduced common bean yield. Common bean grain quality was not affected by the cultivation of rice as sole crop and intercropped with green manures. Although none of the intercropping systems increased yield compared to sole-crop rice (control), it can be concluded that the intercropping of upland rice is viable depending on the green manure species, allowing greater biomass production per area that can help long-term soil conservation and increase the system's yield.

Introduction

The intensification of land use to increase food production in the world has led to a reduction in its quality (Norris and Congreves, 2018), due to improper soil management, causing compaction, erosion, reduced fertility and contamination of the soil-water-plant environment (Bindraban *et al*., 2012). In order to reverse this situation, combining the formation of dry matter for soil cover and food production, the intercropping between crops has been adopted. This system has been identified as a great alternative worldwide for intensifying food production in a sustainable way (Martin-Guay *et al*., 2018).

Among the various modalities, the intercropping between commercial grain-producing species with plants called green manures or cover crops has stood out as an advantageous production system. The species involved in the intercropping have roots with different morphology, increasing water absorption and avoiding losses through percolation and evaporation (Rahman *et al*., 2017). In addition, the roots of intercropped species grow so that the plants benefit each other by facilitating nutrient uptake (Li *et al*., 2006). The species used as green manures are also able to fix atmospheric nitrogen and share part of this nutrient with the intercropped crop and in succession (Calegari and Carlos, 2014).

Green manures promote improvements in the physical, chemical and biological attributes of the soil, increasing water infiltration rate and the formation of vegetation cover, as well as preventing erosion processes. Besides, they increase soil organic matter content, promote nutrient cycling and alter soil biota, providing conditions for the development of arbuscular mycorrhiza and microorganisms antagonistic to pathogens, promoting increases in grain yield (Amado *et al*., 2014; Calegari and Carlos, 2014).

In Brazil, the intercropping of corn (*Zea mays* L.) with green manures (*Urochloa ruziziensis* and *Crotalaria spectabilis*) is used for grain production, as well as the formation of straw for the no-tillage systems (NTS). When used as a forage, it can also contribute to cattle breeding by supplying pasture, while when intercropped with the legume, aside from supplying N to the subsequent crop, it helps to reduce nematode populations (Arf *et al*., 2018; Souza *et al*., 2019).

In Brazil, rice (*Oryza sativa* L.) is also intercropped with essential crops for human consumption such as beans, cassava, corn and coffee, only as a subsistence crop, but with low frequency. Rice is also intercropped with forage, mainly *Urochloa decumbens* and *U. brizantha*, aiming to reduce costs, partially or totally, in the recovery/renewal of degraded pastures (Fornasieri Filho and Fornasieri, 2006). However, the inclusion of rice in this production system is extremely difficult, due to the lack of synchronism in growth between species, resulting in competition for water, light and nutrients, leading to losses in grain yield (Ramalho *et al*., 2005; Saito *et al*., 2006), which is the reason why in the world there is no technical recommendation to combine the cereal with green manures.

On the other hand, the dry biomass resulting from the intercropping of rice with green manures may increase the C/N ratio, promoting a longer period of soil cover compared to the sole cropping of green manures. In addition, the release of nutrients may be faster compared to the cultivation of rice as sole crop. This diversity of dry matter can cause the release of nutrients because its decomposition is synchronized with the demand required by the subsequent crop (Kaewpradit *et al*., 2009), benefiting the grain yield of the crop in succession.

In Brazil, the succession of rice and common bean (*Phaseolus vulgaris* L.) makes it possible to bring benefits to the production system because they have morphologically different roots, are not susceptible to the same pests and diseases, and have different nutritional requirements. Rice is grown in the spring-summer season, in two large ecosystems, which are flooded and upland, either rainfed or with supplementary sprinkler irrigation (Fornasieri Filho and Fornasieri, 2006). Worldwide, rice cultivation ranks second in cultivated area, only after wheat (*Triticum aestivum* L.). Common bean has great flexibility in growing seasons, being the main grain-producing crop exploited in the autumn-winter season under irrigated conditions in the Central and Southeast regions of Brazil (Mingotte and Lemos, 2018). Brazil is the country with the largest area cultivated with common bean crop in the world, with approximately 3.2 million ha (CONAB, 2020).

However, to make a production system feasible and sustainable, it is not enough to evaluate the increase in food production and the conservation of the environment. It is also necessary to assess the quality of the food produced. Rice is one of the main staple foods worldwide, with demand expected to increase by 8.5% by 2025 (OECD and FAO, 2019). This cereal provides 20% of the world's dietary energy, in addition to protein and vitamins. Common bean is an important source of protein, especially in developing countries, besides being a source of carbohydrates, fibres, vitamins and micronutrients (Castro-Guerrero *et al*., 2016).

The combination of rice and common bean in human food is essential for adequate nutrition and widely used by the Brazilian population. The common bean has a high protein value, being rich in lysine, but it contains a low content of sulphur amino acids. Rice, in turn, in its protein composition, is rich in sulphur amino acids and has a low lysine content. Thus, when ingesting the combination of rice and common bean, the biological value obtained is close to that of the protein of animal origin (Lajolo *et al*., 1996), being an extremely important strategy in the context of food security.

The objective of this study was to verify the possibility of intercropping rice with green manure, as well as the impact of the dry biomass yield of these intercropping systems on common bean in succession, evaluating the agronomic and qualitative performance of grains from both crops.

Materials and methods

Experimental area location and characterization

The experiment was conducted in the 2018 and 2019 growing seasons using the succession of upland rice cultivated as a sole crop and intercropped with green manure in the spring/summer and common bean in the autumn/winter under NTS. The experiment was carried out in the city of Jaboticabal, São Paulo, Brazil, located at 21°14′33″S latitude and 48°17′10″W longitude, at an elevation of 565 m above sea level, under Aw climate type (humid tropical with rainy season in the summer and dry season in the winter), in a *Latossolo Vermelho eutrófico* (Oxisol), with clay texture (Santos *et al*., 2013).

In the experimental area, millet (*Pennisetum glaucum*), cultivar ADR 300, was grown from December 2017 to March 2018. After its desiccation, the experimental area was under fallow until the implementation of rice cropping systems.

Prior to the installation of the experiment, soil collection was carried out in the 0.00–0.20 m layer for chemical and granulometric characterization, obtaining the following results: OM (organic matter) = 20 g dm^{-3}; $P_{(resin)}$ = 65 mg dm^{-3}; pH ($CaCl_2$) = 5.6; K^+ = 5.9 mmol$_c$ dm^{-3}, Ca^{2+} = 39 mmol$_c$ dm^{-3}, Mg^{2+} = 19 mmol$_c$ dm^{-3}, H + Al = 29 mmol$_c$ dm^{-3}, Al^{3+} = 0 mmol$_c$ dm^{-3} and CEC (cation exchange capacity) = 93 mmol$_c$ dm^{-3}, respectively; base saturation = 69% (w/v); clay = 540 g kg^{-1}; silt = 230 g kg^{-1} and sand = 230 g kg^{-1}.

Experimental design and treatments

The experimental design was a randomized block with four replications. The treatments consisted of eight rice cropping systems, one with rice as sole crop and seven with rice intercropped with green manures, preceding the common bean crop. The cropping systems were: sole-crop rice, rice + *Crotalaria breviflora*; rice + *C. spectabilis*; rice + jack bean; rice + dwarf pigeon pea; rice + calopo; rice + forage peanut; rice + stylo. All green manures were sown simultaneously with rice. After rice harvest, the common bean was cultivated in the same location as the plots defined for rice.

Upland rice conduction

Each plot consisted of five 5 m-long rows of rice, with a spacing of 0.45 m between rows. The useful area was composed of three central rows, considering the lateral rows as a border. The green manures were sown between the rice rows, 0.225 m away from these.

Rice was sown on 13 November 2018, using 70 kg ha^{-1} of seeds of the cultivar BRS Esmeralda, which has long/fine grains, yield potential of 7525 kg ha^{-1}, plant height ranging from 95 to 108 cm, cycle of about 77 days until flowering and from 105 to 110 days until maturation. This cultivar has initial vigour, with a fast canopy closure between rows, resistance to lodging, persistence of green colour of the leaves at the stage of grain maturation (stay green), as well as drought tolerance and moderate resistance to blast (Castro *et al*., 2014).

The sowing density of green manures was the recommended amount according to Calegari and Carlos (2014) for *C. breviflora* D.C. (12 kg ha^{-1}), *C. spectabilis* Roth (12 kg ha^{-1}), jack bean – *Canavalia ensiformis* L. (80 kg ha^{-1}), dwarf pigeon pea – *Cajanus cajan* L. (35 kg ha^{-1}), calopo – *Calopogonium mucunoides* Desv. (8 kg ha^{-1}), forage peanut – *Arachis pintoi* Krap. and Greg. (8 kg ha^{-1}), stylo – *Stylosanthes guianensis* Aubl. Sw.

(4 kg ha^{-1}). Rice and green manure seeds were treated with pyraclostrobin (5 ml 100 kg seed^{-1}) + thiophanate-methyl (45 ml 100 kg seed^{-1}) + fipronil (50 ml 100 kg seed^{-1}), aiming to control termites and *Elasmopalpus lignosellus*.

Fertilization at sowing of the rice crop was carried out with 210 kg ha^{-1} of the formulation 08-28-16, equivalent to 16.8 kg ha^{-1} of N, 58.8 kg ha^{-1} of P_2O_5 and 33.6 kg ha^{-1} of K_2O, according to the recommendations of Cantarella and Raij (1997). Top-dressing nitrogen (N) fertilization was performed at stage V_3 (formation of the 3rd leaf collar on the main stem and beginning of tillering), at 22 DAE (days after emergence) at a dose of 60 kg ha^{-1} of N, using as source ammonium sulphate (Cantarella and Raij, 1997).

Phytosanitary management was performed according to the recommendation of Fornasieri Filho and Fornasieri (2006). Rice was harvested on 19 March 2019. After rice harvest, the area was desiccated and, subsequently, the dry biomass was managed with a mechanical disintegrator.

Common bean conduction

The common bean crop was planted on 07 May 2019, spaced by 0.45 m between rows, with 12 seeds m^{-1}, using the cultivar BRS Estilo. This cultivar belongs to the commercial group of 'Carioca' grains, with indeterminate growth habit, type II, of cycle between 85 and 95 days, has erect plant architecture and is resistant to lodging (Melo *et al*., 2009). Each plot consisted of five 5 m-long rows of common bean, with a spacing of 0.45 m between rows. The useful area was composed of three central rows, considering the lateral rows as a border.

Fertilization at sowing was carried out with 200 kg ha^{-1} of the formulation 04-20-20, equivalent to 8 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 40 kg ha^{-1} of K_2O, according to the recommendations of Ambrosano *et al*. (1997). Top-dressing N fertilization was carried out at the stage V_{4-3} (3rd trifoliate leaf fully open) with 100 kg ha^{-1} of N using urea as a source (Ambrosano *et al*., 1997). Common beans were harvested on 21 August 2019. Phytosanitary management was performed according to the recommendation of Fornasieri Filho and Fornasieri (2006) and Arf *et al*. (2015) for each crop.

Climatic characterization of the experimental period

Weather data of rainfall and maximum and minimum temperatures along the experiment are presented in Fig. 1. In order to meet the water requirements of the plants, a conventional sprinkler irrigation system was installed in the experimental area.

Upland rice evaluation

In order to determine the agronomic performance of the rice crop, the number of panicles m^{-2} was evaluated by counting the panicles in 2.0 m of row of plants and subsequently calculating the number for m^{-2}. The total number of spikelets per panicle was determined by the average number of grains from 20 panicles collected at the time of harvest. After separation of the grains by airflow, the numbers of filled and unfilled spikelets panicle^{-1} were determined. The mass of 100 grains was evaluated by weighing four samples of 100 grains in each plot (13% wet basis). The grains from the useful area of the plots were weighed, their moisture contents were corrected to 13% and the values were converted to kg ha^{-1}, obtaining grain yield.

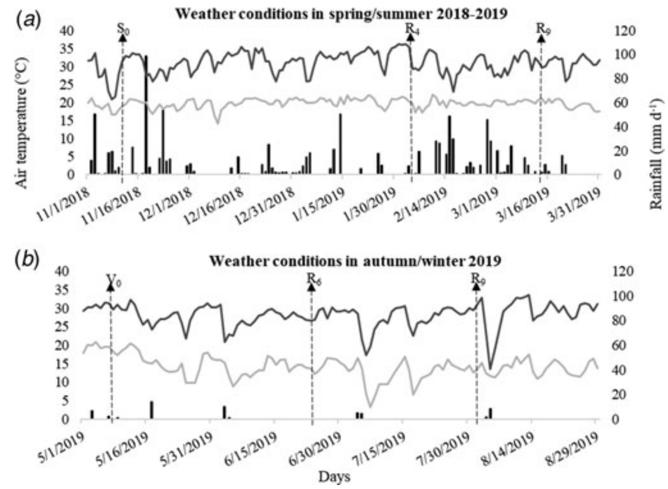

Fig. 1. Daily total rainfall and maximum and minimum temperature during the cultivation of rice as a sole crop and intercropped with green manures (a), and for common bean (b). Jaboticabal (SP), Brazil. 2018/19. S_0 = rice sowing, R_4 = rice flowering, R_9 = complete maturity of panicle, V_0 = common bean sowing, R_6 = common bean flowering, R_9 = physiological maturity of common bean.

The quality of rice grains was determined based on the crude protein content, obtained by multiplying the N content in the grains (Sarruge and Haag, 1974) by 6.25. The milling yield was obtained using a 100 g sample of rice paddy from each plot after processing in a mill, for 1 min. Afterwards, the polished grains were weighed, and the value found was considered as milling yield. After this process, burnished grains were placed in the 'trieur' n° 0 for 30 s, to separate the grains. The grains that remained in the 'trieur' were weighed to determine the head rice yield (whole milled grains) and the others were used to determine the broken-grain yield.

The residual dry biomass and consequently its decomposition, originating from cropping systems of rice with green manures, were evaluated by collecting the plant material with a 0.25 m^2 frame (0.45 × 0.55 m) at two points in each plot. The material was dried in a forced-ventilation oven at an average temperature of 60–70°C until it reached equilibrium mass, and the values were converted into kg ha^{-1}. The dry material was placed in nylon bags ('litter bags'), with a 2 mm opening mesh, with dimensions of 0.25 × 0.25 m (0.06 m^2) in a proportional amount to that obtained in kg ha^{-1}. Three litter bags were placed per plot on 07 May 2019, just after sowing the common bean, and later the collection was made at 30, 60, 90 days after the installation of the litter bags, coinciding with the stages V_3 (1st trifoliate leaf fully open), R_6 (end of flowering) and R_9 (beginning of pod maturation) of common bean, respectively. Each litter bag was dried in a forced-ventilation oven at an average temperature of 60–70°C until it reached an equilibrium mass, after which weighing was carried out.

Common bean evaluation

In the common bean crop, the agronomic performance was evaluated by the aerial dry biomass after the collection of ten plants in the useful area of the plot, during the full flowering of the plants (R_6), which were packed in paper bags, submitted to drying in a forced-ventilation oven at an average temperature of 60–70°C until reaching constant mass. After weighing, the values were converted into kg ha^{-1}.

Common bean yield components were evaluated at harvest with the collection of ten consecutive plants, in the central row

Table 1. Number of panicles m^{-2}, number of total spikelets, filled and unfilled spikelets panicle^{-1}, mass of 100 grains and grain yield of rice as sole crop or intercropped with green manures

Treatments	Panicles m^{-2} n°	Total spikelets	Filled spikelets	Unfilled spikelets	Mass of 100 grains g	Grain yield kg ha^{-1}
Rice	270.8 a	143.2	125.8	17.5	2.72 a	6875 a
Rice + dwarf pigeon pea	–	–	–	–	–	–
Rice + *C. breviflora*	200.5 b	138.5	117.0	21.2	2.61 b	2681 b
Rice + *C. spectabilis*	–	–	–	–	–	–
Rice + stylo	266.5 a	151.5	133.8	18.0	2.74 a	6131 a
Rice + forage peanut	254.5 a	148.8	128.0	21.2	2.75 a	6090 a
Rice + calopo	–	–	–	–	–	–
Rice + jack bean	–	–	–	–	–	–
F test[1]	5.12*	1.42^{ns}	2.94^{ns}	1.10^{ns}	4.39*	41.73**
CV (%)	11.56	6.67	6.43	19.86	2.25	10.67
Average[2]	248.1	145.5	126.1	19.5	2.71	5444

Jaboticabal (SP), Brazil. 2018/19.
[1]*F* test: **, * and ^{ns} – significant at 1% and 5% probability levels and not significant, respectively. Averages followed by the same letter in a column do not differ by Scott–Knott's test ($P < 0.05$). CV, coefficient of variation. [2]Average: composed of treatments with values greater than zero.

of the useful area of the plots. The number of pods plant^{-1} was evaluated as the relationship between the total number of pods and the number of plants. The average number of grains pod^{-1} was determined by the ratio of the total number of grains to the total number of pods. The mass of 100 grains was obtained by weighing four samples of 100 grains per plot. Grain yield was determined by manual harvesting of three rows; after drying in full sun, the grains were submitted to the mechanical threshing. The grains were weighed and the data were transformed into kg ha^{-1}, corrected to 13% moisture. The percentage of Fusarium wilt (*Fusarium oxysporum* f. sp. *phaseoli*) incidence was obtained by the ratio between plants affected by the disease in the useful area of the plot and the total of plants.

The quality of the common bean grains was evaluated based on sieve yield ≥12, which was obtained by classifying the grains with the aid of sieves with oblong holes 12/64″ × 3/4 (4.76 × 19.05 mm) in agitation for 1 min. The percentage of grains retained was obtained by the relationship between the mass of grains on the sieve and the total mass of grains. The crude protein content was determined after obtaining the N content in the grains (Sarruge and Haag, 1974) and multiplying it by 6.25.

Cooking time was determined with a Mattson cooker, after 16 h of hydration of the grains (Farinelli and Lemos, 2010). The level of resistance of the grains to cooking was verified according to the scale of Proctor and Watts (1987). To evaluate the maximum hydration time, 50 g of common bean were weighed and 200 ml of deionized water were added. The volume was checked every 2 h with a test tube for 16 h. The data obtained were submitted to polynomial regression analysis, finding the value of the time needed for maximum hydration of the grains. The hydration ratio was determined by the difference between the mass of the grains after 16 h of hydration and the initial mass of the grains.

Statistical analyses

The data were submitted to analysis of variance (ANOVA) and, when significance was found for the *F* test (<0.05), the means were compared using the Scott–Knott test (0.05). The data presented in percentage were transformed to meet the criteria of the ANOVA. The analysis of the dry biomass decomposition of the intercropping plants was performed by the regression test according to the collection times, following the methodology of Wider and Lang (1982), adopting an equation with a higher coefficient of determination (R^2) and significant ($P < 0.05$).

Results

The intercropping of rice and green manures affected the agronomic performance of the cereal, with a statistical difference between the cropping systems for the variables number of panicles m^{-2}, mass of 100 grains and grain yield (Table 1).

The use of *C. breviflora* enabled the development and production of rice, but reduced the amount of panicles m^{-2}, mass of 100 grains and grain yield in comparison to the cultivation of rice as sole crop and intercropped with forage peanut and stylo, indicating that there was also competition between these species (Table 1). The rice intercropped with *C. breviflora* reduced the grain yield of the cereal by 61% compared to the sole-crop cultivation.

The quality of rice grains was influenced by the intercropping systems with green manures, with statistical differences for all variables, except for the percentage of broken-grain yield (Table 2).

The dry matter decomposition for all cropping systems, except for the rice intercropped with dwarf pigeon pea, followed the logarithmic mathematical model, with rapid decomposition in the first 30 days of common bean development. Rice intercropped with dwarf pigeon pea showed exponential decomposition, that is, gradual decomposition over time (Fig. 2).

Prior to the cultivation of common beans, rice intercropped with stylo, calopo and forage peanut and sole-crop rice obtained dry biomass yields close to 6000 kg ha^{-1}. For the intercropping of rice with jack bean, *C. spectabilis* and *C. breviflora*, the values were close to 8000 kg ha^{-1}, while the intercropping with dwarf pigeon pea produced a dry biomass yield of around 11 000 kg ha^{-1}.

The dry biomass yield of rice intercropped with *C. breviflora* favoured the dry biomass production of common bean plants

Table 2. Crude protein content, milling yield, head rice yield and broken-grain yield of rice as sole crop or intercropped with green fertilizers

Treatments	Crude protein content	Milling yield	Head rice yield	Broken-grain yield
	%			
Rice	8.5 b	69.5 a	67.5 a	2.0
Rice + dwarf pigeon pea	–	–	–	–
Rice + *C. breviflora*	11.1 a	64.2 b	62.5 b	1.6
Rice + *C. spectabilis*	–	–	–	–
Rice + stylo	8.6 b	69.0 a	67.3 a	1.6
Rice + forage peanut	8.3 b	68.7 a	67.0 a	1.7
Rice + calopo	–	–	–	–
Rice + jack bean	–	–	–	–
F test[1]	14.87**	16.04**	13.41**	0.45^{ns}
CV (%)	3.16	0.92	0.99	13.72
Average[2]	9.12	67.82	66.07	1.76

Jaboticabal (SP), Brazil. 2018/19.
[1]*F* test: ** and ^{ns} – significant at 1% probability level and not significant, respectively. Averages followed by the same letter in a column do not differ by Scott–Knott's test ($P < 0.05$). CV, coefficient of variation.
[2]Average: composed of treatments with values greater than zero.

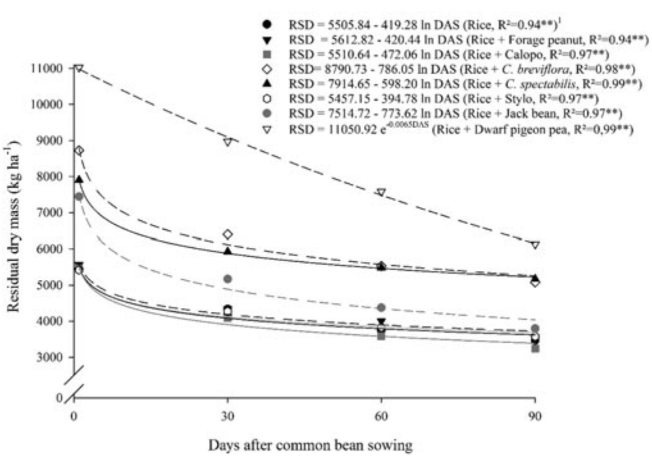

Fig. 2. Residual dry biomass of rice as a sole crop and intercropped with green manures remaining in the soil during common bean cultivation. Jaboticabal (SP), Brazil. 2019. [1]*F* test: **significant at 1% probability level.

over the other cropping systems, followed by rice intercropping with dwarf pigeon pea and *C. spectabilis*, despite making rice grain yield unfeasible (Table 3).

The number of pods per plant and the number of grains per pod of common bean showed statistical differences due to rice cropping systems (Table 3). The cultivation of rice as a sole crop and intercropped with stylo resulted in fewer pods per plant when compared to the other treatments. For the number of grains per pod, treatments of rice intercropped with dwarf pigeon pea, *C. breviflora*, *C. spectabilis* and calopo stood out. The mass of 100 grains of common bean was not influenced by rice cropping systems (Table 3).

The intercropping of rice with dwarf pigeon pea, *C. breviflora* and *C. spectabilis* provided greater dry biomass over the common bean cycle (Fig. 2), with positive effects on grain yield (Table 3). These cropping systems of intercropped rice, together with the sole-crop one, allowed grain yields higher than the average in the state of São Paulo, Brazil, for irrigated autumn-winter beans, 2713 kg ha^{-1} (IEA, 2020). These plants accumulate more N in the aerial part than stylo, forage peanut and calopo (Mendonça *et al.*, 2017), making this nutrient available to the common bean cultivated in succession. N is the most exported nutrient by common bean, being a constituent of proteins and molecules such as chlorophyll, besides being related to the increase in photosynthetic rate, leaf growth, development of vegetative and reproductive organs and biomass production (Taiz *et al.*, 2017).

Despite the lower dry biomass yield, the cultivation of sole-crop rice also stood out in terms of grain yield of common bean in succession, due to the lower incidence of Fusarium wilt, when compared to the intercropping of rice with stylo, forage peanut and calopo, which showed higher incidence of the disease despite having dry biomass production and decomposition similar to those of sole-crop rice (Table 3). The higher residual biomass and decomposition of the rice intercropped with jack bean did not contribute to the grain yield of common bean, because of the incidence of Fusarium wilt disease in this succession of crops.

As for the quality of common bean, the percentage of grains retained on the sieve ≥12 (sieve yield), crude protein content, cooking time, time for maximum hydration and the hydration ratio of the grains were not affected by previous cropping systems (Tables 4 and 5). Sieve yield ≥12 of the common bean was close to 70% considered as ideal by Carbonell *et al.* (2010) in all treatments. The crude protein content in common bean grains, in all rice cropping systems, was below that indicated for the cultivar BRS Estilo, which is 23% (Melo *et al.*, 2009), corroborating Vanier *et al.* (2019). This may be due to the variation of this component according to the place of cultivation and climatic conditions (Lajolo *et al.*, 1996).

The average value of the cooking time was 21 min and 50 s, considered adequate for being below 30 min (Ramalho and Abreu, 2006). In this context, for the cultivar BRS Estilo, used in this work, Melo *et al.* (2009) obtained a cooking time of 26

Table 3. Aerial dry biomass, number of pods plant^{-1}, grains pod^{-1}, mass of 100 grains, grain yield and incidence of Fusarium wilt in common bean in succession to rice as sole crop or intercropped with green manures

Treatments	Aerial dry biomass kg ha^{-1}	Pods plant^{-1} n°	Grains pod^{-1}	Mass of 100 grains *g*	Grain yield kg ha^{-1}	Fusarium wilt %
Rice	2880 c	18.0 b	4.5 b	25.09	3.052 a	1.85 c
Rice + dwarf pigeon pea	3208 b	21.8 a	5.0 a	24.78	3.628 a	1.75 c
Rice + *C. breviflora*	3917 a	22.5 a	4.8 a	25.43	3.435 a	0.92 c
Rice + *C. spectabilis*	3335 b	27.0 a	5.0 a	25.67	3.412 a	1.82 c
Rice + stylo	3028 c	15.5 b	4.0 b	24.90	2.879 b	3.50 b
Rice + forage peanut	2719 c	20.8 a	4.2 b	24.62	2.821 b	3.92 b
Rice + calopo	2664 c	20.8 a	5.0 a	25.47	2.313 c	6.45 a
Rice + jack bean	2392 c	21.8 a	4.5 b	24.74	2.304 c	3.92 b
F test[1]	5.38**	2.94*	3.69**	1.33^{ns}	6.68**	5.30**
CV (%)	13.54	18.62	8.51	2.70	13.00	31.90
Average[2]	3018	21.0	4.6	25.09	2.980	3.00

Jaboticabal (SP), Brazil. 2019.
[1]*F* test: **, * and ^{ns} – significant at 1 and 5% probability levels and not significant, respectively. Averages followed by the same letter in a column do not differ by Scott–Knott's test (P < 0.05). CV, coefficient of variation. [2]Average: composed of treatments with values greater than zero.

min. In addition, the values obtained were classified as normal cooking resistance, according to Proctor and Watts (1987), which promotes energy savings and practicality in preparing meals (Perina *et al*., 2014).

From the regression equations between the hydration time and the amount of water absorbed by the grains (Table 5), the time necessary for maximum hydration of the grains was obtained. The average value was 11 h and 24 min, which is a favourable result, since common beans are usually soaked for 12 h before cooking in Brazilian cuisine (Souza *et al*., 2019). In all treatments, the common bean grains showed a hydration ratio >2, indicating that the water absorption was equivalent to their initial weight, that is, there was an adequate performance of the grains in relation to this characteristic (Farinelli and Lemos, 2010).

Discussion

It is noteworthy that the yield of rice when intercropped with forage peanut and stylo was statistically similar to that obtained with its sole cropping (Table 1). This was possible due to the slow development and reduced size of forage peanut and stylo, resulting in low competition for water, light and nutrients. Shampazuraini *et al*. (2016) found that forage peanuts intercropped with rice did not affect grain yield, but increased the aerial dry biomass compared to the cultivation of rice as sole crop.

All cropping systems (sole-crop rice and intercropping systems) showed grain yield above the world average (4100 kg ha^{-1}) and close to the Brazilian average, which is 6020 kg ha^{-1} (IRRI, 2020). These results are also due to the adequate crop management, with emphasis on the choice of the cultivar BRS Esmeralda, which has great stability and adaptability in several regions of Brazil (Castro *et al*., 2014). Regarding the weather conditions that occurred during rice cultivation (Fig. 1a), three drought periods were observed: 03–12 December 2018, 15–24 January 2019, and 28 January 2019 to 05 February 2019. According to Guimarães *et al*. (2016), 10 days of drought can cause 31 and 51% reductions in rice grain yield when it occurs at the stages of panicle appearance (R_3) and grain length expansion (R_5), respectively. The water supply was carried out in the short-term drought periods by supplemental irrigation, and the water depth supplied was 90 mm, added to 830 mm from the rain in the rest of the rice cycle. It is also noteworthy that the cultivar BRS Esmeralda has drought tolerance (Castro *et al*., 2014), and the physical and chemical attributes of the soil such as clayey texture, having greater capacity to store water, low acidity, as well as high levels of phosphorus, potassium, calcium and magnesium, contributed to root development and plant nutrition, positively affecting grain yield.

The intercropping of rice with dwarf pigeon pea, *C. spectabilis*, calopo and jack bean, made the development and grain yield of rice unfeasible due to the rapid growth and competitiveness of these green manures in comparison to the cereal. These plants suppressed the rice plants, due to shading, reducing the development of cells in young and old leaves, damaging the leaf area (Wu *et al*., 2017), besides decreasing the absorption and utilization of nutrients (Taiz *et al*., 2017). Wang *et al*. (2013) observed that shading, especially at more advanced phenological stages, change the composition of rice starch, increasing the amount of broken and poorly developed grains. Chen *et al*. (2019) observed that shading reduces spikelet filling and rice grain mass, directly interfering with crop yield. The authors found that shading interferes with the availability and quality of light for rice, a factor that affects the content and ratio of chlorophylls a and b and, consequently, reduces photosynthetic efficiency and increases heat energy dissipation. Pan *et al*. (2016) also found that shading reduced photosynthetic rate, total root length, grain mass and, consequently, rice yield.

Another aspect that may have contributed is that rice plants have slow initial development until 30–40 days after emergence (Ramalho *et al*., 2005), in addition to being a species with C3 metabolism, having lower efficiency of energy conversion into biomass compared to plants with C4 metabolism (Taiz *et al*., 2017). The intercropping of rice with *C. breviflora* promoted a higher protein content in the grains, probably due to the concentration effect (Jarrel and Beverly, 1981). However, this

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Table 4. Grains retained on the sieve ≥12, crude protein content, cooking time and level of resistance to cooking of common bean in succession to rice as sole crop or intercropped with green manures

	Sieve yield ≥12	Crude protein content	Cooking time	Resistance level
Treatments	%		min:sec	–
Rice	65.8	19.40	22:26	Normal
Rice + dwarf pigeon pea	70.6	19.84	21:40	Normal
Rice + *C. breviflora*	71.6	19.54	20:40	Normal
Rice + *C. spectabilis*	70.6	20.42	23:39	Normal
Rice + stylo	64.4	18.81	21:34	Normal
Rice + forage peanut	64.8	19.83	21:56	Normal
Rice + calopo	61.7	20.13	21:57	Normal
Rice + Jack bean	63.9	20.86	20:50	Normal
F test[1]	1.96^{ns}	1.28^{ns}	1.28^{ns}	–
CV (%)	7.95	2.44	7.60	–
Average[2]	66.7	19.85	21:50	–

Jaboticabal (SP), Brazil. 2019.
[1]*F* test: ^{ns} – significant at 1 and 5% probability levels and not significant, respectively. Averages followed by the same letter in a column do not differ by Scott–Knott's test ($P \leq 0.05$). CV, coefficient of variation.
[2]Average: composed of treatments with values greater than zero.

Table 5. Regression equation between the time (T – h) for grain hydration and the amount of water absorbed (WA – ml) by common bean, determination coefficient (R^2) and time for maximum grain hydration (TMH) and the hydration ratio (HR) of the common bean in succession to rice as sole crop or intercropped with green manures

	Regression equation[2]	R^2	TMH	HR
Treatments	–	–	h:min	–
Rice	$WA = -0.0001\ T^2 + 0.1377\ T + 11.62738$	0.82	11:29	2.05
Rice + dwarf pigeon pea	$WA = -0.0001\ T^2 + 0.1376\ T + 11.2767$	0.83	11:28	2.05
Rice + *C. breviflora*	$WA = -0.0001\ T^2 + 0.13525\ T + 10.89968$	0.84	11:16	2.04
Rice + *C. spectabilis*	$WA = -0.0001\ T^2 + 0.1358\ T + 11.45812$	0.82	11:19	2.04
Rice + stylo	$WA = -0.0001\ T^2 + 0.13647\ T + 11.48743$	0.83	11:22	2.05
Rice + forage peanut	$WA = -0.0001\ T^2 + 0.13601\ T + 11.78054$	0.82	11:20	2.04
Rice + calopo	$WA = -0.0001\ T^2 + 0.13964\ T + 11.17982$	0.84	11:38	2.05
Rice + jack bean	$WA = -0.0001\ T^2 + 0.13577\ T + 11.81515$	0.82	11:19	2.05
F test[1]	–	**	0.95^{ns}	0.54^{ns}
CV (%)	–	–	2.98	0.56
Average	–	–	11:24	2.05

Jaboticabal (SP), Brazil. 2019.
[1]*F* test: ** and ^{ns} – significant at 1% probability level and not significant, respectively. CV, coefficient of variation.
[2]x = time for hydration (min) and y = amount of water absorbed (ml).

intercropping system hampered the quality of the grains, reducing the percentage of milling yield and head rice yield, when compared to rice as sole crop or intercropped with stylo and forage peanut (Table 2). It should be noted that the protein values found in rice cropping systems are within the recommended range for the cereal, which can vary from 5.1 to 11.3% (Champagne *et al*., 1999). Crusciol *et al*. (2008) found protein values in rice grains ranging from 7.5 to 8.4%.

In Brazil, the recommended milling yield is above 68% (Fornasieri Filho and Fornasieri, 2006), and only the intercropping of rice with *C. breviflora* led to milling yield below this value. The values of milling yield and head rice yield were similar to those found by Portugal *et al.* (2020) in rice cultivation under NTS, for the cultivar BRS Esmeralda. Rice quality is also assessed by the percentage of broken-grain yield and rice grits. The classification varies in category 1–5, in which 1 tolerates up to 7.5% of broken-grain and category 5, up to 45% of broken-grain yield and rice grits (Brazil, 2010). In the present study, in all rice cropping systems, the percentage was <3%, indicating that they fall into type 1. This characteristic gives greater value to the product in commercialization, since the consumer has a preference for rice with uniform and head rice grains.

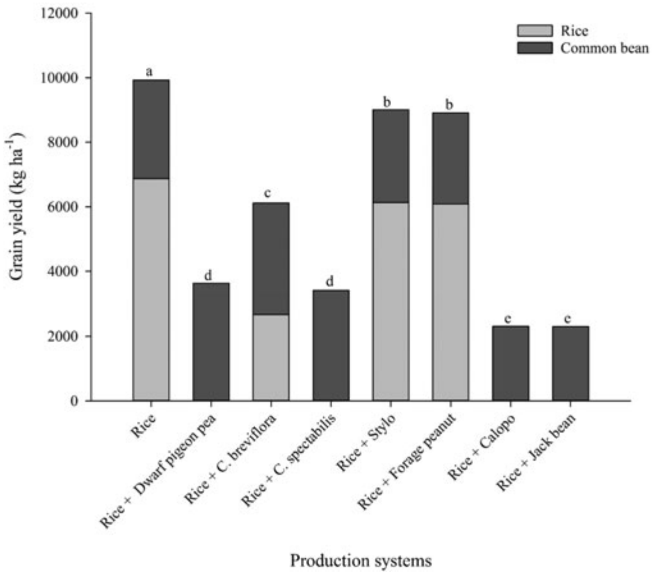

Fig. 3. Total grain yield of rice (as sole crop and intercropped with green manures) and common bean. Jaboticabal (SP), Brazil. 2018/19. *F* test = 128.32** – significant at 1% probability level. Means followed by the same letter on the bars do not differ by the Scott–Knott ($P \leq 0.05$). Coefficient of variation = 9.92%.

We highlight that the dry biomass yield obtained in the intercropping is important for the viability of the NTS, and consequently for conducting a conservational and sustainable agriculture, since it enables the covering of the soil, contributing to the reduction of erosive processes, through the lower impact of raindrops on the soil, allowing greater water infiltration in the soil and less runoff. In order to have adequate soil cover in this production system, it is recommended that 7000–8000 kg ha^{-1} of dry biomass be produced in tropical and subtropical regions in the Brazilian Cerrado (Aidar *et al.*, 2007). Thus, the intercropping systems of rice with jack bean, *C. spectabilis*, *C. breviflora* and dwarf pigeon pea showed dry biomass yield values above 8000 kg ha^{-1}, proving to be advantageous for the quality of NTS.

Another important aspect refers to the results of dry biomass yield being similar to that found by Arf *et al.* (2018) in an intercropping of corn with green manures (jack bean, dwarf pigeon pea and *C. spectabilis*), noting that the amount of N present in the dry biomass of the intercropped cultivation was 48% higher than that of sole-crop corn. Common bean crop shows higher macronutrient absorption in the leaves between 28 and 31 DAE (Pegoraro *et al.*, 2013). Thus, the greater initial decomposition of the previous crop may have favoured the development of common bean in the first 30 days, which was at stage V_3, with this decomposition being higher in the cropping systems of rice intercropped with *C. breviflora*, jack bean, dwarf pigeon pea and *C. spectabilis* (2328, 2276, 2055 and 1977 kg ha^{-1}, respectively).

In intercropped systems, as in the present work, where different species are cultivated in the same period, there are improvements in the diversification of microbial species in the soil, favouring microorganisms that have the function of biocontrol against certain pathogens (Vukicevich *et al.*, 2016). However, some plant exudates may also favour an increase in the population of pathogenic microorganisms (Nicol *et al.*, 2003). Plants grown before common bean can be hosts of the pathogen, such as jack beans, and other bad hosts such as rice (Dhingra and Coelho-Neto, 2001).

In this sense, we verified that the cultivation of stylo, forage peanut, calopo and jack bean with rice increases Fusarium wilt incidence in common bean cultivated in succession. According to Calegari and Carlos (2014), some species of green manures can multiply diseases and pests that attack crops of economic interest, such as common bean. Thus, green manure species that multiply pathogens should be avoided when economic interest crops are also susceptible to them. Gridi-Papp *et al.* (1970) observed that green manures can multiply Fusarium wilt and increase the inoculum source and disease incidence in crops grown in succession.

Common bean grain yield ranged from 2304 to 3628 kg ha^{-1}, obtained after the cultivation of rice intercropped with jack bean and dwarf pigeon pea, respectively (Table 3). Average grain yield was 2980 kg ha^{-1}, which is higher than the Brazilian average for autumn-winter cultivation, which is 1348 kg ha^{-1} (CONAB, 2020). In addition to the influence of rice cropping systems, as sole crop and intercropped with green manures, the common bean grain yield may be linked to cultural management, with emphasis on water supply, totalling 423 mm of total water depth, being 48 mm from rain and the rest supplied by irrigation. Regarding the climatic conditions, it was found that in the period from 06 to 07 November 2019, there were minimum temperatures below 10°C (Fig. 1b), which paralyze plant development (Wutke *et al.*, 2000). However, this cold period was short so that it did not influence the cycle and the yield performance of the common bean.

We found that the cultivation of rice (sole crop) and common bean was the crop succession that promoted the largest total amount of grains, 9927 kg ha^{-1}, with 6875 kg ha^{-1} coming from rice and 3052 kg ha^{-1} from beans (Fig. 3). The cropping systems of rice intercropped with stylo and forage peanut also stood out for the total grain yield, which was 9010 kg ha^{-1} (6131 kg ha^{-1} of rice grains and 2879 of common bean) and 8911 kg ha^{-1} (6091 kg ha^{-1} of rice grains and 2821 kg ha^{-1} of common bean), respectively. Grain yield close to 10 000 kg ha^{-1} year^{-1} has been observed in the succession of grain crops under NTS, such as for soybean/corn (Nóia Júnior and Sentelhas, 2019) and corn/common bean (Souza *et al.*, 2019).

Conclusion

The results from this study show that intercropping of upland rice is viable depending on the green manure species. The intercropping of rice with stylo and forage peanut made it possible to obtain grain yield and quality similar to those obtained with the cultivation of sole-crop rice. The cropping systems of rice intercropped with dwarf pigeon pea, *C. breviflora* and *C. spectabilis*, although unfeasible in terms of cereal grain yield, provided greater dry biomass yield that can help long-term soil conservation and increase the system's yield.

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References

Aidar H, Kluthcouski J and Cobucci T (2007) Palhada de braquiária: redução dos riscos e do custo de produção das lavouras. In Paula Júnior TJ (ed.), *Integração lavoura–pecuária*. Belo Horizonte: Epamig, pp. 30–38.

Amado TJC, Fiorin JE, Arns U, Nicoloso RS and Ferreira AO (2014) Adubação verde na produção de grãos e no sistema plantio direto. In Lima Filho OF, Ambrosano EJ, Rossi F and Carlos JAD (eds), *Adubação verde e plantas de cobertura no Brasil: fundamentos e práticas. v.2.* Brasília: Embrapa, p. 81–125.

Ambrosano EJ, Wutke EB, Bulisani EA and Cantarella H (1997) Feijão. In Raij BV, Cantarella H, Quaggio JA and Furlani AMC (ed.), *Recomendação de adubação e calagem para o Estado de São Paulo*, 2nd Edn. Campinas: Instituto Agronômico, pp. 194–195. (Boletim técnico, 100).

Arf O, Lemos LB, Soratto RP and Ferrari S (2015) *Aspectos gerais da cultura do feijão*. Botucatu: FEPAF, 433 p.

Arf O, Portugal JR, Buzetti S, Rodrigues RAF and Sá ME (2018) Crop rotation, green manure and nitrogen fertilizers in upland rice under no-tillage. *Pesquisa Agropecuária Tropical* **48**, 153–162.

Bindraban PS, Velde MVD, Ye L, Berg MVD, Materechera S, Kiba DI, Tamene L, Ragnarsdóttir KV, Jongschaap R, Hoogmoed M, Hoogmoed W, Beek CV and Lynden GV (2012) Assessing the impact of soil degradation on food production. *Current Opinion in Environmental Sustainability* **4**, 478–488.

Brazil (2010) Ministério da agricultura, pecuária e abastecimento. *Instrução Normativa n° 12 de 12 de março de* 2010. Brasília: MAPA/ACS.

Calegari A and Carlos JAD (2014) Recomendações de plantio e informações gerais sobre o uso de espécies para adubação verde no Brasil. In Lima Filho OF, Ambrosano EJ, Rossi F and Carlos JAD (eds), *Adubação verde e plantas de cobertura no Brasil: fundamentos e práticas. v.2.* Brasília: Embrapa, pp. 451–478.

Cantarella H and Raij BV (1997) Cereais. In Raij BV, Cantarella H, Quaggio JÁ and Furlani AMC (eds), *Recomendação de adubação e calagem para o Estado de São Paulo* (2nd Edn.). Campinas: Instituto Agronômico de Campinas, pp. 48–49.

Carbonell SAM, Chiorato AF, Gonçalves JGR, Perina EF and Carvalho CRL (2010) Tamanho de grão comercial em cultivares de feijoeiro. *Ciência Rural* **40**, 2067–2073.

Castro-Guerrero NA, Isidra-Arellano MC, Mendoza-Cozatl DG and Valdés-López O (2016) Common bean: a legume model on the rise for unraveling responses and adaptations to iron, zinc, and phosphate deficiencies. *Frontiers in Plant Science* **7**, 600.

Castro AP, Morais OP, Breseghello F, Lobo VLS, Guimarães CM, Bassinello PZ, Colombari Filho JM, Santiago CM, Furtini IV, Torga PP and Utumi MM (2014) *BRS Esmeralda: cultivar de arroz de terras altas com elevada produtividade e maior tolerância à seca*. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 4 p.

Champagne ET, Bett-Garber KL, Vinyard BT, McClung AM, Barton IIFE, Moldenhauer K, Linscombe S and McKenzie K (1999) Correlation between cooked rice texture and rapid visco analyzer measurements. *Cereal Chemistry* **76**, 764–771.

Chen H, Li QP, Zeng YL, Deng F and Ren WJ (2019) Effect of different shading materials on grain yield and quality of rice. *Scientific Reports* **9**, 1–9.

Conab – Companhia nacional de abastecimento (2020) *Acompanhamento da safra brasileira de grãos, safra 2019/20*. Brasília: Conab, v. 7, pp. 1–112.

Crusciol CAC, Arf O, Soratto RP and Mateus GP (2008) Grain quality of upland rice cultivars in response to cropping systems in the Brazilian tropical savanna. *Scientia Agricola* **65**, 468–473.

Dhingra O and Coelho-Neto RA (2001) Reservoir and non-reservoir host of bean-wilt pathogen, *Fusarium oxysporum* f. sp. *phaseoli*. *Journal of Phytopathology* **149**, 463–467.

Farinelli R and Lemos LB (2010) Produtividade, eficiência agronômica, características nutricionais e tecnológicas do feijão adubado com nitrogênio em plantio direto e convencional. *Bragantia* **69**, 165–172.

Fornasieri Filho D and Fornasieri JL (2006) *Manual da cultura do arroz*. Jaboticabal, SP: FUNEP, p. 589.

Gridi-Papp IL, Fuzatto MG, Ferraz CA and Cia E (1970) Seleção do algodoeiro para resistência à fusariose em área onde ocorre doença semelhante em plantas de labelabe (*Dolichos lablab* L.). *Bragantia* **29**, 67–72.

Guimarães CM, Stone LF and Silva ACL (2016) Evapotranspiration and grain yield of upland rice as affected by water deficit. *Revista Brasileira de Engenharia Agrícola e Ambiental* **20**, 441–446.

IEA – Instituto de Economia Agrícola (2020) Feijão de inverno irrigado. Available at http://ciagri.iea.sp.gov.br/ (Accessed 24 March 2020).

IRRI – International Rice Research Institute (2020) World rice statistics. Available at http://ricestat.irri.org/ (Accessed 13 January 2020).

Jarrel WM and Beverly RB (1981) The dilution effect in plant nutrition studies. *Advances in Agronomy* **34**, 197–224.

Kaewpradit W, Toomsan B, Cadisch G, Vityakon P, Limpinuntana V, Saenjan P, Jogloy S and Patanothai A (2009) Mixing groundnut residues and rice straw to improve rice yield and N use efficiency. *Field Crops Research* **110**, 130–138.

Lajolo FM, Genovese MI and Menezes EW (1996) Qualidade nutricional. In Araújo RS, Rava CA, Stone LF and Zimmermann MJO (eds), *Cultura do feijoeiro no Brasil*. Piracicaba: Potafos, pp. 23–56.

Li L, Sum J, Zhang F, Guo T, Bao X, Smith FA and Smith SE (2006) Root distribution and interactions between intercropped species. *Oecologia* **147**, 280–290.

Martin-Guay M, Paquette A, Dupras J and Rivest D (2018) The new green revolution: sustainable intensification of agriculture by intercropping. *Science of the Total Environment* **615**, 767–772.

Melo LC, Peloso MJD, Pereira HS, Faria LC, Costa JGC, Díaz JLC, Rava CA, Wendland A, Carvalho HWL, Costa AF, Almeida VM, Melo CLP, Vieira Júnior JP, Faria JC, Souza JF, Marangon MA, Cargnin A, Abreu AFB, Moreira JAA, Pereira Filho IA, Guimarães CM, Bassinello PZ, Brondani RPV and Magaldi MCS (2009) *BRS Estilo: cultivar de grão tipo comercial carioca, com arquitetura de planta ereta associada com alto potencial produtivo*. Santo Antônio de Goiás: Embrapa. v. 186, pp. 1–4.

Mendonça ES, Lima PC, Guimarães GP, Moura WM and Andrade FV (2017) Biological nitrogen fixation by legumes and n uptake by coffee plants. *Revista Brasileira de Ciência do Solo* **41**, e0160178.

Mingotte FLC and Lemos LB (2018) Rotação e sucessão de culturas: formação de palha para o sistema plantio direto de qualidade no Cerrado. In Paes JMV and Andrade AT (eds), *Sistema plantio direto no Cerrado*. Belo Horizonte: Epamig, pp. 28–41.

Nicol RW, Yousef L, Traquair JA and Bernards MA (2003) Ginsenosides stimulate the growth of soilborne pathogens of American ginseng. *Phytochemistry* **64**, 257–264.

Nóia Júnior RS and Sentelhas PC (2019) Soybean-maize succession in Brazil: impacts of sowing dates on climate variability, yields and economic profitability. *European Journal of Agronomy* **103**, 140–151.

Norris CE and Congreves KA (2018) Alternative management practices improve soil health indices in intensive vegetable cropping systems: a review. *Frontiers in Environmental Science Agroecology* **6**, 1–18.

OECD, FAO (2020) Organisation for Economic Co-operation and Development, Food and Agricultural Organization. *Agricultural Outlook*. Available at https://stats.oecd.org (Accessed 4 January 2020).

Pan S, Liu H, Mo Z, Patterson B, Duan M, Tian H, Hu S and Tang X (2016) Effects of nitrogen and shading on root morphologies, nutrient accumulation, and photosynthetic parameters in different rice genotypes. *Scientific Reports* **6**, 1–14.

Pegoraro RF, Oliveira D, Moreira GBL, Kondo MK, Maia VM and Vieira NMB (2013) Absorption, accumulation and export of macronutrients by common bean irrigated, and influenced by nitrogen fertilization. *Journal of Agricultural Science* **5**, 34–48.

Perina EF, Carvalho CRL, Chiorato AF, Lopes RLT, Gonçalves JGR and Carbonell SAM (2014) Technological quality of common bean grains obtained in different growing seasons. *Bragantia* **73**, 14–22.

Portugal JR, Arf O, Buzetti S, Portugal ARP, Garcia NFS, Meirelles FC, Garé LM, Abrantes FL and Rodrigues RAF (2020) Do cover crops improve the productivity and industrial quality of upland rice? *Agronomy Journal* **112**, 327–343.

Proctor JR and Watts BM (1987) Development of a modified Mattson bean cooker procedure based on sensory panel cookability evaluation. *Canadian Institute of Food Science and Technology Journal* **20**, 9–14.

Rahman T, Liu X, Hussain S, Ahmed S, Chen G, Yang F, Chen L, Du J, Liu W and Yang W (2017) Water use efficiency and evapotranspiration in maize-soybean relay strip intercrop systems as affected by planting geometries. *PLoS ONE* **12**, e0178332.

Ramalho MAP and Abreu AFB (2006) Cultivares. In Vieira C, Paula Junior TJP and Borém A (eds), *Feijão*, 2nd Edn. Viçosa: Universidade Federal de Viçosa, pp. 415, 436.

https://doi.org/10.1017/S0021859621000940 Published online by Cambridge University Press

Ramalho AR, Utumi MM and Godinho VPC (2005) *Cultivares de arroz de terras altas indicadas para Rondônia – período 2004/06*. Porto Velho: Embrapa, p. 10.

Saito K, Linquist B, Keobualapha B, Phanthaboon K, Shiraiwa T and Horie T (2006) *Stylosanthes guianensis* as a short-term fallow crop for improving upland rice productivity in northern Laos. *Field Crops Research* **96**, 438–447.

Santos HG, Jacomine PKT, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Cunha TJF and Oliveira JB (2013) *Sistema brasileiro de classificação de solos*, 3rd Edn. Brasília: Embrapa, p. 353.

Sarruge JR and Haag HP (1974) *Análises químicas de plantas*. Piracicaba: Escola Superior de Agricultura Luiz de Queiroz, p. 56.

Shampazuraini S, Husein AG, Sitiaminah W and Nurhasanah S (2016) Study on the growth performance of aerobic rice intercropping with *Vigna radiata* and *Arachis pintoi*. *International Journal of Advanced Research* **4**, 701–706.

Souza SS, Couto Júnior PA, Flôres JA, Mingotte FLC and Lemos LB (2019) Maize cropping systems and response of common bean in succession subjected to nitrogen fertilization. *Pesquisa Agropecuária Tropical* **49**, e55718.

Taiz L, Zeiger E, Møller IA and Murphy A (2017) *Fisiologia e Desenvolvimento Vegetal*. Porto Alegre: Artmed, p. 858.

Vanier NL, Ferreira CD, Lindemann IS, Santos JP, Bassinello PZ and Elias MC (2019) Physicochemical and technological properties of common bean cultivars (*Phaseolus vulgaris* L.) grown in Brazil and their starch characteristics. *Revista Brasileira de Ciências Agrárias* **14**, e5675.

Vukicevich E, Lowery T, Bowen P, Úrbez-Torres JR and Har M (2016) Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. A review. *Agronomy for Sustainable Development* **36**, 1–14.

Wang L, Deng F, Ren WJ and Yang WY (2013) Effects of shading on starch pasting characteristics of indica hybrid rice (*Oryza sativa* L.). *PLoS ONE* **8**, e68220.

Wider RK and Lang GE (1982) A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* **63**, 1636–1642.

Wu Y, Gong W and Yang W (2017) Shade inhibits leaf size by controlling cell proliferation and enlargement in soybean. *Scientific Reports* **7**, 9259.

Wutke EB, Brunini O, Barbano MT, Castro JL, Gallo PB, Kanthack RAD, Martins ALM, Pereira JCVNA, Bortoleto N, Paulo EM, Sakai M, Saes LA, Ambrosano EJ, Carbonell SAM and Silveira LCP (2000) Estimativa de temperatura base e graus-dia para feijoeiro nas diferentes fases fenológicas. *Revista Brasileira de Agrometeorologia* **8**, 55–61.