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EARLY POTASSIUM FERTILIZATION IN THE COVER CROP AND ITS RESIDUAL ON MAIZE SILAGE IN SUCCESSION

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ABSTRACT – This study aimed to evaluate the effects of the application of potassium fertilizer (K) on *Urochloa ruziziensis* cultivated in fall/winter in the silage maize (*Zea mays* L.) cultivated in succession. The experiment was performed in a randomized block design in the fall/winter. The plots were composed of *U. ruziziensis* and six K doses (0, 30, 60, 90, 120 and 150 kg ha^{-1}) as muriate of potash (57% K_2O) and a fallow treatment. For the summer crop, the treatments were composed of silage maize and six K_2O doses (120, 90, 60, 30, 0, and 0 (sowing and broadcast kg ha^{-1}) complementary to the treatments applied to the fall/winter crop (totalling 150 kg K_2O ha^{-1}). In addition, we applied a recommended fertilization amount (60 and 90 kg K_2O ha^{-1} at sowing and broadcasting, respectively to silage maize. For *U. ruziziensis*, plant height, green and dry biomass yields, and soil coverage were evaluated. For the maize silage, agronomic traits, leaf nutrient contents, and green and dry biomass yields were evaluated. The application of K fertilizer at advanced rates to *U. ruziziensis* did not alter its yield components or silage maize grown in succession; however, the complementary doses of 90 and 120 kg ha^{-1} of K_2O promoted silage maize ears with larger diameters than those observed under the recommended fertilization.

Keywords: *Zea mays* L., potassium, brachiaria, cover crops, *Urochloa ruziziensis*

Maize silage (*Zea mays* L.) is one of the most widely used in intensive meat and milk production systems, especially during dry periods, due to its high mass productivity, good fermentation quality, and high nutritional value (Klein et al., 2018; Melo et al., 2021). However, during whole-plant harvesting for silage, all plant material that could contribute to nutrient cycling is exported from the cultivated area. This procedure depletes soil nutrients, especially potassium (K), which is abundant in corn straw (Ueno et al., 2011, 2013). In regions where it is difficult to grow crops in succession due to low rainfall amounts, the soil remains exposed until the next harvest (Moreira et al., 2014), causing an increase in weed infestation (Assis et al., 2016), while the accumulation of small amounts of organic matter in the soil is slow (Ueno et al., 2011).

In situations where continuous silage maize cultivation is adopted, it is essential to implement management practices that sustain production systems. In this sense, the successive growth of crops with the use of cover crops is a viable alternative, given the advantages it provides to the systems. Cover crops have efficient biomass production and promote good soil cover (Andrioli & Prado, 2012); they can increase soil organic matter content and thus improve chemical, physical and biological properties of soil, contribute to the recycling of nutrients, and regulate the temperature of the soil, in addition to efficiently suppressing weeds and controlling erosion (Adetunji et al., 2020). Therefore, given the expected benefits of cultivating a cover crop, the choice of species should be based on the climate and soil type where it will be grown.

Urochloa ruziziensis (R. Germain & Evrard) is a forage plant widely used for biomass production and soil cover in direct seeding systems (Balbinot Júnior et al., 2017), because it desiccates easily with nonselective herbicides and forms fewer clumps than other *Brachiaria* species (Franchini et al., 2014). In addition, it has a high capacity for shoot biomass production and root volume even under deficit water conditions (Petter et al., 2013). In areas with low water availability in the Cerrado, it shows good regrowth at the start of the rainy season when planted in fall/winter (Pacheco et al., 2013). *Urochloa ruziziensis* also has great potential to recycle nutrients, especially potassium (K), and is therefore considered a suitable plant for soil nutrient management and the sustainability of agricultural production systems (Rosolem et al., 2012).

In early fertilization, the fertilizer dose required for a summer crop can be applied partially or fully, delivered in bulk or incorporated into the growth medium, or applied to the previous crop (i.e., in the fall/winter) (Francisco et al., 2007). Early fertilization provides advantages to the producer, such as the reduction of costs and time by performing the operations in the summer cultivation period and the use of labour and machines, considering that these would already be in use in the fall/winter cultivation (Francisco et al., 2007; Timossi et al., 2016). However, when potassium fertilizer is applied in advance, it is necessary to consider soil texture, nutrient content, and water availability to avoid leaching losses (Lage et al., 2019).

The objective of this study was to evaluate the effects of early application of potassium fertilization on *U. ruziziensis* cultivated during fall/winter on the yield of silage maize grown in succession.

The research presented in this paper was part of a larger experiment that examined the effects of early K fertilization on *Pennisetum glaucum*, *U. ruziziensis* cover crops, and the succeeding silage maize crop (Bertolino et al., in review). The experimental approach and the effects of K fertilization on *P. glaucum* and the succeeding silage maize were discussed in the previous paper. The effect of K on silage maize in the absence of a cover crop - the control treatment for comparison- was also included in this paper for convenience in comparing the impact of *P. glaucum* to that of fallow. In this paper, we focus on *U. ruziziensis*. The experiment was performed during the fall/winter harvest of 2020 and the summer harvest of 2021 at the Center for Development and Technology Transfer (CDTT) of the Federal University of Lavras (21°10'S and 44°55'W) at Ijaci, MG, Brazil. The region's climate is humid temperate (Cwa), with hot, humid summers and dry, cold winters, with an average annual temperature of 19.4 °C and an average annual rainfall of 1,530 mm. The climatic variations occurring in the area during the experiment are shown in Figure 1.

The soil in the experimental area was classified as dystrophic Red Yellow Latosol (Santos et al., 2018). A soil analysis performed in the 0-20 layer at the beginning of the experiment was: pH H_2O, 6.9; Ca^{2+}, 3.2 $cmol_c$ dm^{-3}; Mg^{2+}, 0.60 $cmol_c$ dm^{-3}; Al^{3+}, 0 $cmol_c$ dm^{-3}; H+Al, 1.8 $cmol_c$ dm^{-3}; effective CEC (t), 4.2 $cmol_c$ dm^{-3}; CEC at pH 7, 6.0 $cmol_c$ dm^{-3}; P (Rem), 17.50 mg dm^{-3}; K^+, 142.2 mg dm^{-3}; sum of bases, 4.17 $cmol_c$ dm^{-3}; base saturation, 70%; OM, 2.4%; clay, 64%; silt, 5%; and sand, 31%.

In the fall/winter harvest of 2020, the soil was prepared for *U. ruziziensis* planting with two harrows, and then furrows were opened with a furrower. *U. ruziziensis* from BR Seeds (Cultural value: 62%) was manually sown using 10 kg seed ha^{-1} in April 2020 to 6 of 7 treatments in each replication – one plot per replication was left fallow. The plots totalled 12.5 m^2, consisting of five m long planting rows spaced 0.25 m apart and were arranged in a randomized complete block with four replications. Forty- seven days after sowing *B. ruziziensis* six early K application treatments (0, 30, 60, 90, 120 and 150 kg K_2O ha^{-1} as KCl, 57% K_2O), was broadcast to the plots with a complementary dose to be applied in the summer to achieve a total application of 150 kg K_2O as is recommended for maize in the Cerrado (Sousa & Lobato, 2004). A seventh treatment was left fallow and no K_2O was applied. There were three replications of each treatment.

In November 2020, the *U. ruziziensis* were cut close to the ground using a backpack brush-cutter, then the residues were evenly distributed uniformly within each plot. To eliminate existing weeds and possible resprouting of the cover crop, all plots were sprayed with glyphosate at 2.0 kg ai ha^{-1}.

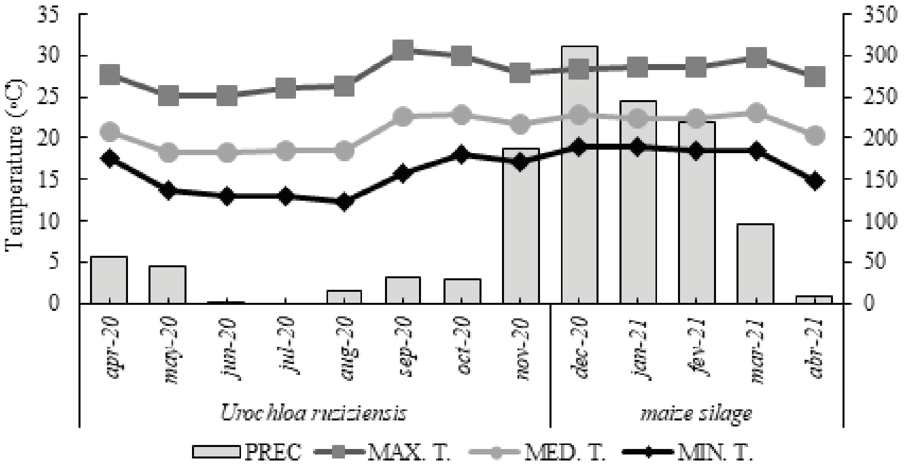

Figure 1. Monthly precipitation (PREC) and maximum (T MAX), mean (T AVER) and minimum (T MIN) temperatures from April 2020 to April 2021 in the municipality of Ijaci in the state of Minas Gerais, Brazil.

In the summer harvest of 2020/21, the experimental plots were installed in the previously harvested plots. Maize (R9080 PRO 2 hybrid) was sown in December 2020 at 60.000 seeds ha^{-1} with a no-till planter equipped with a colter that placed 350 kg ha^{-1} of monoammonium phosphate at sowing. Thirty kg K_2O ha^{-1} was manually broadcast on the soil surface for all but 2 treatments – the treatment that had previously received 150 kg K_2O ha^{-1} applied to *U. ruziziensis* and the fallow treatment. Additional K was broadcast at V4 at rates to total 150 kg K_2O ha^{-1} (150, 120, 60, 30, 0 kg K_2O ha^{-1}, including the different rates of K_2O applied to *U. ruziziensis* and 30 K_2O ha^{-1} at maize sowing), was applied to the plot that received K when sown to *U. ruziziensis*. The treatment without *U. ruziziensis* cover crop (fallow) received the standard recommendation for maize – 60 and 90 K_2O ha^{-1} broadcast at sowing and at V_4, respectively (Sousa & Lobato, 2004). Also, at V4, 180 kg N ha^{-1} as urea (46% N), glyphosate (2.00 kg ai ha^{-1}), and atrazine (1.25 kg ai ha^{-1}) were broadcast to all plots. Maize at growth stage R5 was harvested for ensiling in April 2021 (112 days after sowing).

Urochloa ruziziensis parameters were determined in November 2020 from the center of each plot. Plant height from the soil surface to the last leaf was determined for 10 randomly selected plants. Whole plants were collected from 1 m^2 and the wet weight was determined. A 500 g subsample of the entire plant was weighed after drying in a forced-air oven at 65 °C until constant weight. Wet and dry biomass were extrapolated to t ha^{-1}.

The area of soil covered by *U. ruziziensis* residue was determined on the day of harvest. A 0.05 m^{-2} wooden frame with string spaced at 0.05 m to create 0.05 m^{-2} was used to estimate percent residue cover at 5 locations in the middle of each plot (Alvarenga, 1993).

At maize growth stage R1, 10 plants were randomly chosen from the center of each plot for determination of plant height from the soil level to the insertion of the flag leaf node; height of ear insertion, taken from the ground level to the insertion of the first ear; length of the ear with husk diameter of the ear, measured in the middle third of each ear; stem diameter, measured in the middle region of the stem after the second node; and average ears per plant. The leaf below and opposite the ear at R1 was collected from 10 plants in the center of each plot. Tissue samples were dried in a forced-air oven at 65°C and ground in a Wiley mill to pass a 20 mm mesh screen. Nitrogen, P, K, Ca, Mg, and S were determined according to methods outlined by Malavolta et al. (1997).

All plants were harvested at the R5 growth stage from the center of each plot (6 m^2), beginning at 0.2 m above the soil surface, and weighed to estimate green biomass. After grinding the maize plants with a forage harvester, homogenized samples of ~900 g were dried in a forced-air oven at 65 °C to constant weight, then reweighed.

The data for green and dry biomass and *U. ruziziensis* were analysed by ANOVA; if significant, the treatment means were subjected to regression analysis. To meet the statistical assumptions for the analysis of variance, the percentage of soil covered with *U. ruziziensis* was transformed using the $\log_e(x)$ function, and, if significant, the treatment means were subjected to regression analysis. The data were backtransformed for graphing.

The data on the agronomic traits of the silage maize and the levels of leaf macronutrients present in the maize silage were subjected to analysis of variance. They were found to be significant using Tukey's test (α=0.05). For all the analyses, the statistical program Sisvar version 5.6 (Ferreira, 2011) was used.

The different doses of potassium fertilizer applied in advance to *U. ruziziensis* cultivated during the fall/winter of 2020 did not influence height, green or dry biomass yields, or the percentage of soil cover ($p \geq 0.05$; Table 1).

The mean value (52.2 cm) of *U. ruziziensis* height in this study was higher than that observed by Lima et al. (2017) when this plant was grown in fall (March to May) in Seropédica, RJ, with different doses of N and K_2O (120, 240 and 360 kg ha^{-1} for each nutrient), yielding heights of 38, 38, and 46 cm, respectively. The authors attributed the result to climatic conditions (low availability of growth factors such as water, light, and temperature) during the growing season, which did not favour the specie's development. In comparison to our results, Pacheco et al. (2017) obtained greater dry biomass (7.8 t ha^{-1}) and soil cover (100%) for *U. ruziziensis* cultivated without fertilization after soybean cultivation (March to October) in Rondonópolis, MS. According to the authors, *U. ruziziensis* had a higher dry biomass yield than other cover crops evaluated in their study because it is a perennial plant with great resprouting capacity after the beginning of the rainy season.

The presence of mulch on the soil surface is one

Table 1. Height, green biomass (GB), dry biomass (DB), and percentage of soil cover (SC) of *U. ruziziensis* plants.

K_2O applied to *U. ruziziensis* (kg ha^{-1})	Height	GB	DB	SC
	----- m -----	---------------t ha^{-1}--------------		------%------
0	56.5	11.2	2.0	61.3
30	52.7	10.2	1.9	62.9
60	53.6	18.0	3.2	68.9
90	54.9	12.7	2.2	69.0
120	45.2	11.0	2.1	58.0
150	50.3	13.6	2.6	61.6
Mean	52.2	12.8	2.3	63.6
cv%	13.6	15.6	14.1	5.6

of the obstacles to direct seeding, especially in the Cerrado region. Therefore, a minimum of 6 t ha^{-1} of dry biomass and a coverage rate of at least 50% are recommended (Alvarenga et al., 2001). Thus, in the present study, the averages biomass yield was considered low; however, the percentage of soil cover provided by *U. ruziziensis* plants (63%) was satisfactory for maintaining this system. The lack of response to potassium fertilizer application in *U. ruziziensis* may be related to the high soil nutrient levels, which seem to have been necessary for the plants during the growth period and to the low rainfall and temperatures at the site during the cultivation season. The *U. ruziziensis* has reasonable drought tolerance and moderate tolerance to cold but excellent recovery speed after the first seasonal rainfall (Masetto et al., 2013).

Although high dry biomass productivity was not achieved, using *U. ruziziensis* in seasons when silage maize is not grown is an interesting alternative to promote soil cover, especially in regions with almost no rainfall during this season, making cultivation difficult. Although not quantified in this study, *U. ruziziensis* accumulates K and thus contributes to reductions in nutrient leaching, since the nutrient remains protected from losses in living or dead plant tissue (Rosolem et al., 2012). Although the initial development of *U. ruziziensis* was slow in this study, after the return of the rainy season, the plants resumed growth, providing good soil cover for the next harvest. Thus, for direct planting performed in successive cultivation, the straw produced by *U. ruziziensis* may contribute in some way to the recycling of K in subsequent harvests.

The concentration of macronutrients in the ear leaf of the silage maize was not influenced by the different doses of K_2O as a complement to the doses applied in the fall/winter harvest ($p \geq 0.05$; Table 2).

Ear leaf concentrations of Ca (6.8 g ha^{-1}), Mg (2.1g kg^{-1}), and S (2.1 g kg^{-1}) were within values considered adequate according to Sousa and Lobato (2004). Ear leaf concentration of N (25.1 g kg^{-1}) was considered below, and the concentrations of P (3.4 g kg^{-1}) and K (30.4 g kg^{-1}) were considered above those values considered adequate. According to

Table 2. Concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) in the ear leaf of silage maize at growth stage R1.

K_2O applied to *U. ruziziensis* (kg ha^{-1})	K_2O applied to maize (kg ha^{-1})	N	P	K	Ca	Mg	S
		---------------------------------g kg----------------------------					
0	120	24.7	3.5	30.6	7.1	2.2	2.2
30	90	24.9	3.6	31.9	6.9	2.1	2.2
60	60	24.2	3.1	29.6	6.1	1.9	2.0
90	30	25.7	3.6	31.9	7.0	2.0	2.1
120	0	25.8	3.3	26.7	6.8	2.0	2.1
150	0 (sowing and broadcast)	25.3	3.4	30.7	7.3	2.3	2.3
Fallow	60 (sowing) + 90 (broadcast)	25.3	3.4	31.4	6.5	2.0	2.2
Mean		25.1	3.4	30.4	6.8	2.1	2.1
cv%		6.0	10.0	6.8	10.1	10.7	6.0

these authors, the optimal concentrations of ear leaf nutrients of N, P, K, Ca, Mg, and S are 28 to 35, 1.8 to 3.0, 13 to 30, 2.5 to 10, 1.5 to 5, and 1.4 to 3.0 g kg $^{-1}$, respectively.

The cultivation of soybean in succession with maize, sorghum, and millet at different K_2O doses (0, 35, 70, and 120 kg ha^{-1}) also did not cause variations in leaf nutrient content (Bossolani et al., 2018). However, the residual effect of applying potassium fertilizer (0, 40, 80, and 120 kg ha^{-1}) to off-season maize in a soybean cropping system with adequate soil K levels affected leaf Mg content in soybean and N, K, Ca, and Mg in maize. The highest K extraction for off-season maize was observed in the treatment that received a dose of 72 kg K_2O ha^{-1} (Lage et al., 2019).

The lack of significant responses to different doses of potassium fertilization in the K (57%) present in maize silage leaves may be due to the initial soil nutrient content (142.2 mg dm^{-3}) being high (≥ 80 mg dm^{-3}) (Sousa & Lobato, 2004). Also, the previous fertilization and cultivation of *U. ruziziensis* with a dose of 0 (sowing and broadcast), in which the K_2O necessary for maize development (150 kg ha^{-1}) was fully applied to the fall/winter crop, contributed to this result. Thus, it can be inferred that the K bioavailability may have been sufficient to provide the nutrient to the maize development.

The higher-than-necessary concentrations of P and K in the maize leaves may also be related to the high nutrient levels in the soil, in addition to adequate water availability during the experiment, which may have favoured their absorption. Nutrient uptake by plant roots depends, among other factors, on the concentration of the nutrient in the soil solution and its transport to the root surface (Chen & Gabelman, 2000). Like K, P mobility in soil occurs by diffusion, a process highly dependent on adequate soil moisture (Novais et al., 2007; Petter et al., 2013).

Similarly, the low N concentration in maize may be related to soil solution K levels and nutrient interactions. Ammonium (NH_4^+) is one of several cations that compete with K^+ for uptake sites on the plasma membrane of plants; thus, the lower availability of a given cation leads to increased absorption of the others (Novais et al., 2007). Low N concentration might also be explained by the fertilizer source utilized. Urea is susceptible to high N losses when applied to the soil surface via ammonia (NH_3) volatilization (Degaspari et al., 2020), especially when in contact with crop residues . In some cases, more than 64% of the applied N can be lost by the NH_3 volatilization (Pan et al., 2016). The timing and rate of K application did not affect the ear leaf concentrations of Ca and Mg at R1, in contrast to what has been observed in another study (Firmano et al., 2020).

The different complementary doses of K also did not affect the agronomic traits of silage maize except for ear diameter ($p \geq 0.05$; Table 3).

The complementary doses of 120 and 90 kg ha^{-1} applied to the silage maize (0 and 60 kg K_2O previously applied to *U. ruziziensis*, respectively) increased ear diameter 5.76 and 5.78 cm, respectively, compared to maize that received the recommended timing of K (5.51 cm). Green and dry biomasses, and the percentage of dry matter in the maize silage, were unaffected by the timing of potassium application (Table 4).

Lage et al. (2019), who evaluated the effect of potassium doses (0, 40, 80, and 120 kg ha^{-1} of K_2O) applied to an off-season maize crop and its residual effect on subsequent harvests (soybean and off-season maize), obtained a similar result. These authors suggested that the lack of response to K fertilizer applied to the previous maize crop in subsequent soybean and maize crops may have been due to high soil nutrient levels. Thus, the crops may have drawn on soil nutrient reserves present in the soil to meet their needs. Similarly, Cibotto et al. (2016) studied the effects of early potassium fertilization (100% K_2O applied to the winter crop; 50% applied to the winter crop and 50% applied to soybean; and 100% applied during soybean sowing) of black oat, canola, and wheat cover plants and found that there were no differences in soybean yield. However, applying 100% or 50% of the fertilizer dose to black oat decreased the number of reproductive structures and pods on the soybean plants, but did not affect the yield production. According to these authors, this result is due to the high levels of K in the soil, in which case fertilization could be performed entirely in advance or not at all.

The evaluation of the agronomic and productive traits of silage maize plants is of great importance for determining the quality of the silage produced (Skonieski et al., 2014; Klein et al., 2018). Thus, ear diameter is an important characteristic of maize when consumed in its natural form, as it is related to commercial sales patterns (Rodrigues et al., 2018). However, in maize silage, ear diameter can influence quality because smaller ears are correlated with less grain (Francelli & Dourado Neto, 2004). Although there were significant differences in this trait across the potassium doses used in our study, no direct evaluation of silage quality was

Table 3. Agronomic traits in maize silage (*Zea mays*): ear insertion height (EH), plant height (PH), ear length (EL), ear diameter (ED), stem diameter (SD), and ears per plant (EPP).

K_2O applied to *U. ruziziensis* (kg ha^{-1})	K_2O applied to maize (kg ha^{-1})	EH	PH	EL	SD	ED	EPP
		-------m-------		----------cm----------			
0	120	1.3	2.5	22.4	2.31	5.76a	1.1
30	90	1.3	2.4	23.1	2.36	5.78a	1.1
60	60	1.2	2.4	22.7	2.25	5.66ab	1.1
90	30	1.3	2.5	22.2	2.27	5.70ab	1.1
120	0	1.2	2.4	23.0	2.20	5.66ab	1.1
150	0 (sowing and broadcast)	1.2	2.3	22.8	2.31	5.71ab	1.1
Fallow	60 (sowing) + 90 (broadcast)	1.2	2.4	22.9	2.16	5.51b	1.1
Mean		1.2	2.4	22.7	2.27	5.68	1.1
cv%		9.4	6.0	2.8	8.0	1.5	7.1

*Means followed by the same letter in a column do not differ according to Tukey's test ($p \leq 0.05$).

Table 4. Green biomass (GB), dry biomass (DB), and percentage of dry matter (PDM) of silage maize (*Zea mays*).

K_2O applied to *U. ruziziensis* (kg ha^{-1})	K_2O applied to maize (Kg ha^{-1})	GB	DB	PDM
		---------t ha^{-1}--------		%
0	120	41.2	16.7	0.39
30	90	44.1	18.4	0.41
60	60	38.9	16.7	0.42
90	30	38.5	16.7	0.43
120	0	47.8	20.9	0.43
150	0 (sowing and broadcast)	45.5	20.2	0.44
Fallow	60 (sowing) + 90 (broadcast)	41.1	18.0	0.43
Mean		42.4	18.2	0.42
cv%		17.9	22.6	8.52

performed.

Regarding the green and dry biomass yields, the average production in Brazil varies by approximately 55 and 18 t ha^{-1}, respectively (Galvão et al., 2017; Velho et al., 2020). The ideal percentage of dry biomass for maize silage consumption and conservation ranges from 28 to 35% (Silva Júnior et al., 2017). Water deficits strongly influence the percentage of dry matter in maize (Domingues et al., 2013). Dry matter percentages greater than 40% make it more difficult to properly compact silage, thereby causing fermentation problems and loss of nutritional quality (Macedo et al., 2019). Maize silage productivity is determined by water availability, temperature, and solar radiation (Melo et al., 2021). Thus, the high dry mass percentages and the low green biomass productivity observed in this study are likely related to the climatic conditions during the experiment. Although cultivation was performed during a period of good water availability, a drought occurred at the end of the crop cycle in the rainy season (summer), resulting in many senescent leaves before harvest.

Crop responses to potassium fertilization occur only when soil nutrient levels are below the critical level, which may vary with soil type (Galvão et al., 2015). Therefore, based on the results of this study, we can infer that in areas with high potassium content, the total potassium required for maize silage can be fully applied to the winter crop in advance, without losses in productivity. Therefore, early fertilization is a practice that can provide significant advantages, including labour and machinery savings or, as in this study, the elimination of K_2O in planting rows, thus preventing seed damage caused by high salt levels (Silva & Lazarini, 2014). In addition, suitable timing should be considered when establishing crops to prevent nutrient deficiencies and reduced productivity (Francisco et al., 2007).

The early application of potassium fertilizer to *U. ruziziensis* cultivated in the off-season did not alter green and dry biomass yields of *U. ruziziensis,* nor the green and dry biomass yield of silage maize grown in succession. However, complementary fertilization of maize at 90 and 120 kg K_2O ha^{-1} (30 and 0 kg K_2O ha^{-1} to *U. ruziziensis*) increased ear diameter compared to the commonly recommended fertilization regime of 90 and 120 kg K_2O ha^{-1} applied to the maize at sowing and side dressing, respectively.

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