Maximizing land utilization efficiency and competitive indices of roselle and cluster bean plants by intercropping pattern and foliar spray with lithovit

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ABSTRACT

To maximize the land utilization efficiency of Hibiscus sabdariffa L. (roselle) and Cyamopsis tetragonoloba, Taub (cluster bean), this experiment was executed successfully at Experimental Farm, Fac. Agric., Zagazig Univ., Egypt during 2018 and 2019 at summer season. Intercropping pattern treatments as main plots (sole planting of each component as control, 1: 2, 1: 3 and 2: 3 of roselle: cluster bean as row ratio, respectively), lithovit as sub-plots (CO2 nano-material) at various rates (0.0, 2.0, 4.0 and 6.0 g/l) as well as their interaction effects were estimated. In addition, from calculating competitive indices, it was clear that, the highest land equivalent ratio (abbreviated as LER), area time equivalent ratio (abbreviated as ATER), land utilization efficiency percentage (abbreviated as LUE%) and relative crowding coefficient (abbreviated as RCC) values 1.24 and 1.12, 1.16 and 1.03, 120.57% and 108.06% as well as 0.82 and 0.41 were achieved by the treatment of intercropping pattern of 1 row of roselle alternating with 3 rows of cluster bean during the 1st and 2nd seasons, respectively. The highest values in this concern were achieved with 1: 3 planting pattern combined with 0.0 lithovit rate in the first seasonas well as 1: 2 planting pattern combined with 6.0 g/l lithovit rate in the second one. Also, the highest values of competitive ratio for roselle (Crr) were achieved by combination between 4.0 g/l lithovit rate under 1: 3 pattern, in contrary, the highest values of competitive ratio for cluster bean (Crc) were recorded by combination between 1: 2 pattern with 2.0 g/l lithovit rate in first season. Regardless of the planting patterns combined with different lithovit rates, aggressivity, based on the results, therewas a positive sign for roselle and a negative sign for the intercropped cluster bean, indicating that roselle was dominant, while, cluster bean was dominated.

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1. Introduction

Roselle (Hibiscus sabdariffa L.) is a tropical or sub-tropical plant belongs to the family Malvaceae, and it is named in Egypt as Kar-kadeh. The roselle sepals (calyxes) contain organic acids (oxalic, tartaric, malic, succinic and ascorbic acids), lycopene, glucose, and ß-carotene (Peng-Kong et al., 2002). Roselle has several properties as a medicinal plant since it is used as a diuretic, antihelminthic, and antiscorbutic, digestive, laxative, choleric, and hypotensive. Furthermore, its seed contain fixed oil (Khare, 2007). The sepals (calyxes) extraction (anthocyanin glycoside) has a major therapeutic action for blood pressure (Hassan, 2009). In addition, cluster bean or guar (Cyamopsis tetragonoloba, Taub) belongs to the Leguminosae family. It is a vigorous and drought-tolerant crop with diffuse roots that uses the available moisture more effectively (Kherawat et al., 2013). The commercial prominence of cluster bean is due to its gum (galactomannan or guaran) that is taken out from the seed and utilized in pharmaceuticals, food processing as an emulsifier in burrowing beds for the industry of petroleum and paper manufacturing (Whistler and Hymowitz, 1979). Cluster bean is used as a laxative and anti-bilious. Furthermore, using cluster bean gum orally with meals was found to reduce postprandial
glucose levels in patients with type 1 diabetes (Khare, 2007). Small-scale farmers in Africa have used intercropping for generations to reduce the risk of crop loss, increase yields, and improve soil productivity (Litsinger and Moody, 1976). Through more effective utilization of solar energy water and nutrients, intercropping patterns can significantly improve plants growth and productivity compared to the sole planting of crops (Midmore, 1993). A part of the nitrogen fixed in the nodule of the legume component’s root may become available to the nonlegume plant in intercropping patterns with a non-legume and a legume component (Li et al., 2009). Many indices such as RCC (relative crowding coefficient), LER (land equivalent ratio) and ATER (area time equivalent ratio) as well as LUE (land utilization efficiency) have been utilized to evaluate the potential economic features and competition in intercropping patterns (De Wit, 1960, Mead and Willey, 1980; Hiebesh and McCollum, 1987; Ghosh, 2004). Furthermore, an intercropping system has been proposed as a potential approach for increasing both yield and biodiversity on a broad scale (Brandmeier et al., 2021). Researchers’ directories indicated the benefits of a well-managed intercropping pattern in resource use and crop yields when produced with the least input (Maitra et al., 2021). Application of lithovit ameliorated growth and yield than the other growth stimulators may be due to that lithovit the easiness to be released into the active CO2 wanted for metabolism, and lithovit has enhanced the production by 50% in some crops and improves the capability of the plant to resist the several environment conditions (Byan, 2014; Moisa and Berar, 2015). Lithovit promotes plant development and yield by increasing naturalist photosynthesis, which adds up carbon dioxide (CO2) in the most beneficial proportions. The majority of these amounts remains as a delicate layer on the leaves’ surface and enter extensively when they are moistened by dew at night (Attia et al., 2016). Furthermore, Hamed (2018) on Origanum syriacum, Szczepanek (2018) on maize, Helaly and Hegazy (2016) on Lavandula officinalis, Abdelkaderet al. (2018) on coriander and Abd El-All (2019) on sweet pepper pointed out that utilizing foliar spray with lithovit increased yield components compared to control (unsprayed plants). The main target of this study was maximizing the crop productivity by utilizing different intercropping patterns combined with lithovit rate treatments on roselle and cluster bean plants under conditions of Sharkia Governorate, Egypt.

2. Materials and methods

The current study was performed at the Experimental Farm of Fac. Agric., Zagazig Univ., Egypt (30° 34’ 07” N, 31° 34’ 33” E) during two consecutive seasons of 2018 and 2019. Roselle (Hibiscus sabdariffa, L.) as well as cluster bean (Cymopnis tetragonoloba Taub) seeds was given from Res. Centre of Aromatic and Medicinal Plants, Dokly, Giza as well were sown on 15th May during both seasons. Seeds of both components were sowed and watered. Seedlings of both crops were trimmed to one plant per hill for roselle and two plants per hill for cluster bean crop three weeks after sowing. The chemical and physical parameters of the used experimental farm soil are shown in Table A. The plot area included twelve rows was 3.00 × 7.20 m; each row was 60 cm apart and 3 m in length. Seeds of both crops were sown on row in hills on 1 side of row. The spaces were 50 cm between hills for roselle and 30 cm for cluster bean plant. This experiment contained 16 treatments, which were the combinations between four intercropping patterns and four lithovit rates which were; control (without lithovit application), 2.0, 4.0 and 6.0 g/l. The powder of lithovit was bought from Agrolink Company. The two crops (roselle and cluster bean) under investigation were sprayed 5 times/ season with lithovit at 35, 50, 65, 80 and 95 days, respectively, from sowing data. The intercropping pattern treatments were as follows:

1. Sole planting pattern of roselle, since it was practice on 1 side of the row, 1 plant/hill, at 50 cm distance apart. Such treatment was used as control for roselle parameters. Sole planting system of cluster bean; since it was applied on one side of the row, two plants / hill as well as at 30 cm distance apart. Such treatment was used as control for cluster bean parameters.

2. Intercropping pattern of 1:2; since sowing 1 row of roselle followed by 2 rows of cluster bean (1 row of roselle: 2 rows of cluster bean). Such pattern gives the proportional area of 0.333: 0.667 to each of roselle and cluster bean, respectively.

3. Intercropping pattern of 1:3; since sowing 1 row of roselle followed by 3 rows of cluster bean (1 row of roselle: 3 rows of cluster bean). Such pattern gives the proportional area of 0.25: 0.75 to each of roselle and cluster bean, respectively.

4. Intercropping pattern of 2: 3; since sowing 2 rows of roselle followed by 3 rows of cluster bean (2 rows of roselle: 3 rows of cluster bean). Such pattern gives the proportional area of 0.40: 0.60 to each of roselle and cluster bean, respectively. Cropping pattern treatments were randomly grouped in the main plots, whereas lithovit rates were randomly distributed in the sub-plots, in a split-plot design with three repetitions.

2.1. Calculated competitive indices:

2.1.1. Land equivalent ratio (LER)

LER refers to the amount of land required for solitary cropping to produce the same yields as an intercropping scheme. The most important virtue is crucial value. Furthermore, the LER is greater than one, intercropping increases component yield. Whenever, LER is bringing down than 1 the intercropping passively influences the growth and yield of the two plants grown in mixture. It was estimated using the following equation for roselle and cluster bean production per feddan:

\[ LER = \frac{Lr}{Yrr} + \frac{Lc}{Ycc} \]

Where, Yrr and Ycc are the roselle yields per feddan and cluster bean, respectively, as sole components and Yrc and Ycc are the roselle and cluster bean yields, respectively, as intercrops (Mead and Willey, 1980).

i. Area Time Equivalent Ratio (ATER):

This index was determined according to the next equation:

\[ ATER = \frac{\frac{Yrr}{tr} \times Yrc + \frac{Ycc}{fc} \times Ycc}{T} \]

Where: Yrc = Intercrop roselle yield, Yrr = Sole roselle yield, Ycr = Intercrop cluster bean yield, Ycc = Sole cluster bean yield and tr = The roselle duration period in days (180 days) as well as tc = The cluster bean duration period in days (160 days) and T = The intercropping system overall duration in days (Hiebesh and McCollum, 1987).

ii. Land Utilization Efficiency (LUE %):

By utilizing values of LER plus ATER, the land utilization efficiency (LUE %) percentage was determined by using equation according to (Mason et al., 1986) as next:

\[ LUE\% = \frac{LER + ATER}{2} \times 100 \]
iii. Relative Crowding Coefficient (RCC):

Another indicator that is utilized is this indice (RCC or K) which is an estimate of the relative overcrowding of one component over the other in an intercropping (De Wit, 1960). The RCC was determined as next:

\[ K = (K_{roselle} \times K_{cluster\ bean}) \]

\[ K_{roselle} = \frac{Y_r Z_{cr}}{(Y_r - Y_r/Z_{cr})Z_{cr}} \]

\[ K_{cluster\ bean} = \frac{Y_c Z_{rc}}{(Y_c - Y_c/Z_{rc})Z_{rc}} \]

Where \( Z_{rc} = \) the sown ratio of roselle in mixture with cluster bean and \( Z_{cr} = \) the sown ratio of cluster bean in mixture. When the production of the 2 coefficients (\( K_{roselle} \times K_{cluster\ bean} \)) is over than 1, there is a priority of yield, when RCC is when it is less than 1 as well as equal to 1 there is no advantage of yield, there is a dis-priority.

iv. Competitive ratio (CR):

It’s another approach to figure out how competitive different species. The competitive ratio is a better indicator of a crop’s competitive aptitude, and it may also be used to compare aggressivity and RCC (Willey and Rao, 1980). The CR determines the percentage of the two components in which they are originally seeded by calculating the ratio of single LERs of both component crops. The following formula is used to calculate the CR:

\[ CR_{roselle \times \ cluster\ bean} = \frac{LER_{roselle}}{LER_{cluster\ bean}} \frac{Z_{cr}}{Z_{rc}} \]

\[ CR_{cluster\ bean \times \ roselle} = \frac{LER_{cluster\ bean}}{LER_{roselle}} \frac{Z_{rc}}{Z_{cr}} \]

v. Aggressively value (A):

Aggressively value was determined according to Mc Gilchrist (1965) equation as follows:

\[ Arc = \frac{Y_r}{Y_r/Z_{cr}} - \frac{Y_c}{Y_c/Z_{rc}} \]

\[ Acr = \frac{Y_c}{Y_c/Z_{rc}} - \frac{Y_r}{Y_r/Z_{cr}} \]

Where

\( Y_r = \) intercrop yield of roselle;
\( Y_c = \) intercrop yield of cluster bean;
\( Y_r = \) sole yield of roselle;
\( Y_c = \) sole yield of cluster bean;
\( Z_{rc} = \) sowing rate of roselle
\( Z_{cr} = \) sowing rate of cluster bean.

3. Results

3.1. Effect of planting pattern

Data in Table 1 reveal that, the LER, ATER and LUE indices values were greater for roselle and cluster bean in planting pattern of (1:3 pattern in the first season as well as 1:2 patterns in the second one), there was an priority of planting pattern for exploiting the environment resources. A same trend to that of LER, ATER and LUE was also noticed for (RCC) relative crowding coefficient with 1:3 patterns in both seasons. Indeed, planting of roselle and cluster bean at 1:1, 1:2 and 1:3 were more productive (except that of 2:3 pattern regard ATER indicator in the second season only) than growing them solely, as can be seen from the abovementioned values which were maximal than 1.00 or 100%. Furthermore, the highest values of competitive ratio for roselle (Crr) were obtained by 1:3 patterns, in contrary; the highest values of competitive ratio for cluster bean (Crc) were achieved by 2:3 pattern in both seasons. It is known that an aggressively value of 0.0 indicate that the component plants (roselle or cluster bean) are equally competitive. The two components will have the same numerical value for any other state, with (+) for the dominant component and (-) for the dominated component. The higher numerical number gave the greater variation in competing ability. Roselle had a positive aggressively score, indicating that it was the dominating component, whereas cluster bean had a negative value, indicating that it was the dominated one (Table 2). Data showed that the highest positive aggressivity of roselle was recorded with 1:3 planting pattern compared with 1:2 and 2:3 planting patterns during both seasons.

3.2. Effect of lithovit rate

Data in Table 3 point out that, the maximum increase in LER, LUE and RCC were achieved by lithovit at the rate of 2.0 g/l in the first season and 6.0 g/l in the second one compared with the control. Moreover, LER, LUE and RCC were increased with increasing lithovit rates from 0 rate to 6.0 g/l in the second season. Moreover, all lithovit rate treatments mostly increased abovementioned indices compared with control. In addition, planted roselle and cluster bean had higher competitive ratios in all ratios with cluster bean, reveals that roselle plants was more competitive (Crr > one) than cluster bean (Crc < one). Under different lithovit rates, positive (+) aggressivity values for roselle reveal that roselle was the dominant component, while, the negative (-) values for cluster bean show that it was the dominated one (Table 2).

3.3. Effect of combination between planting pattern and lithovit rate

Data presented in Tables 3 and 4 show that, the highest LER, ATER and LUE (1.31, 1.22 and 127.20) were obtained by the combination treatment between planting pattern with 1 row of roselle alternating with 3 rows of cluster bean without lithovit application during first season, respectively. While, the highest LER, ATER and LUE (1.22, 1.13 and 118.33) were obtained by the combination treatment between planting pattern with 1 row of roselle alternating with 2 rows of cluster bean with lithovit application at 6.0 g/l during second season, respectively. In both seasons, the abovementioned treatments followed by highest LER, ATER and LUE values (1.27 and 1.19, 1.18 and 1.11 as well as 122.83 and 115.50) were obtained by the combination treatment between planting pattern with 1 row of roselle alternating with 2 rows of cluster bean with 4.0 g/l lithovit rate during 1st and 2nd seasons, respectively. This outcome demonstrate that it could be achieved from one feddan by utilizing this planting pattern (1:2) and 4.0 g/l lithovit the same yield which would require about 1.24 or 1.19 feddan if each component planted solely. The highest values of RCC were noticed when roselle planted with cluster bean at 1:3 pattern and sprayed with lithovit at 4.0 g/l rate in the two seasons. Also, the highest values of competitive ratio for roselle (Crr) were achieved by combination between 1:3 patterns and 4.0 g/l lithovit rate, in contrary, the highest values of competitive ratio for cluster bean (Crc) were noticed by combination between 1:2 pattern with 2.0 g/l lithovit rate in first season. Regardless of the planting patterns combined with different lithovit rates, aggressivity, based on the results, there was a positive sign (+) for roselle and a negative sign (-) for the intercropped cluster bean, suggesting that roselle was dominant while cluster bean was dominated (Table 2).
Table 1
Effect of planting pattern on land equivalent ratio (LER), area time equivalent ratio (ATER), land utilization efficiency percentage (LUE %), relative crowding coefficient (RCC) and competitive ratio (Cr) during 2018 and 2019 seasons.

| Planting pattern (roselle: cluster bean | Land equivalent ratio (LER) | Area time equivalent ratio (ATER) | Land utilization efficiency percentage (LUE %) | Relative crowding coefficient (RCC) | Competitive ratio (Cr) | Competitive ratio (Cr) |
|-----------------------------------------|----------------------------|----------------------------------|---------------------------------------------|-----------------------------------|----------------------|----------------------|
| First season (2018)                     |                            |                                  |                                             |                                   |                      |                      |
| Sole crop                               | 1.00                       | 1.00                             | 100.00                                      | 0.00                              | 1.00                 | 1.00                 |
| 1 row: 2 rows                           | 1.23                       | 1.14                             | 118.87                                      | 0.27                              | 1.25                 | 0.80                 |
| 1 row: 3 rows                           | 1.24                       | 1.16                             | 120.57                                      | 0.82                              | 1.79                 | 0.55                 |
| 2 row: 3 rows                           | 1.10                       | 1.04                             | 107.39                                      | 0.23                              | 1.23                 | 0.81                 |
| LSD at 5 %                              | 0.03                       | 0.03                             | 3.18                                        | 0.05                              | 0.05                 | 0.03                 |
| Second season (2019)                    |                            |                                  |                                             |                                   |                      |                      |
| Sole crop                               | 1.00                       | 1.00                             | 100.00                                      | 0.00                              | 1.00                 | 1.00                 |
| 1 row: 2 rows                           | 1.13                       | 1.05                             | 109.59                                      | 0.20                              | 1.20                 | 0.83                 |
| 1 row: 3 rows                           | 1.12                       | 1.03                             | 108.06                                      | 0.41                              | 1.41                 | 0.70                 |
| 2 row: 3 rows                           | 1.05                       | 0.98                             | 101.91                                      | 0.08                              | 1.09                 | 0.91                 |
| LSD at 5 %                              | 0.03                       | 0.02                             | 2.92                                        | 0.04                              | 0.05                 | 0.03                 |

Table 2
Effect of planting pattern, lithovit rate and their interaction treatments on aggressivity value (A) of roselle (Arc) and cluster bean (Acr) during the two seasons of 2018 and 2019.

| Planting pattern (roselle: cluster bean) | Lithovit rate as g/l (L) | Aggressivity values of roselle (Arc) | Aggressivity values of cluster bean (Acr) |
|-----------------------------------------|--------------------------|--------------------------------------|------------------------------------------|
|                                        | 0.0                      | For (I) = 0.05                        | For (L) = 0.04                          |
|                                        | 2.0                      | For (I) = 0.04                        | For (L) = 0.04                          |
|                                        | 4.0                      | For (I) = 0.08                        | For (L) = 0.08                          |
|                                        | 6.0                      | For (I) = 0.08                        | For (L) = 0.08                          |
|                                        | Mean (I)                 |                                     | Mean (L)                                |
|                                        |                          |                                     |                                          |
| First season                           |                          |                                     |                                          |
| Sole crop                               | +0.00                    | +0.00                               | +0.00                                   |
| 1 row: 2 rows                           | + 0.31                   | + 0.12                              | + 0.26                                  |
| 1 row: 3 rows                           | + 0.78                   | + 0.84                              | + 0.87                                  |
| 2 row: 3 rows                           | + 0.20                   | + 0.20                              | + 0.26                                  |
| Mean (L)                                | + 0.32                   | + 0.29                              | + 0.34                                  |
| LSD at 5 %                              |                          |                                     |                                          |
| Second season                           |                          |                                     |                                          |
| Sole crop                               | +0.00                    | +0.00                               | +0.00                                   |
| 1 row: 2 rows                           | + 0.33                   | + 0.19                              | + 0.14                                  |
| 1 row: 3 rows                           | + 0.38                   | + 0.43                              | + 0.43                                  |
| 2 row: 3 rows                           | + 0.42                   | + 0.07                              | + 0.12                                  |
| Mean (L)                                | + 0.19                   | + 0.17                              | + 0.17                                  |
| LSD at 5 %                              |                          |                                     |                                          |

4. Discussion
Intercropping enhancing utilizing of environmental resources (land, water, light and nutrients) by 10–50 % over singular crop on the same area of land expressed when calculated land equivalent ratio indice (Willey, 1979). The obtained results of this work are in harmony with those found by Aasim et al. (2008) on cotton intercropped with cowpea, Nurbakhsh et al. (2013) on cotton intercropped with cowpea.
sissance when intercropped with bean, Mohammed et al. (2016) on coriander intercropped with fenugreek, Abd-Elghany et al. (2016) on fennel intercropped with fenugreek, Abdellkader et al. (2020) on dill planted with onion. In addition, the priority of growing components (roselle and cluster bean) in multiple cropping depends firstly on the degree of inter-crop against intra-crop competition. Minimize inter-crop differentiation with intra crop competitiveness happens when companion crops vary in their utilizing of growth resources (for example CO2molecule). Moreover, Abdellkader et al. (2018) indicated that the high values of coriander fruits yield per plant and per feddan were achieved with 6 g/l Lithovit rate. Moreover, according to the obtainable literature, there was no information regarding the influence of lithovit treatments between planting pattern and lithovit rates might be attributed to the reducing in intra and inter competition between roselle and cluster bean plants for light and CO2. Moreover, at this row ratios of roselle plants resulting in low yield of cluster bean. Thirdly, the low inter-competition between roselle and cluster bean plants on available nutrients.

5. Conclusion

Under Sharkia Governorate conditions, using of lithovit rate (4 g/l) for both components, under the intercropping patterns of 1:3 as well as 1:2, resulted in maximizing in land equivalent ratio and land utilization efficiency as well as relative crowding coefficient of intercropping roselle and cluster, so, it is the economic treatment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table A

| Mechanical analysis | Soil texture |
|---------------------|--------------|
| Clay (%)            | Sandy clay   |
| Silt (%)            |              |
| Fine sand (%)       |              |
| Coarse sand (%)     |              |
| Chemical analysis   |              |
| pH                  |              |
| E C m.mols/cm       |              |
| Organic matter (%)  |              |
| Soluble cations (meq./l) | Mg++, Ca++, K+ Na+ |
| Soluble anions (meq./l) | Cl-, HCO3-, SO4 - |
| Available (ppm)     | N, P, K      |
| 7.82                | 0.97         |
| 0.58                | 2.7          |
| 1.6                 | 1.5          |
| 1.5                 | 3.5          |
| 4.4                 | 1.6          |
| 3.5                 | 21.0         |
| 21.0                | 9.35         |
| 23.0                | 73.0         |
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