Collard greens and chicory intercropping efficiency as a function of chicory
\textit{(Cichorium intybus)} transplant time

\textbf{Eficiencia de los cultivos intercalados de col y achicoria en función del tiempo de transplante de la achicoria \textit{(Cichorium intybus)}}

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\textbf{Abstract}

Vegetable intercropping has advantages over single cultivation in terms of less environmental impact. However, to convince farmers to adopt this production system, it is necessary to prove greater efficiency in the production of more food per unit area and therefore an increase in productivity. An experiment was carried out aiming to evaluate the effect of the chicory transplant time in intercrops with collard greens on crop yields and land use efficiency index (LUE). The experimental design was a randomized block, with nine treatments in a $2 \times 4 + 1$ factorial scheme, and four replications. Crop systems (intercrop and monoculture) and chicory transplant time (0, 14, 28 and 42 days after transplant (DAT) of collard greens) were evaluated. The collard greens yield increased as the chicory transplant time was delayed. The total and per harvest yields of chicory were not influenced by its transplant time. Regardless of chicory transplant time, collard greens and chicory intercropping provided greater LUE than their monocultures and reached the maximum value (52\% higher) when the chicory was transplanted 42 days after collard greens.

\textbf{Keywords}
\textit{Brassica oleracea} L. var. \textit{acephala} • \textit{Cichorium intybus} • crop systems • intercropping feasibility • land use efficiency

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Resumen

El cultivo intercalado de hortalizas tiene ventajas sobre el monocultivo en cuanto a su menor impacto ambiental. Sin embargo, para convencer al productor de que adopte este sistema de producción, es necesario demostrar mayor eficiencia en la producción de más alimentos por unidad de superficie, y por tanto, un aumento de la productividad. Se llevó a cabo un experimento con el fin de evaluar el efecto del tiempo de trasplante de la achicoria en los cultivos intercalados con la col en el rendimiento de los cultivos y el índice de eficiencia del uso de área (LUE). El diseño experimental fue en bloques aleatorios, con nueve tratamientos en un esquema factorial 2 x 4 + 1, y cuatro repeticiones. Se evaluaron los sistemas de cultivo (intercalado y monocultivo) y el tiempo de trasplante de la achicoria (0, 14, 28 y 42 días después del trasplante (DAT) de la col). El rendimiento de la col aumentó al retrasarse el tiempo de trasplante de la achicoria. El rendimiento total y por cosecha de la achicoria no se vio influido por su tiempo de trasplante. Independientemente del tiempo de trasplante de la achicoria, la col y el cultivo intercalado de achicoria proporcionaron una mayor LUE en comparación con los sistemas de monocultivos, y alcanzaron el valor máximo (52% más alto) cuando la achicoria se trasplantó 42 días después de la col.

Palabras clave
Brassica oleracea L. var. acephala • Cichorium intybus • sistemas de cultivo • viabilidad de los cultivos intercalados • eficiencia del uso de área

Introducción

Vegetable production is an activity characterized by intense soil management and exposure, and intensive use of water and fertilizers, which provide considerable environmental impact (16). Developing technologies that allow the rational use of land for food production is therefore necessary, and intercropping is an available technology that can assist in production but which has less environmental impact, mainly due to complementary use of resources in time and space among different species (10, 13). In addition, intercropped cultivation allows a reduction of production costs, making the activity better remunerated and the producer more competitive in the market (6, 7, 9, 11).

Intercropped cultivation efficiency depends on the species involved in the system and the planting time of the second species, because these factors affect the period for which the species coexist and, consequently, the spatial and/or temporal complementarity, with impacts on crop yields and on the whole system (5, 6, 8).

Cecílio Filho et al. (2011, 2015) observed that land use efficiency decreased on increasing the transplanting time between tomato and lettuce (2011) and between cucumber and lettuce (2015), due to increased shading of tomato and cucumber on lettuce. The longer the period between transplantations, the larger were the tomato and cucumber plants when the lettuce was transplanted. Consequently, less solar radiation was available to the lettuce that grew under the tomato and cucumber canopy. Similarly, Ohse et al. (2012) evaluated the agronomic viability of broccoli and lettuce intercropping and they verified that the yield of lettuce was affected by its transplanting time. The authors obtained the best result when lettuce was transplanted on the same day as broccoli. Consequently, the effect of lettuce transplant time impacted intercropping efficiency in the same way.

This study aims to evaluate the yields for intercropping between collard greens (Brassica oleracea var. acephala) and chicory (Cichorium intybus), two vegetables commonly grown by small farmers (family farming), which can easily incorporate the technology of an intercropping system to replace the monoculture system of those crops. Also, the two species have different characteristics such as size, height and foliar architecture, which are important to the success of intercropping (5, 12, 14).

No studies about collard greens and chicory intercropping have been found in the literature. However, Cecílio Filho et al. (2017) studied the effect of New Zealand spinach (Tetragonia expansa) transplanting time in intercropping with collard greens. The authors observed that the New Zealand spinach, regardless of the time at which it is transplanted in
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relation to collard greens, does not affect collard greens yield. However, collard greens cause a loss of New Zealand spinach yield, regardless of the spinach transplanting time, by about 13.5% in relation to the yield obtained in monoculture. It is expected that a simple change of the intercropped species can alter the crop system viability. In this case, chicory and New Zealand spinach have differences such as size and height, kind and velocity of growth, and architecture among other characteristics, which can cause different effects on spatial and/or temporal complementarity in intercropping with collard greens. Our hypothesis is that the production of collard greens and chicory in an intercropping system has greater land use efficiency than in monoculture systems and that the chicory transplanting time in the intercropping affects the yields of both species in the system.

Thus, this study was performed with the aim to evaluate the agronomic efficiency of collard greens and chicory intercropping as a function of the chicory transplant time in relation to that of collard greens.

MATERIALS AND METHODS

Characterization of experimental site

The experiment was carried out in the field at São Paulo State University (21°14'39" S, 48°17'10" W; 575 m a.s.l) from May to November 2018.

The soil was classified as a Eutrudox with sand = 253 g kg$^{-1}$, silt = 132 g kg$^{-1}$ and clay = 615 g kg$^{-1}$. The chemical attributes before installation of the experiment were: pH (CaCl$_2$) 5.6; 17 g dm$^{-3}$ organic matter; 31 mg dm$^{-3}$ P (resin); 3.3 mmol$_c$ dm$^{-3}$ K; 22 mmol$_c$ dm$^{-3}$ Ca; 10 mmol$_c$ dm$^{-3}$ Mg; and soil base saturation = 71%.

During the experimental period, the climate parameters were: relative humidity 63.9%, rainfall 330 mm and average temperature 22°C, with maximum and minimum averages of 29.8 and 16.2°C, respectively.

Treatments and experimental design

Nine treatments were evaluated as result of combining two crop systems (intercropping and monoculture) and four chicory transplanting times (0, 14, 24 and 42 days after transplanting collard greens - DATCG). The treatments were arranged in a $2 \times 4 + 1$ factorial scheme, in a randomized block, with four replications. The additional treatment corresponded to collard greens monoculture. Collard greens was considered as the main crop and chicory as the secondary crop.

Each experimental unit (3.36 m$^2$) contained 14 collard greens plants and 70 chicory plants. Two rows of collard greens were transplanted in the centre of the bed, with 0.75 m between rows and 0.40 m between plants in a row. Five rows of chicory were transplanted to the bed, being three from their between the collard greens rows with 0.25 m spacing between rows and 0.20 m between plants in a row. The useful area for the evaluation of the experiment corresponded to the plants in the centre of the bed excluding two collard greens plants from each end of the row. For evaluation of chicory, three central rows were considered, excluding 0.40 m at the beginning and end of each row. In total, 30 chicory plants and 10 collard greens plants were evaluated (figure 1, page 94).

Installation of experiment

According to the results of the soil analysis, liming was carried out, applying lime to increase the soil base saturation to 80%. Planting and covering fertilization for both crops were performed according to Trani and Raij (1997) and Trani et al. (2018). At the planting time, 40, 320 and 80 kg ha$^{-1}$ of nitrogen (urea), phosphorus (simple superphosphate) and potassium (potassium chloride) were supplied, respectively.

The ‘HS-20’ collard greens seedlings were transplanted on a single date and the 'Pão de Açúcar' chicory seedlings were transplanted on the dates established in the treatments. At the time of chicory transplanting at 0, 14, 28 and 42 DATCG, the height of collard greens plants was measured and corresponded to 4.6, 11.9, 19.3 and 39.9 cm, respectively. The chicory seedlings were formed on several dates in order to obtain plants with four leaves for all treatments (transplanting times).
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Figure 1. Graphical representation of an experimental unit of intercropping system showing the arrangement of crops.

Figura 1. Representación gráfica de una unidad experimental de sistema de cultivo intercalado en la disposición de los cultivos.

The cover fertilization for collard greens was carried out by applying 40 kg ha\(^{-1}\) of N (urea) and 20 kg ha\(^{-1}\) of K\(_2\)O (potassium chloride) every 15 days after the transplant until completing 45 days. For the chicory, 30 kg ha\(^{-1}\) of N and 20 kg ha\(^{-1}\) K\(_2\)O were applied at 14 and 24 days after transplanting the chicory and immediately after each harvest for both cultures. The experiment was irrigated periodically by spraying throughout the crop cycle. Weed control was performed by manual weeding, weekly.

Every 10 days, leaves of collard greens were harvested, totalling 14 harvests. The chicory was harvested when the head was formed, which happened twice.

Characteristics evaluated

Yield (kg ha\(^{-1}\)): obtained by summing the harvests carried out throughout the crop cycle. Relative yield (RY %): obtained by the ratio between crop yields in intercropping and in monoculture. RY was proposed by Wit and Bergh (1965) and calculated from the following equations:

\[
\begin{align*}
R_{Y_{cg}} &= \frac{Y_{12}}{Y_{11}} \times 100 \\
R_{Y_{c}} &= \frac{Y_{21}}{Y_{22}} \times 100
\end{align*}
\]

where:

- \(R_{Y_{cg}}\) and \(R_{Y_{c}}\) correspond to relative yields of collard greens and chicory, respectively
- \(Y_{12}\) = collard greens yield when intercropped with chicory
- \(Y_{11}\) = collard greens yield obtained in monoculture
- \(Y_{21}\) = chicory yield when intercropped with collard greens
- \(Y_{22}\) = chicory yield obtained in monoculture.

Land use efficiency (LUE): obtained by the equation proposed by Willey (1979):

\[
LUE = R_{Y_{cg}} + R_{Y_{c}}
\]

Statistical analysis

The average value for monocultures (blocks) was considered as the denominator of the indices, as recommended by Bezerra Neto et al. (2012).

The data of total and per harvest yields of collard greens and chicory were subjected to variance analysis (F test) and, when significant, the means of the intercropped and monoculture systems were compared by the Tukey test at 5%. For collard greens, a complete randomized block design was used, with five treatments (four intercrops and one monoculture) and four replications. For chicory, a complete randomized block design was used in a 2 × 4 factorial scheme, with two cultivation systems and four transplant times. For LUE and RY indices, a randomized complete block design was used, with four treatments (intercrops). The regression equations were obtained according to the chicory transplanting time. In all analyses, the AgroEstat statistical program was used (2).
RESULTS

Collard greens yield

The total and per harvest yields were influenced by the crop system (table 1). The collard greens total yield in the intercropping system established by chicory transplant at 42 DATCG did not differ from the yield obtained in monoculture. On the other hand, the collard greens total yields obtained in intercropping systems established with chicory transplanted at 0, 14 and 28 DATCG were lower than that obtained in monoculture, reaching 36% less when both crops were transplanted on the same day (table 1).

In the partial harvests, the yields of intercropped crops sometimes did not differ from those in monoculture; sometimes they differed, sometimes being higher or lower (table 1). Table II shows adjusted polynomial equations for total and per harvest yields of collard greens when intercropped with chicory. The collard greens total yield increased linearly as the chicory transplant was performed later in relation to the collard greens transplant. The collard greens yield increased by 438.11 kg ha\(^{-1}\) for each day of delaying the chicory transplant (table 2, page 96).

### Table 1. Summary of variance analysis for total yield (TY) and yield per harvest (HY) (kg ha\(^{-1}\)) of collard greens as a function of crop system.

| Source of variation | TY  | HY1 | HY2  | HY3  | HY4  |
|---------------------|-----|-----|------|------|------|
|                      | kg ha\(^{-1}\) |     |      |      |      |
| Treatment           |     |     |      |      |      |
| I-0 DATCG           | 11.73** | 1.48ns | 25.68** | 8.07** | 16.82** |
| I-14 DATCG          | 54029.20bc | 5518.49a | 1099.98b | 2646.39bc | 5235.63b |
| I-28 DATCG          | 58037.71bc | 6542.76a | 1603.55b | 3977.80ab | 4932.07b |
| I-42 DATCG          | 66979.71ab | 7080.84a | 1747.12b | 4517.79ab | 6667.76a |
| Monoculture         | 75384.59 a | 7185.61a | 3985.66a | 4999.93a | 4092.80bc |
| CV %                | 10.49 | 25.30 | 23.97 | 23.40 | 13.07 |
| I-0                 | 47870.69c | 5007.05a | 1242.84b | 2157.11c | 3317.81c |
| I-14                | 54029.20bc | 5518.49a | 1099.98b | 2646.39bc | 5235.63b |
| I-28                | 58037.71bc | 6542.76a | 1603.55b | 3977.80ab | 4932.07b |
| I-42                | 66979.71ab | 7080.84a | 1747.12b | 4517.79ab | 6667.76a |
| Monoculture         | 75384.59 a | 7185.61a | 3985.66a | 4999.93a | 4092.80bc |

The number beside HY corresponds to the collard greens harvest number (e.g. HY1 = Yield of the first harvest); I = Intercropping; DATCG = days after transplant of collard greens; means followed the same letter in a column do not differ by Tukey test (p > 0.05); F Test: ns: not significant; *: p ≤ 0.05; ** p ≤ 0.01.

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Table 2. Adjusted equations, significance (F values) and determination coefficients (R²) for yields per harvest (HY) and total yield (TY) of collard greens as a function of the chicory transplanting time.

Table 2. Ecuaciones ajustadas, significancia (valores F) y coeficientes de determinación (R²) para los rendimientos por cosecha (HY) y el rendimiento total (TY) de la col en función del tiempo de trasplante de la achicoria.

| Yield | Equations                                      | R²  | F   |
|-------|-----------------------------------------------|-----|-----|
| HY1   | no adjust                                     | -   | -   |
| HY2   | no adjust                                     | -   | -   |
| HY3   | \( y = 2062.7535 + 60.0961x \)                | 0.96| 18.23** |
| HY4   | \( y = 3575.3720 + 69.6164x \)                | 0.84| 42.97** |
| HY5   | \( y = 50599.56500 - 57.0398x + 3.1887x² \)   | 0.99| 7.76** |
| HY6   | no adjust                                     | -   | -   |
| HY7   | no adjust                                     | -   | -   |
| HY8   | no adjust                                     | -   | -   |
| HY9   | no adjust                                     | -   | -   |
| HY10  | \( y = 3802.4447 + 28.4943x \)                | 0.92| 5.64* |
| HY11  | no adjust                                     | -   | -   |
| HY12  | no adjust                                     | -   | -   |
| HY13  | no adjust                                     | -   | -   |
| HY14  | no adjust                                     | -   | -   |
| TY    | \( y = 47528.9923 + 438.11105x \)             | 0.98| 15.04** |

The number beside HY corresponds to the collard greens harvest number (e.g. HY1 = yield of the first harvest);*: p ≤ 0.05; **p ≤ 0.01.

El número delante de HY corresponde al número de la cosecha de col (Ej.: HY1 = rendimiento de la primera cosecha);*: p ≤ 0.05; **p ≤ 0.01.

**Chicory yield**

The total and per harvest yields of chicory were not influenced by the chicory transplant time or by interaction of the evaluated factors, but they were influenced by the crop systems. Monoculture produced more than the intercropping system (table 3). There was no adjustment of regression equations for chicory yield (total and per harvest) according to the chicory transplanting time.

Table 3. Summary of variance analysis for total yield (TY) and per harvest yield (HY) of chicory as a function of crop system (CS) and chicory transplanting time (CTT) in relation to collard greens transplant.

Table 3. Resumen del análisis de varianza del rendimiento total (TY) y por cosecha (HY) de la achicoria en función del sistema de cultivo (CS) y el tiempo de trasplante de la achicoria (CTT) en relación con la col.

| Source of variation | TY     | HY1   | HY2   |
|---------------------|--------|-------|-------|
| CS                  | 111.26** | 206.94** | 36.38** |
| CTT                 | 0.85ns | 0.67ns | 1.75ns |
| CS x CTT            | 0.10ns | 0.52ns | 0.39ns |
| CV %                | 11.2   | 8.18  | 19.69 |

Yield (kg ha⁻¹)

| TY     | HY1          | HY2          |
|--------|--------------|--------------|
| I      | 44068.40b    | 24208.86b    |
| M      | 67330.73a    | 36917.00a    |
| I      | 19859.55b    | 30413.72a    |
| M      |              |              |
Relative yields and land use efficiency

RYcg was influenced by treatments, which was not observed for RYc (table 4). RYcg increased linearly as function of chicory transplanting time and reached 28% more when the chicory transplant happened 42 DATCG in relation to the RYcg obtained when both crops were transplanted on the same day.

Table 4. Summary of variance analysis for relative yield of collard greens (RYcg), relative yield of chicory (RYc) and land use efficiency (LUE) as a function of chicory transplanting time (CTT) in relation to collard greens transplant.

| Source of variation | RYcg (%) | RYC (%) | LUE  |
|---------------------|----------|---------|------|
| F value             |          |         |      |
| CTT                 | 5.5*     | 0.17ns  | 2.96ns|
| CV %                | 12.47    | 13.29   | 8.22 |
| kg ha⁻¹             |          |         |      |
| 0 DATCG             | 63.50b   | 67.33a  | 1.31a|
| 14 DATCG            | 71.67ab  | 63.41a  | 1.35a|
| 28 DATCG            | 76.99ab  | 66.52a  | 1.44a|
| 42 DATCG            | 88.85a   | 64.52a  | 1.53a|

DATCG = days after transplant of collard greens; F Test: ns: not significant; *: p ≤ 0.05; means followed by the same letter in a column do not differ by Tukey test (p > 0.05).

Therefore, the later the chicory transplant, the higher the intercropped collard greens yield and the nearer it is to the monoculture yield (figure 2).

Regarding LUE, there was no effect of the treatments (table 4), but there was a significant adjustment of the linear equation (figure 2).

Figure 2. Relative yield of collard greens (RYcg) and chicory (RYc) and land use efficiency (LUE) as a function of chicory transplanting time in relation to collard greens transplant (DATCG).

Figura 2. Rendimiento relativo y eficiencia en el uso de la tierra (LUE) de la col (RYcg) y la achicoria (RYc) en función del tiempo de trasplante de la achicoria en relación con el trasplante de la col (DATCG).
DISCUSSION

According to the results, the chicory affected the collard greens yield, especially when both species were transplanted on the same day. The chicory grew faster than the collard greens and quickly occupied the area. Due to that and the proximity to collard greens plants, the chicory leaves intercepted the solar radiation and reduced the availability of this resource for collard greens plants. However, the later the chicory was transplanted, the weaker its interference with the collard greens since that was itself more developed. When chicory was transplanted at 14, 28 and 42 DATCG, the height of the collard greens plants was 11.9, 19.3 and 39.9 cm, respectively, while when transplanted at 0 DATCG it was 4.6 cm.

The delay in the chicory transplant determined lower interference capacity of the chicory in the interception of solar radiation to the collard green. In an intercropping system, competition between plants is greater for light than for water and nutrients (3), which are adequately supplied to crops according to the management of the production system.

The results observed for collard greens and chicory intercropping differ from those found by Cecílio Filho et al. (2017), who evaluated collard greens and New Zealand spinach intercropping. The authors observed that total and per harvest yield of collard greens was influenced neither by crop system (intercropping and monoculture) nor by New Zealand spinach transplanting time (0 to 98 DATCG). Therefore, the secondary species associated with collard greens determines the collard greens performance, since in the collard greens and chicory intercropping system, the chicory grew faster. On the other hand, according to Cecílio Filho et al. (2017), collard greens grows faster than New Zealand spinach and quickly positions its photosynthetic canopy above the stratum occupied by the spinach, which has prostrate growth. Then, the collard greens intercepted the incident solar radiation, causing shading and negatively impacting the chicory yield. Despite the chicory yield reduction was no observed harmful to the commercial aspect.

The results for interspecific competition between collard greens and chicory for light corroborate the results observed for tomato–lettuce intercropping by Cecílio Filho et al. (2011), broccoli–lettuce intercropping by Ohse et al. (2012), cucumber–lettuce intercropping by Cecílio Filho et al. (2015) and collard green–New Zealand spinach intercropping by Cecílio Filho et al. (2017). These authors observed that, similar to what happened with chicory in relation to collard greens, the photosynthetic process and, consequently, growth of lettuce and spinach was harmed, due to their low height and shading by broccoli, tomato and cucumber, respectively. In the present study, the highest chicory yield was obtained in the monoculture system and, unlike the intercropping systems mentioned above, there was no effect of the time at which chicory was transplanted on its yield.

The RYcg and RYc indices were less than 1, showing that there was competition between species. The lowest RYcg happened when both crops were transplanted on the same day, determined by greater interference of the chicory on collard greens.

All collard greens–chicory intercropping systems showed a LUE greater than 1, which reflects the complementarity of the species, i.e., there was an advantage in food production per unit area in the intercropping system due to the better use of environmental resources (1). The LUE was at a maximum (1.52) when chicory transplant was performed at 42 DATCG, meaning that 1 ha in the intercropping system yielded the same quantity of food (collard greens and chicory) as 1.52 ha in the monoculture system.

CONCLUSION

The later chicory transplanting is performed, the greater the collard greens yield.

The chicory total yield is not influenced by chicory transplanting time in relation to collard greens transplanting time.

Collard greens–chicory intercropping promotes greater LUE than their monocultures and the efficiency is at a maximum (+52%) when the chicory transplant is performed at 42 DATCG.
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