Dry matter and nutrient partitioning in Castor plants in two growing seasons

Partição de matéria seca e nutrientes em plantas de mamona em duas épocas de cultivo

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Abstract
The aim of the present study was to evaluate dry matter partitioning and macro- and micronutrient accumulation and distribution in small-sized castor plants grown in season and off-season. The experiments were conducted during the 2005-2006 season and in the 2006 off-season in an Oxisol. A completely randomized block design was used, with eight replications. Plots consisted of plant sampling periods, which were conducted in the vegetative period (17 days after emergence - DAE), the grain fill period (between 73 and 80 DAE) and at end of the cycle (120 DAE). Castor leaves accumulated most of dry matter (DM) and macro- and micronutrients in the vegetative period, regardless of the growing period. In the following cycle periods, most of biomass and nutrients were located in the reproductive structures and grains, especially in the off-season crop. It was concluded that leaves and stems are strong nutrient sinks in the castor plant in season crops, while lower availability during off-season induces plants to use physiological mechanisms to allocate more resources (biomass and nutrients) for their reproduction.

Additional keywords: dry matter; macronutrients; micronutrients; Ricinus communis; source/sink relation.

Resumo
Objetivou-se neste estudo avaliar a partição de matéria seca, o acúmulo e a distribuição de macro e micronutrientes em mamona de porte baixo, cultivada na safra e na safrinha. Os experimentos foram conduzidos na safra de 2005-2006 e na safrinha de 2006, em Latossolo Vermelho distroférrico. Utilizou-se do delineamento em blocos casualizados, com oito repetições. As parcelas foram constituídas pelas épocas de coleto de plantas, que foram realizadas na fase vegetativa (17 dias após a emergência - DAE), na fase de enchimento de grãos (entre 73 e 80 DAE) e no final do ciclo (120 DAE). As folhas da mamoneira, na fase vegetativa, acumularam a maior parte da matéria seca (MS) e dos macronutrientes e micronutrientes, independentemente da época de cultivo. Nas fases seguintes do ciclo, a maior proporção de biomassa e nutrientes estava presente nas estruturas reprodutivas e nos grãos, especialmente no cultivo de safrinha. Conclui-se que, no cultivo de safra, as folhas e os caules são fortes drenos de nutrientes na planta de mamona, enquanto na safrinha a menor disponibilidade hídrica faz com que as plantas utilizem mecanismos fisiológicos para alocar mais recursos (biomassa e nutrientes) para sua reprodução.

Palavras-chave adicionais: macronutrientes; matéria seca; micronutrientes; relação fonte/dreno; Ricinus communis.

Introduction
The castor bean (Ricinus communis L.) is an excellent crop option to be used in succession planting and crop rotation in no-tillage systems. The castor bean can be grown both in season, integrating succession planting and crop rotation (Silva et al., 2010), as in the off-season period, where the species has been an important crop option (Moro et al., 2011). However, even with the release of new castor bean varieties and hybrids in recent years, the area cultivated with castor in Brazil is still small compared to its crop areas in the 80s. In addition, the area planted with this oilseed has gradually decreased in
recent years (Conab, 2016), and its yield has been very low (Fanan et al., 2009; Moro et al., 2011). Despite the unfavorable scenario, Brazil still holds a prominent position in the castor bean production, and is the fifth largest castor bean producer (FAO, 2016). However, this position could be improved with the use of new cultivation technologies, once the Brazilian castor bean yield is well below that of countries such as India, Ethiopia, Syria, Pakistan and Ecuador, which reach grain yields above 15 t ha\(^{-1}\) (FAO, 2016).

As castor growth and yield are directly related to its proper nutrition (Crusciol et al., 2012a), it is expected that a proper nutrient supply will result in grain yield increases. Therefore, studies have been conducted to assess the nutritional requirement of modern castor bean hybrids (Crusciol et al., 2012a; Crusciol et al., 2012b; Nascimento et al., 2012). However, little research has been conducted to evaluate dynamic allocation of biomass and nutrients in different castor plant organs (Hocking, 1982), as well as the contribution of these processes to the crop final yield. A crop final yield not only depends on the dry matter (DM) amount produced, but also on how DM is distributed between plant parts of economic interest (Jenkins & Mahmood, 2003). Thus, high yield in the castor bean crop depends on the plant DM production capacity and its efficiency in DM allocation to developing fruits. However, such processes are highly dependent on plant nutritional status, given that nutrients are implicated in several physiological processes related to vegetative development, ripening and senescence (Moreira & Fageria, 2009). Some research has indicated that, in castor plants, nutrient demand is associated to DM accumulation (Crusciol et al., 2012a; Crusciol et al., 2012b; Nascimento et al., 2012), showing that higher DM production is consequentially followed by higher nutritional demands. However, plant nutrient demand may not vary according to yield, as when fruiting is low, leaf and stem vegetative growth may replace the fruit as carbohydrate and nutrient sinks in the plant (Malavolta et al., 2002). Thus, it is important to know the DM and nutrient allocation pattern between castor plant organs in various growing conditions, since water availability and plants nutritional status may interfere with flowering and fruit development (Malavolta et al., 2002; Malavolta et al., 2006; Freitas et al. 2010; Biscaro et al., 2012; Silva et al., 2013).

Therefore, in order to have good plant development and production, flower and fruit mineral requirements must be adequately supplied by the soil, fertilizer and reserve mobilization of organs like stems, branches, leaves and roots (Malavolta et al., 2002). In the castor bean crop, it was already observed that nutrient remobilization from fruit capsules to the grains under development is small and has little contribution to their nutrition. It was suggested that, in order to obtain higher seed yields, the castor plant requires adequate nutrient supply by soil (Hocking, 1982). However, there is still lack of information about the allocation patterns of DM and mineral resources in castor bean crops under different growing conditions.

Thus, the aim of this study was to evaluate dry matter partitioning and macro- and micronutrient accumulation and distribution in small-sized castor plants grown in season and off-season, in order to obtain information for fertilization practices.

### Material and methods

Two experiments (one in the 2005/06 season and another in the 2006 off-season) were conducted in an Oxisol managed for six years in a no-tillage system. Experiments were conducted at Lageado Experimental Farm, Botucatu, SP, located in the 48° 26’ W, 22° 51’ S coordinates, with 740 m above sea level. Before experiment installation, soil samples were collected from the areas at a depth of 0-20 cm, in order to determine chemical characteristics. Soil analysis of the season crop showed the following parameters: O.M., 24.0 g dm\(^{-3}\); pH (CaCl\(_2\)), 5.1; P (resin), 16.0 mg dm\(^{-3}\); K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), H\(_2\)Al, and CEC, 1.5, 31, 17, 38, and 87 mmol dm\(^{-3}\), respectively, with 56% base saturation. In the off-season crop, the following soil characteristics were found: O.M., 36.0 g dm\(^{-3}\); pH (CaCl\(_2\)), 5.1; P (resin), 28.0 mg dm\(^{-3}\); K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), H\(_2\)Al, and CEC, 1.3, 26, 13, 51, and 92 mmol dm\(^{-3}\), respectively, with 45% base saturation. Maximum and minimum temperatures and rainfall that occurred in the study period are shown in Figure 1.

For castor bean sowing in no-tillage system, plants in the area were desiccated with glyphosate (1.8 kg ha\(^{-1}\) of a.i.). Lyra seeds were used, which is a hybrid with early cycle (140 days), flowering at about 30-35 days after emergence (DAE). Seeds were treated with carboxin-thiran (60 g 100 kg\(^{-1}\) of a.i. seeds) and thiamethoxan (210 g 100 kg\(^{-1}\) of a.i. seeds). Afterwards, sowing was carried out with 0.50 m spacing between rows and density of 45,000 seeds per hectare. In the season crop, sowing took place on 12/23/2005 on oat straw, and in the off-season it was held on 04/03/2006 on corn straw.

Sowing fertilization was carried out with 250 kg ha\(^{-1}\) NPK 08-28-16 + 4.5% S + 0.5% Zn. In the season, emergence occurred on 01/08/2006, while it occurred on 04/23/06 in the off-season. Crop emergence was recorded when more than 50% of plot plants were visible above the soil. Topdressing was applied with 50 kg ha\(^{-1}\) of N in ammonium nitrate form at 20 days after emergence (DAE), when plants had 4 to 5 fully expanded leaves.

During growing, pests and diseases control in the experimental area was carried out in accordance with the technical recommendations described by Savy Filho (2005). In both seasons, flowering occurred at around 25 DAE.
Results and discussions

Regardless of growing season, DM accumulation was higher in leaves than in the stem in the vegetative period, and represented more than 77% of all DM accumulated in the plant shoot, showing that there is higher carbon allocation for the formation of new leaf tissues in the vegetative period (Figures 2a, b, c, d). Higher carbon partitioning to the leaves increases leaf area and leaf area index, resulting in a larger light interception and increasing the accumulated DM amount (Santos et al., 2015).

In the vegetative period of both seasons, K and Mg contents in the stem of Lyra hybrid were higher than in leaves, although the opposite occurred to the other macronutrients (Table 1), as it was also observed in the Savana castor hybrid by Crusciol et al. (2012a). The results show that, in the vegetative period, K and Mg are concentrated on the castor plant stem, where they are subsequently translocated to reproductive structures (Table 1). Only the B in season and Mo in the off-season had...
higher levels in the stem than in the leaves (Table 1). Crusciol et al. (2012b) have also found that, at the beginning of the castor cycle, Mo occurred in higher contents in the stem, although B contents were always higher in leaves. Differences between studies regarding nutrient contents in the plant tissues are probably related to growing condition variations, although these nutrients were not supplied via fertilization in both studies.

During the vegetative period, Cu and Mo contents in season and B contents in the off-season had similar stem and leaf values (Table 1). In both seasons, Fe, Mn, and Zn contents were higher in leaves, although Cu leaf contents were only higher than the stem in the off-season. Generally, the castor stem had lower macro- and micronutrient contents than leaves in the vegetative period (Table 1). In orange trees, it was observed that branches had lower nutrient contents than leaves, as they work as nutrient sources for flowers (Malavolta et al., 2006).

Figure 2 - Dry matter accumulation and allocation in different parts of Lyra castor plant in the vegetative (a, b, c, d) and grain fill periods (e, f, g, h) and at end of cycle (i, j, k, l) of season (a, c, e, g, i, k) and off-season (b, d, f, h, j, l) crops. Rac.: raceme; RS: reproductive structure. Vertical bars in the columns indicate the least significant difference (LSD) value by Tukey's test at 5% probability.
Macronutrient and micronutrient accumulation in the vegetative period of both seasons was higher in
leaves than in the stem, which was the result of the
intense leaf and leaf area growth that occurred in
this cycle period (Figure 2 and Table 1). Larger leaf
areas favor transpiration, which is a condition that
increases the absorption of some nutrients in the soil
(Aquino et al., 2012). Therefore, transport of nutri-
tents absorbed in the roots to the leaves is increased
by the transpiration stream that moves through the
xylem (Taiz & Zeiger, 2013). In both seasons, from
63 to 95% of the macronutrient total accumulated in
the shoots during the vegetative period was allocat-
ed in the leaves, while the rest was allocated in the
stem (Table 1). For micronutrients, leaf allocation
ranged from 76 to 95% in both seasons studied, i.e.,
the main castor plant photoassimilate and nutrient
sink in the vegetative period are the leaves (Crucio-
li et al., 2012a; Cruciol et al., 2012b). Mo was only
allocated in equal ratios between leaves and the
stem in the off-season (Table 1). The fact that Mo is
a constituent of the nitrate reductase enzyme
(Marschner, 1995) and that N allocation in the stem
was 50% higher in the off-season increased Mo
amounts demanded by castor plant stems in the off-
season. Although DM and macronutrient and micronutrient
amounts accumulated by the plant were lower in the
off-season, DM and nutrient partitioning in favor of
leaf growth during the vegetative period was equal to
the season crop (Figure 2 and Table 1).

In the season crop, DM accumulation in
reproductive structures during the grain fill period
was lower than in leaves, but the reproductive struc-
tures were the preferred carbon sinks in the off-
season (Figure 2e, f, g, h). Higher DM accumulation
and allocation in off-season reproductive structures
is a result of unfavorable weather conditions for crop
vegetative growth (Figure 1). Since water is the main
interference factor in plant physiological processes
(Gouveia Neto, 2011), and its restriction triggers
plant phenological development acceleration, DM
and nutrient partitioning between the different
plant organs is changed. Although developing grains act
as strong photoassimilate sinks in the plant
(Dantas Júnior et al., 2010; Soratto et al., 2013; Santos et al.,
2015), in the season cultivation, where there was
greater water availability (Figure 1), DM allocation to
stem and leaf growth was high, even after flowering
(Figure 2e, f, g, h), confirming reports that stress
affects photoassimilate partitioning in plants
(Thornley, 1972; Cruz et al., 2004).

In both seasons, K contents in reproductive
structures during the grain fill period were higher than
those observed in other plant organs (Table 2). That

Table 1 - Nutrient content, accumulation and allocation in different parts of Lyra castor plant during the vege-
tative period of season and off-season crops.

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<th>PP</th>
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Means followed by the same letter in the columns do not differ by Tukey's test (p ≤ 0.05) (Plant parts; Variation coefficient.

Macronutrient and micronutrient accumulation in
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In both seasons, K contents in reproductive
structures during the grain fill period were higher than
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is, as K acts in cell osmotic control and is easily reallocated inside the plant, it is remobilized from leaves to growing fruit (Malvolta, 2006). Thus, as in this cycle period reproductive structures are the main growing organs. DM accumulation and K contents in this organ increased (Figure 2 and Table 2). Moreover, as K is also involved in the translocation of carbohydrates synthesized in the photosynthetic process (Marschner, 1995), the sharp increase in reproductive structures growth also increased their K demand. In the season crop, the highest P contents occurred in reproductive structures (Table 2), which is because this nutrient is accumulated in larger ratios in castor plant grains than in the plant biomass (Nakagawa et al., 1982; Crusciol et al., 2012a), and more than 80% of all P contained in castor plant fruits are present in the seeds (Hocking, 1982). However, in the off-season, P contents of reproductive structures did not differ from leaf contents, possibly due to the effect of content concentration in leaves, as the off-season leaf DM was 3.2 times lower than in season (Table 2 and Figures 2e, f, g, h).

In both seasons, N, Ca, Mg, and S contents in castor leaves were always higher than in other plant structures (Table 2), which was also observed by Lavres Júnior et al. (2005) for N, Ca, and S nutrients. The results indicate that, in the grain fill period, castor reproductive structures are not necessarily the main sinks of these nutrients in the plant (Table 2).

| Table 2 – Nutrient content, accumulation and allocation in different parts of Lyra castor plant during the grain fill period of season and off-season crops. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PP(1) | N | P | K | Ca | Mg | S | B | Cu | Fe | Mn | Mo | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain fill period – season 2005/2006 | | | | | | | | | | | | | |
| Leaf | 33a | 2.6b | 11b | 17a | 6.9a | 6.9a | 37a | 10a | 260a | 339a | 0.26b | 41b |
| Stem | 12c | 1.4c | 9b | 9b | 5.3b | 2.0c | 29b | 5b | 51c | 106b | 0.66a | 37c |
| RS(2) | 26b | 3.4a | 21a | 4.4c | 2.8a | 4.7b | 24c | 7ab | 164b | 59c | 0.59a | 46a |
| VC(%)(3) | 10.4 | 7.5 | 11.0 | 10.5 | 8.6 | 10.3 | 5.4 | 17.5 | 16.1 | 10.9 | 15.7 | 3.3 |
| Accumulation (g kg⁻¹) | | | | | | | | | | | | | |
| Leaf | 69a | 5.4a | 24b | 35a | 15a | 15a | 77a | 21a | 539a | 707a | 0.5c | 86a |
| Stem | 22c | 2.6b | 16b | 16b | 10b | 4c | 52b | 9b | 91c | 190b | 1.2a | 66b |
| RS | 42b | 5.5a | 34a | 7c | 5c | 7b | 38b | 10b | 257b | 94b | 0.9b | 72b |
| VC(%) | 7.5 | 11.6 | 17.5 | 12.4 | 16.4 | 10.3 | 11.8 | 12.2 | 7.5 | 13.9 | 8.6 | 7.7 |
| Allocation (%) | | | | | | | | | | | | | |
| Leaf | 52a | 40a | 32b | 60a | 51a | 57a | 46a | 51a | 61a | 72a | 21c | 38a |
| Stem | 16c | 19b | 23b | 28b | 33b | 14c | 31b | 23b | 10c | 19b | 44a | 30b |
| RS | 32b | 41a | 45a | 12c | 16c | 29b | 23b | 26b | 29b | 9c | 35b | 32b |
| VC(%) | 6.4 | 10.5 | 16.9 | 11.0 | 15.0 | 6.9 | 11.9 | 14.9 | 7.6 | 8.0 | 8.0 | 7.6 |
| Grain fill period – off-season 2006 | | | | | | | | | | | | | |
| Leaf | 30a | 2.0a | 10b | 23a | 6a | 16a | 31a | 11a | 757a | 288a | 0.17a | 30a |
| Stem | 10c | 0.9b | 9c | 10b | 5b | 3c | 17b | 5c | 169b | 55b | 0.29a | 25b |
| RS | 25b | 2.0a | 13a | 5c | 5c | 5b | 20b | 8b | 73c | 62b | 0.27a | 21b |
| VC(%) | 7.7 | 11.3 | 6.6 | 5.7 | 7.2 | 5.6 | 6.7 | 9.5 | 7.5 | 6.0 | 11.4 | 9.2 |
| Accumulation (g ha⁻¹) | | | | | | | | | | | | | |
| Leaf | 20b | 1.3b | 7b | 15a | 4a | 10a | 20b | 7b | 489a | 186a | 0.11b | 19b |
| Stem | 4c | 0.4c | 4b | 4b | 2c | 1c | 8c | 2c | 72b | 24c | 0.12b | 11c |
| RS | 30a | 2.8a | 16a | 6b | 3b | 6b | 24a | 9a | 86b | 73b | 0.32a | 24a |
| VC(%) | 10.3 | 12.9 | 12.2 | 15.4 | 10.9 | 12.4 | 7.6 | 12.6 | 14.4 | 15.8 | 9.3 | 11.4 |
| Allocation (%) | | | | | | | | | | | | | |
| Leaf | 36b | 29b | 25b | 59a | 43a | 59a | 39b | 39b | 75a | 66a | 20b | 36b |
| stem | 8c | 9c | 14c | 17b | 22c | 6c | 14c | 12c | 11b | 8c | 22b | 19c |
| RS | 56a | 62a | 61a | 24b | 35b | 35b | 47a | 49a | 14b | 26b | 58a | 45a |
| VC(%) | 9.9 | 12.0 | 12.1 | 12.2 | 11.1 | 8.6 | 5.8 | 13.5 | 4.7 | 11.6 | 14.7 | 10.9 |

Means followed by the same letter in the columns do not differ by Tukey’s test (p ≤ 0.05). (1) Plant parts; (2) Reproductive structure - represented by raceme + grain; (3) Variation coefficient.

In the off-season the Mo contents in the grain fill period were similar between plant organs, but the Mo contents in leaves were lower in the season crop due to the dilution effect caused by higher leaf DM (Table 2 and Figure 2). In season, Zn occurred at higher levels in reproductive structures, but in the off-season the highest Zn contents were observed in leaves, i.e., the highest contents occurred in the organs with the lowest DM accumulation. This occurs because as the plant grows, there is nutrient concentration dilution in tissues, so that physiologically young and less developed tissues, in general, have higher concentrations (Maia, 2012), specially of nutrients with a certain plant phloem mobility, such as Zn (Rodrigues et al., 1997). In both growing seasons, B, Cu, Fe, and Mn contents were higher in leaves (Table 2), which is a
result of their low mobility in tissues (Malavolta et al., 1997; Malavolta, 2006).

K accumulation in reproductive structures during grain fill in the season crop was higher than in other plant parts, while P accumulation in the stem was lower than in leaves and reproductive structures, which did not differ (Table 2). In the off-season crop, N, P, and K nutrients were accumulated in higher ratios in the reproductive structures (Table 2). Higher accumulation in reproductive structures during off-season indicates that in season crops, even after flowering (25 DAE), there is higher N allocation to leaf growth, unlike the off-season, in which N allocation in the leaves was 30% lower than in season. In the season crop, P and K were also allocated in a lower ratio in reproductive structures, while the allocation of these nutrients in the reproductive structures was above 60% of the total accumulated in the shoot in the off-season. The results indicate that in the off-season, when water deficit stress is higher (Figure 1), the castor plant changes the partitioning of DM and some nutrients in favor of raceme growth (Nascimento et al., 2012). DM and nutrient partitioning change occurs because water restriction triggers phenological evolution acceleration in the crop, which seeks to perpetuate the species by increasing the development of plant organs that ensure survival. However, higher development of reproductive organs is heavily influenced by plant nutritional status (Table 2). A similar response was observed in corn grown in competition with weeds (Carvalho et al., 2011). Ca, Mg, and S nutrients were accumulated at higher amounts in leaves, i.e., between 43 and 60% of total Ca, Mg, and S absorbed until the grain fill period was located in the leaves, which is the result of the combination of high leaf DM (season) and high contents of these nutrients in the leaf (Table 2 and Figure 2).

In the season, Mo accumulation until the grain fill period was higher in the stem and represented 44% of all Mo absorbed, which was due to high DM and Mo content values in the stem (Table 2 and Figure 2). In the season crop, the largest B, Cu, Fe, Mn, and Zn accumulations occurred in the leaves and accounted for between 38 and 72% of the total absorbed, which reflects the high DM and leaf content of these nutrients. In the off-season, only Fe and Mn were accumulated in larger amounts in leaves, which accumulated between 66 and 75% of the total uptake (Table 2 and Figure 2), demonstrating that castor seeds require low levels of these nutrients for growth (Hocking, 1982). Higher Fe and Mn accumulation in the leaves occurs because nutrient transport to the shoot is carried out via transpiration stream, through the xylem. In addition, these nutrients have low redistribution within the plant, accumulating in larger ratios in the leaves (Dechen & Nachtigall, 2006; Malavolta, 2006).

In the off-season, B, Cu, Mo, and Zn accumulations were higher in reproductive structures and represented 45-58% of the total absorbed (Table 2), demonstrating that there was micronutrient partition change for grain growth in the off-season. These results show that stress occurrence besides affecting plant photoassimilates partition (Thornley, 1972; Cruz et al., 2004) also changes nutrient allocation in sinks.

At the end of the cycle, total DM accumulation was of 8,697 kg ha⁻¹ in season and 2,230 kg ha⁻¹ in the off-season (Figure 2). In addition, in the off-season, there was high DM accumulation and allocation in the grains, which represented more than 54% of the whole plant DM, while DM allocation in the grains was lower than 35% in season (Figures 2i, j, k, l). These results show that in the off-season grains act as heavier photoassimilate sinks than in season, where photoassimilates competition for stem and leaf growth is higher. Other authors found that, at the end of the cycle, the DM of castor reproductive structures, i.e., racemes + grains, accounted for most of the DM accumulated in the castor shoot (Crusciol et al., 2012a; Crusciol et al., 2012b), what indicates that there was not higher DM allocation in the grains (Figures 2i, j, k, l).

At the end of cycle of both seasons, N and P content were higher in grains (Table 3). Nutrients with high plant mobility, such as N and P, underwent remobilization from other plant parts, especially from leaves to growing grains (Crusciol et al., 2012a; Soratto et al., 2013).

In both seasons, at the end of cycle, the highest K contents occurred in racemes and not in grains (Table 3). The results corroborate those obtained by other authors who noted that only a small ratio of K in castor racemes was present in the grains (Hocking, 1982), i.e., the castor grains are not the preferential K sinks in the plant. Ca, Mg, and S contents in grain and racemes were always lower than contents observed in leaves, which indicates that leaves are the preferred sinks of these macronutrients in the castor plant (Table 3). Other authors have also found higher contents of the nutrients aforementioned in castor plant leaves in comparison to other plant parts (Lavres Júnior et al., 2005; Crusciol et al., 2012a.). In season, B contents were high in grains, although B contents in grains were similar to those of other plant parts in the off-season (Table 3). High B contents in grains are due to their role in sugar transport, cell division, and carbohydrate metabolism (Kirkby & Römheld, 2007). As there is intense growth of reproductive structures from 20-25 days after flowering (Crusciol et al., 2012a; Crusciol et al., 2012b), these processes are intensified, and there is increased photoassimilates demand in this tissue, increasing B content.

At the end of cycle of both seasons, Cu, Fe, and Mn contents were higher in leaves (Table 3), which was due to their functions in metabolism, particularly in the transfer of electrons during photosynthesis (Dechen & Nachtigall, 2006; Malavolta, 2006; Crusciol et al., 2012b). In season, the highest Mo
contents occurred in stem and racemes, probably due to their demand intensity as plant sinks, having high Mo allocation (Table 3). In the off-season, the highest Mo contents occurred in leaves, which was apparently related to a Mo content concentration effect, as there was low leaf DM accumulation (Table 3 and Figure 2). In general, N, P, S, B, Cu, Fe, and Mn accumulation in season were higher in the grains, accounting for between 55 and 68% of the N, P, S, and B absorbed, and between 38 and 47% of Cu, Fe, and Mn absorbed (Table 3). High accumulation and allocation of these nutrients in the grains is the result of a relatively high grain DM, associated to high nutrient contents (Table 3 and Figure 2). In the case of N, P, and K during the final phase of the cycle, these nutrients are remobilized from other plant parts to the developing fruits (Crusciol et al., 2012a). High S, Cu, Fe, and Mn allocation in grains occurred because, at the end of cycle, there was leaf falling and the ratio of these nutrients accumulated in

Table 3 - Nutrient content, accumulation and allocation in different parts of Lyra castor plant hybrid at the end of cycle of season and off-season crops.

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<th>PP(1)</th>
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</table>

Means followed by the same letter in the columns do not differ by Tukey’s test (p ≤ 0.05). (1)Plant parts; (2)Variation coefficient.
leaves decreased, even with high leaf contents.

In the off-season, total plant growth and grain yield were lower than in season, but the proportion of total plant DM that was allocated to the grains was 58% higher than in season, while the N, P, and S allocation to the grains was from 20 to 29% higher (Figure 2 and Table 3). K allocation in grains during off-season was 41% higher than in season, and Ca, Mg, Mn, and Zn allocation was above 66% of that obtained in season (Table 3). Mo allocation in grains during off-season was 177% higher than in season, although B, Cu, and Fe allocation to grains was the same in both growing seasons. In the off-season, when rainfall was lower (Figure 1), although plants grew less, grains eventually allocated a higher DM and nutrient ratio compared to other plant organs, something that did not always occur in season (Figure 2 and Table 3). These results show that stress occurrence triggers crop phenological evolution acceleration, changing photoassimilate partitioning in the plant and increasing nutrient allocation to plant organs that can ensure the plant species survival and perpetuation.

**Conclusion**

Castor plant leaves accumulated most of dry matter (DM) and macro and micronutrients in the vegetative period, regardless of growing season. In the following cycle periods, the highest biomass and nutrient ratios were present in reproductive structures and grains, especially in off-season. In the season crop, DM partitioning for stem growth in late cycle periods was higher than in off-season, and leaves and stems formed strong nutrient sinks. In the off-season, lower rainfall prevented castor plants to grow more, but the plants used physiological mechanisms to allocate more resources (biomass and nutrients) in order to reproduce.

**References**


