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# Release of potassium, calcium and magnesium from sugarcane straw residue under different irrigation regimes

**Jonas Pereira de Souza Junior[1*], Rilner Alves Flores[2], Renato Mello Prado[1], Leandro Rosatto Moda[1]**

**[1]Universidade Estadual Paulista "Júlio Mesquita Filho" (UNESP), Faculdade de Ciências Agrárias e Veterinárias – Câmpus Jaboticabal, Departamento de Solos e Adubos, CEP 14884-900 Jaboticabal, SP. Brazil**
**[2]Universidade Federal de Goiás, Escola de Agronomia – Câmpus Samambaia, CEP 74690-900 Goiânia, GO, Brazil**

***Corresponding author: jonas.psj@hotmail.com**

**Abstract**

The sugarcane straw deposited in soil after mechanized harvest can be a valuable source of nutrients. The aim of this research was to estimate the nutrient release from sugarcane straw, under different irrigation regimes and duration of decomposition. The experiment was conducted in a glasshouse using 57 g of sugarcane straw, which represented a total of 10t $ha^{-1}$ of straw. The straw was placed in bags made of plastic screen (mesh size 1.8mm). These bags were arranged inside the trays (total area of 567 cm²) filled with 2 dm³ of Oxisol. Experiments were designed according to randomized complete split plot: three water irrigation levels (450 mm, 900 mm and 1340 mm of water), ten sampling periods (0, 15, 30, 60, 90, 150, 180, 240, 300 and 360 days after the experiment installation), and three replicates. The dry matter accumulated from the straw subjected to decomposition, and the quantities of released calcium (Ca), magnesium (Mg) and potassium (K) were evaluated over 360 days. Sugarcane total dry mass decreased by 46% during the experiment. The nutrient release rate of potassium was 88.8%, 90.45 and 93.6% at irrigation regimes 450 mm, 900 mm and 1340 mm respectively, of calcium: 70.1%, 70.7% and 74.8% at 450 mm, 900 mm and 1340 mm respectively, of magnesium: 49.6%, 60.4% and 61.4% at 450 mm, 900 mm and 1340 mm respectively. Therefore, in regions with large amount of rainfall K application to sugarcane crop can be reduced because this nutrient can be partially supplied from the decomposed straw.

**Keywords:** *Saccarum officinarum*, precipitation, potassium, mechanized harvest, plant nutrition.

## Introduction

The maintenance of high soil nutrients levels fulfill the nutritional demand of cultivated plants possible only through the application of organic and inorganic fertilizers (Ranjbar and Jalali, 2012). However, the use of chemical fertilizers can increase acidity of soil, degrade its physical properties, and lead to loss of organic matter (Aduayi, 1980). These negative effects can interfere with the productivity and sustainability of actual production system (Yadav and Prasad, 1992). Therefore, efficient management of soil organic matter is extremely important to support the long-term productivity of cultivated soils (Robertson and Thorburn, 2007). New production techniques leading to lesser environmental impact resulting from the fertilize use are being developed (Agyarko et al., 2006). As such, sugarcane cultivation represents a highly viable alternative to energy production accompanied by low environmental impact, in comparison to petroleum products (Morais et al., 2012). The organic matter content and fertility of soil in the agricultural areas of conservation system of sugarcane cultivation in Brazil (Flores et al., 2014a) and Australia (Robertson and Thorburn, 2007) have increased (Mendonza et al., 2000; Schultz et al., 2010; Flores et al., 2014b). The cultivation system in these areasis based on the rational use of fertilize, from alternative sources and maintenance of fertilizer residues in soil after mechanical harvesting. The observed increase in yields in conservation system can be explained by the beneficial effect of incorporation and decomposition of plant residues in agricultural soils. This is the major alternative used to maintain high levels of organic matter in soil (Boehm and Anderson, 1997), increase the biological activity, favoring soil nutrient cycle (Lupwayi et al., 2007) and improve the physical properties of the soil (Iyamuremye and Dick, 1996). The maintenance of plant residues in soil after cultivation also confers other benefits for agriculture, such as protection against erosion through the improvement of water retention capacity of the soil (Buerkert et al., 2000). Microbial activity plays an important role in plant residue decomposition processes through the progressive decomposition of organic material (Kumar and Goh, 1999). This decomposition results in physical and chemical degradation of organic material followed by nutrient release from plant residues (Oliveira et al., 1999). Approximately 93% of the potassium present in plant residues after mechanized harvest becomes bioavailable after 12 months (Flores et al., 2014a), which largely contributes to improvement of sugarcane productivity (Ball-Coelho et al., 1993). Potassium does not remain incorporated in the straw with the carbon chain. Consequently, after senescence or harvest of the plants, this nutrient is quickly released to the soil solution and is readily bioavailable to plants (Prado, 2008). Plant residue decomposition rates and nutrient release from residue depend on many factors, including the chemical and biological characteristics of plant residues (Tian et al., 1992). When these residues have high concentration of water-soluble compounds, such as sugars, amino acids, and organic acids, the decomposition of organic matter occurs faster than the decomposition of plant residues containing other residues, such as cellulose, lignin and phenols (Ha et al., 2007). A previous study in Australian showed that the decomposition of plant residues from mechanized harvest accounts for approximately 81% of total dry matter content in one year. This process was primarily affected by temperature and humidity (Robertson and Thorburn, 2007). This finding is in line with the study of Oliveira et al. (1999) who found that approximately 80% of the total sugarcane straw biomass present in soil after mechanized harvest is decomposed after 12 months by the activity of decomposing organism in an area with an average rainfall of 1733 mm. They also found that the K, Ca, and Mg release rates, in relation to their initial content in sugarcane straw, are, 85%, 44% and 39%, respectively. Studies addressing the decomposition speed and nutrient release from plant residues produced after mechanized harvest of sugarcane under different precipitation regimes, and especially those of K, Ca and Mg are scarce. Knowledge regarding the effects of irrigation intensity on plant residues remaining in soil after harvesting during the period of one year is highly important to understand the dynamic of immobilization and release of nutrients from the straw to the soil. This information can be used to reduce the fertilize application rates due to nutrient cycling in soil, especially that of K, Ca and Mg. The objective of this study was to analyze the release of nutrients (K, Ca, and Mg) from the sugarcane plant residues (straw) after the mechanized harvest as a function of different irrigation levels and decomposition duration.

## Results and Discussion

### *Effects of treatments on the sugarcane straw dry mass*

The dry mass of plant residues (sugarcane straw) at different decomposition times is shown in Table 1. Our results showed 45.6% reduction of total dry mass during the straw decomposition (Fig. 1). This finding is in agreement with the study of Schombert et al. (1994) who found a significant increment in decomposition rates of sorghum and wheat plant as a function of irrigation or rainfall intensification. As previously reported, the decomposition speed and nutrient release rates from plant residues are affected by several factors, such as the biological and chemical plant residues characteristics (Tian et al., 1992). According to Ha et al. (2007), plant residues with high levels of water-soluble compounds are quickly decomposed. In the study of Schombert et al. (1994), the difference between the rates of decomposition speed and nutrient release from sorghum and wheat could be explained by the small carbon/nitrogen ratio (C/N) in these plants (~70), which is lower than that of sugarcane straw (~100/1) (Fortes et al., 2012). The C/N relationship is one of the major inherent characteristic of plant tissue that directly reflects the decomposition speed of the plant (Aita and Giacomini, 2003). It is known that plant residue decomposition increases with exposition time (Crusciol et al., 2008; Ranjbar and Jalali, 2012). According to Medrado et al., (2011) residues of Poaceae plants, such as corn, have high decomposition rates during the first sixteen days after the treatment. The decomposition rates of Poaceae plant residues can reach 68%–86% of the total initial dry mass during the first 15 days (Aita and Giacomini, 2003). However, the residue quality and the environmental conditions, such as temperature and precipitation, can significantly affect the decomposition speed and the nutrient release rates (of potassium in particular) (Lupwayi et al., 2007). As seen in Table 1, the interactive effect of irrigation levels and decompositions rates on nutrient release from sugarcane was significant for potassium, calcium and magnesium.

### *Effects of treatments on nutrient (K, C,a and Mg) release from sugarcane straw*

The interactive effects of treatments and irrigation levels on the dry mass of sugarcane residues are shown Table 1.
Our results showed that the irrigation level of 450 mm induced 88.8% reduction of potassium accumulation in sugarcane straw, while at the irrigation levels of 900 mm and 1350 mm, this reduction was 90.4% and 93.6%, respectively (Fig. 2). For calcium and magnesium accumulation our results show a trend similar to that for potassium accumulation, but with smaller intensity. The average reduction of calcium in sugarcane residues was 70.1% at 450 mm, 70.7% at 900 mm and 74.8% at 1350 mm irrigation (Fig. 3) while the average reduction of magnesium was 49.6% at 450 mm, 60.4% at 900 mm and 61.4% at 1350 mm (Fig 4). The release of potassium, calcium and magnesium differed because of the different roles of these elements in plant physiology. Potassium is not an organic cell compound that is present inside the plant in an ionic form, while calcium and magnesium serve structural function. Calcium is a compound of cell wall (calcium pectate), and magnesium is compound of chlorophyll (Marschner, 1995). Irrigation favors plasmatic membrane disruption, and consequently, the release of potassium present inside the cell. This could possibly account for the higher potassium release rate than that of calcium and magnesium. Oliveira et al. (1999) explained this result by the different rates of potassium, calcium, and magnesium release from the sugarcane straw. In their study, the release rates of K, Ca, and Mg from sugarcane were 85%, 44%, and 39%, respectively. Rosolem et al. (2003) found similar results in their study using soil cover crops (Poaceae), in which potassium had the greatest release rate, while calcium and magnesium had lower smaller release rates. Other Poaceae plants also have high release rates of these nutrients. Reduction rates of K, Ca, and Mg from oat were 99%, 71%, and 77%, respectively, in a study by Aita and Giacomini (2003). The authors attributed the high release rate of these nutrients to lower C/N ratio in oat, which is 34/1 compared to the sugarcane straw C/N ration of 100/1.

## Materials and Methods

### *Experimental site, soil, and plant characteristics*

The experiment was performed in a glasshouse of the Faculdade de Ciências Agrárias e Veterinárias Universidade Estadual Paulista "Júlio de Mesquita Filho" – FCAV/UNESP, in Jaboticabal-SP, Brazil, between September 2010 and September 2011. The Local coordinates are 21° 15' 19'' S and 48° 19' 21'' W, altitude 615 m. For this experiment, organic residues (straw) of sugarcane variety RB855156 were used, which were sampled randomly from an unburned productive area of sugarcane. The RB8551156 variety has erect stems with cracks of fine to medium diameter and bright green color (PMGCA, 2008).

### *Treatment details, sugarcane straw and irrigation applications*

Straw samples were cut into smaller fractions of around 10 cm length in order to improve the arrangement of straw in

**Table 1.** Dry mass and accumulation of potassium (K), calcium (Ca) and magnesium (Mg) in sugarcane straw as a function of irrigation regime and the duration of decomposition.

| Treatments | Straw dry mass $t\ ha^{-1}$ | K | Ca | Mg |
|---|---|---|---|---|
| | | ----------------------$g\ ha^{-1}$ | --------------------- | |
| Irrigation Water Level (I) | | | | |
| 450 mm | 7.39 a | 30.13 a | 33.17 a | 8.40 a |
| 900 mm | 7.20 b | 25.11 b | 32.66 a | 8.04 ab |
| 1340 mm | 7.02 c | 18.8 c | 29.55 b | 7.82 b |
| Test F | 13.2* | 33.7** | 8.84** | 4.83* |
| Decomposition Days (D) | | | | |
| 0 (control) | 9.90 a | 56.4 a | 59.0 a | 12.8 a |
| 15 | 8.84 b | 42.7 b | 45.3 b | 10.1 b |
| 30 | 8.24 c | 34.0 c | 39.9 bc | 9.42 bc |
| 60 | 7.76 d | 29.6 cd | 35.4 c | 8.41 cd |
| 90 | 7.30 e | 24.0 de | 29.6 d | 8.20 d |
| 150 | 6.76 f | 20.9 e | 25.9 de | 7.42 de |
| 180 | 6.33 g | 12.7 f | 23.1 e | 7.04 ef |
| 240 | 5.98 gh | 11.6 f | 22.6 e | 6.25 fg |
| 300 | 5.59 hi | 9.85 f | 20.4 ef | 5.76 g |
| 360 | 5.38 i | 5.10 f | 16.6 f | 5.38 g |
| Test F | 257.2** | 83.94** | 120.22** | 88.6** |
| (I) x (D) | | | | |
| Test F | $1.42^{ns}$ | 2.79** | 2.22* | $2.08^{*}$ |
| CV (%) | 3.8 | 21.5 | 11.3 | 8.9 |

**, * and $^{ns}$ – Significant at p < 0.05 and p < 0.001, respectively according to F-test

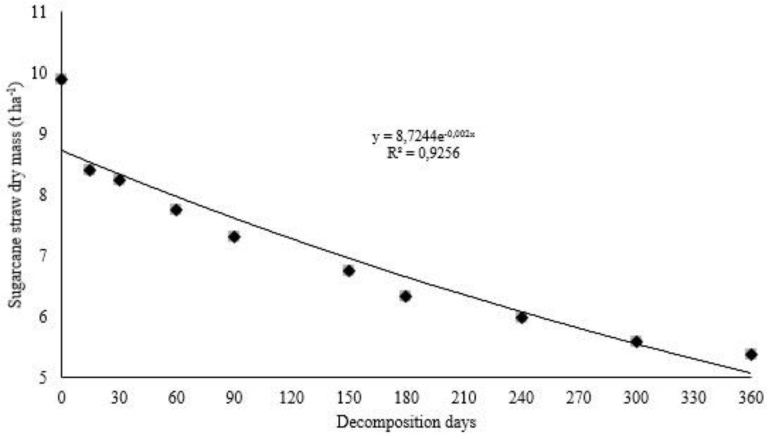


**Fig 1.** Effect of the duration of decomposition on the decomposition rate of sugarcane dry mass in greenhouse under three different irrigation regimes Jaboticabal (Sao Paulo, Brazil).

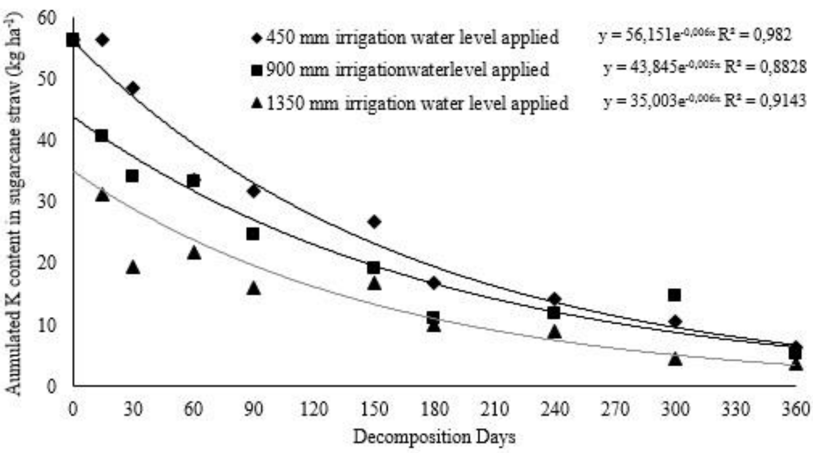


**Fig 2.** Accumulation of K in the sugarcane straw in the greenhouse per hectare as a function of decomposition duration, under three different irrigation regimes (Jaboticabal, Sao Paulo, Brazil).

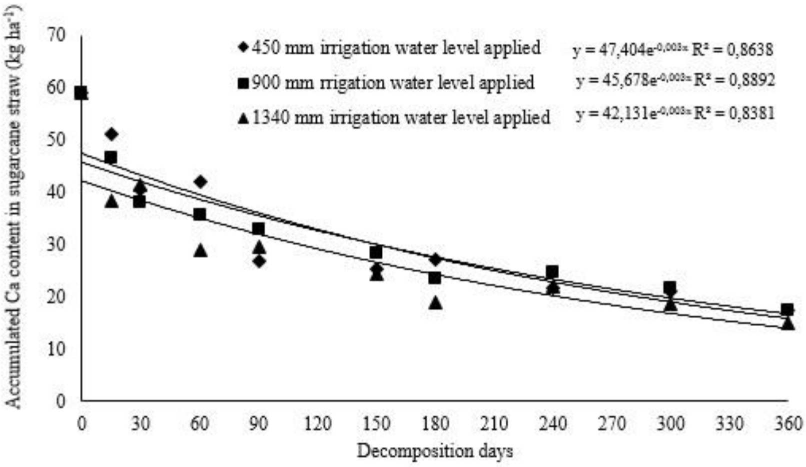


**Fig 3.** Accumulation of Ca in the sugarcane straw in the greenhouse per hectare as a function of duration of decomposition under three different irrigation regimes (Jaboticabal, Sao Paulo, Brazil).

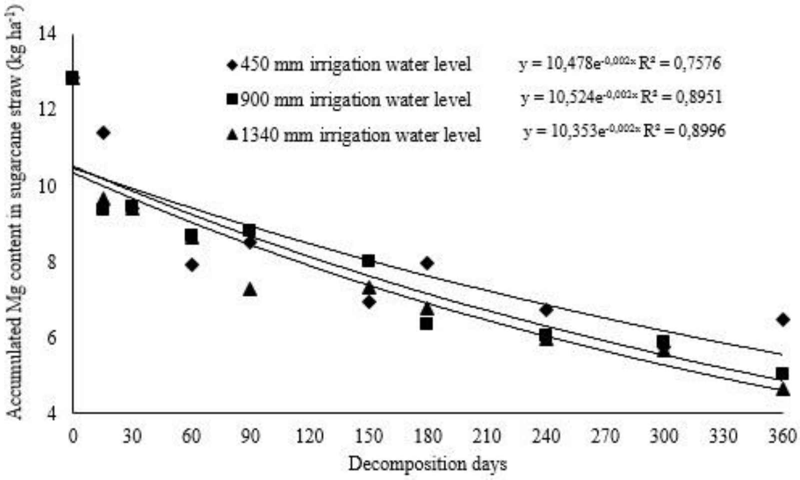


**Fig 4.** Accumulation of Mg in the sugarcane straw in the greenhouse per hectare as a function of duration of decomposition under three different irrigation regimes (Jaboticabal, Sao Paulo, Brazil).

soil. After fractionation the straw was dried in closed circulation ovens at 65ºC ± 5.

The experimental design corresponded to random split plots. Three water irrigation levels were tested (450 mm, 900 mm and 1340 mm), ten periods of decomposition were analyzed (0 (control), 15, 30, 60, 90, 150, 180, 240, 300 and 360 days after the experiment installation) and three replicates. The experimental unit was composed of a plastic container (tray) with an area of 567 cm². These containers were filled with a sample of subsoil upto 20 cm³ (20 cm of depth) of an Oxisol. After filling the trays, 57 g of straws was placed on the soil surfaces representing 9.9 $ha^{-1}$. This amount of straw was determined based on the study of Flores et al. (2014b) who found that this amount represents the annual accumulation of unburned sugarcane straw in soil after the mechanized harvest. The straws was arranged in bags made of plastic screen (1.8 mm mesh size) to avoid possible leakage of plants residues during the experiment. The irrigation was provided weekly in the quantity of 489 ml, 968 ml and 1467 ml in each soil container. This amount of water represents 450 mm, 900 mm and 1340 mm, respectively, as determined at the end of the experiment (360 days). These irrigation regimes were selected to represent locations with low, medium, and high rainfall intensity, respectively. The highest irrigation level (1340 mm) was divided in two applications of 734 ml weekly to improve the water surface distribution and absorption by the straw, and to avoid water loss.

***Straw decomposition and analysis of release rate of nutrient.***

The sugarcane straw decomposition analysis was performed in trays at several time intervals: 0 (control), 15, 30, 60, 150, 180, 240, 300, and 360 days after the commencement of the experiment. Each sample was dried in closed circulation ovens at 65ºC ± 5ºC to obtain the sugarcane dry mass. The initial straw weight in the trays (57 g) was used to determine the straw decomposition rates under different irrigation regimes. The contents of potassium (K), calcium (Ca) and magnesium (Mg) present in sugarcane straw were determined using the method described by Bataglia et al. (1983). Based on the levels of K, Ca and Mg in the straw plant tissues and in the remaining organic matter, we calculated the accumulation rates of these nutrients in each sample at different time intervals.

***Statistical analysis***

Results were analyzed by one-way analysis of variance (ANOVA) and F test ($p \leq 0.01$). When the effect of irrigation regime and sampling time was significant, we also analyzed the results by Tukey's test using Assistat software (Silva and Azevedo, 2002).

**Conclusion**

During the 360 days of the experiment, the decomposition of sugarcane plant residues (straw) decreased by 46% irrespective of irrigation regime, as seen in the results of the total dry mass. The application of different irrigation regimes affected the potassium, calcium and magnesium release during experimental period, with the highest nutrient release observed at the most intensive irrigation level (1340 mm).
The nutrient release rate at different irrigation regimes during 360 days was 88.8% at 450 mm, 90.4% at 900 mm and 93.6% at 1340 mm for potassium; 70.1% at 450 mm, 70.7% at 900 mm and 74.8% at 1340 mm for calcium and 49.6% at 450 mm, 60.4% at 900 mm and 61.4% at 1340 mm for magnesium.

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