Ecological Indicators 41 (2014) 109–114

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Agroeconomic evaluation of intercropping rocket and carrot by uni- and multivariate analyses in a semi-arid region of Brazil

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ARTICLE INFO

Article history:
Received 17 May 2013
Received in revised form
21 November 2013
Accepted 21 January 2014

Keywords:
Daucus carota
Eruca sativa
Agroeconomic indices
Multivariate analysis

ABSTRACT

The emergence of new vegetable cultivars enables the development of novel combinations of intercrops. Producers require information and comparative data on the behavior of these cultivars in intercropping agroecosystems to learn which crops can combine well and can consequently provide higher productivity and agroeconomic efficiency. This study evaluated the agroeconomic performance of two carrot and two rocket cultivars in a strip-intercropping system, with two harvests of rocket, under the hot and sunny conditions of the municipality of Mossoró, Rio Grande do Norte, in northeastern Brazil. The experiments used a randomized complete block design with five replicates and treatments arranged in a 2×2 factorial scheme. The treatments were the four possible combinations of two carrot cultivars (Brasília and Esplanada) and two rocket cultivars (Cultivada and Folha Larga). Each block contained plots of these four treatments and four monocultured plots, one for each carrot and rocket cultivar, for evaluating the efficiencies of the intercropping indices. Each treatment was evaluated for commercial productivity of carrots, green mass yield of rocket, land equivalent ratio, productive efficiency index, gross income, net income, rate of return and profit margin. Intercropping of the rocket cultivar Folha Larga and the carrot cultivar Brasilia is recommended. The multivariate analysis of the vegetable crop yields as compared to the univariate analysis of land equivalent ratio and productive efficiency index was quite effective in the discrimination of the carrot cultivars in the intercropping systems. However, this same method of multivariate analysis applied to the yields of the same vegetable crops when compared to the univariate analysis of the same indices was not effective in the discrimination of the rocket cultivars in the intercropping systems.

1. Introduction

The intensive use of available resources such as soil, water and nutrients in olericulture contribute to high investments per hectare. Intercropping is one of the cropping systems that can promote the attainment of an economically sustainable agriculture. Studies show that income from intercropped systems of vegetables can exceed that from monocultures. To test the advantage of intercropping over single crops, an economic analysis is necessary in addition to the use of indices that quantify the efficient use of land (Rezende et al., 2005; Cecílio Filho et al., 2010). The assessment of the costs of production is becoming more important because agriculture is becoming increasingly competitive (Rezende et al., 2011).

No single form of statistical analysis is appropriate for the variety of data that can be generated in the evaluation of experiments with intercropped systems. Even a simple set of experimental data will require different types of analyses because the different component crops of an intercropping system will provide data that can occur in a variety of structural forms. These data structures are complex, with different types of information on available yield for different subsets of experimental units (Bezerra Neto et al., 2007a). The land equivalent ratio (LER) has been used in this type of analysis to measure the biological efficiency of an intercropped system (Ghosh, 2004). Biological efficiency, however, this should be judged by economic indicators such as gross and net incomes and margin profit in addition to agronomic indicators such as LER (Bezerra Neto et al., 2010).

An alternative to combining the yields of an intercropping experiment is to consider the equivalent production. This new variable may be based on various characteristics such as total amount of protein and economic value. Intercropping systems, though, cannot

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http://dx.doi.org/10.1016/j.ecolind.2014.01.031

be adequately evaluated by criteria of production or economic value in isolation. Evaluating various alternatives from the perspective of multiple criteria is one of the goals of the methods of multicriteria decision support. Gomes et al. (2008) proposed an alternative approach to aggregate into a one-dimensional index the treatments in experimental situations with a multidimensional response, as in the case of intercrops. The authors used models of data envelopment analysis (DEA) (Cooper et al., 2004) for this purpose, with the calculation of a measure that can be called an "index of productive efficiency".

Furthermore, multivariate methods lend themselves well to the analysis of intercropping experiments because of the nature of multivariate data (Federer and Murty, 1987). Some agricultural researchers analyze their experiments by taking into account the nature of the bivariate response of their plots (Bezerra Neto et al., 2007a,b; Jaggi et al., 2001; Wijesuriya and Thattil, 2001). When the performance of each crop can be summarized in a single yield, then a multivariate analysis of variance is the most powerful technique available. The philosophy of this analysis is that two or more yields must be analyzed together, because multivariate analysis takes into account the correlations between the yields of intercropped cultures. According to Bezerra Neto et al. (2007a), this technique provides a more appropriate interpretation of the results by describing the relative superiority of treatments by means of the yield of intercropped, which simultaneously considers the yields of the component crops.

This study aimed to use both univariate and multivariate methods to evaluate the effect of combining two carrot and two rocket cultivars in a strip-intercropping system, with two harvests of rocket, on the agroeconomic performance of these vegetables under the hot and sunny conditions of the municipality of Mossoró, Rio Grande do Norte, in northeastern Brazil.

2. Materials and methods

2.1. Experimental area

The study was conducted from June to October 2006 in the experimental area of the Crop Sciences Department of the Universidade Federal Rural do Semi-Árido (UFERSA), located in Mossoró, Rio Grande do Norte, Brazil. The municipality of Mossoró is located 18 m a.s.l at 5°11′ south latitude and 37°20′ west longitude. The climate of the region is semi-arid and is classified as BSwh in the Köppen system, i.e. dry and very hot, with two well-defined climatic seasons: a dry season, usually from June to January, and a rainy season from February to May (Carmo Filho et al., 1991).

The soil of the research area is classified as a Eutrophic Yellow–Red Ultisol (EMBRAPA, 2006). Samples were collected from the area and pooled to obtain a composite sample, which was processed and analyzed in the Laboratory of Chemistry and Fertility of Soils of the UFERSA, providing the following results: pH (1:2.5 water), 7.90; Ca, 5.80 $cmol_c\,dm^{-3}$; Mg, 1.00 $cmol_c\,dm^{-3}$; K, 7.42 $cmol_c\,dm^{-3}$; Na, 2.06 $cmol_c\,dm^{-3}$; Al, 0.00 $cmol_c\,dm^{-3}$ and P, 388.4 $mg\,dm^{-3}$.

2.2. Experimental design and intercropping systems

The experimental design was randomized complete blocks with five replicates arranged in a 2 × 2 factorial. The treatments were the four possible combinations of two carrot cultivars (Brasilia and Esplanada) and two rocket cultivars (Cultivada and Folha Larga). The cultivars of rocket (Cultivada and Folha Larga) and carrot cultivar Esplanada have been introduced recently in Mossoró, Rio Grande do Norte (Rodrigues et al., 2008; Linhares et al., 2008; Teófilo et al., 2009). Each block had these four treatment plots, along with one monocultured plot for each of the two carrot and rocket cultivars, for obtaining the combined indices of each intercrop.

The intercropping system consisted of alternate strips of the two vegetables, with 50% of the area for carrots (main crop) and 50% for the rocket (secondary crop). Each treatment plot had two strips, one for each vegetable, of four rows, flanked by two rows of rocket on one side of the plot and two rows of carrots on the other (guard rows). The total area of each intercropped plot was 2.88 m^2, with a harvest area of 1.60 m^2. The rocket strips contained 160 rocket plants with a spacing of 0.20 m × 0.05 m (two plants per hole), and the carrot strips contained 80 carrot plants with a spacing of 0.20 m × 0.05 m (one plant per hole). The monocultured plots with guard rows had an area of 1.44 m^2 and a harvest area of 0.80 m^2. The rocket plots contained 80 rocket plants with a spacing of 0.20 m × 0.05 m (one plant per hole), and the carrot plots contained 40 carrot plants with a spacing of 0.20 m × 0.10 m. The population densities recommended for monocultures in the region are approximately 500,000 plants per hectare for carrots (Barros Júnior et al., 2005) and 1,000,000 plants per hectare for rocket (Freitas et al., 2009), not including the 30% of the area reserved for corridors and roads. These densities were also used in the intercropping systems tested in this study.

2.3. Management

Soil preparation consisted of harrowing followed by the construction of the beds. The beds were solarized with transparent plastic (Vulcabrilho Bril Fles, 30 μm) for 56 days before the experiment began to reduce the population of soil phytopathogens that could reduce the productivity of the crops. Shortly after, the beds were organically fertilized with 80 $t\,ha^{-1}$ of cattle manure.

The monocultured and treatment plots were fertilized one week before planting with 30 kg ha^{-1} of nitrogen, as urea, 60 kg ha^{-1} of P_2O_5 in the form of single superphosphate and 30 kg ha^{-1} of K_2O in the form of potassium chloride, in accordance with the soil analysis and the recommendations of the Instituto Agronômico de Pernambuco (IPA, 1998).

The rocket and carrots were directly and simultaneously sown on 17 July 2006. The intercropped plots with both rocket and carrots were sown with three to four seeds per hole, and the rocket was thinned to two seedlings per hole eight days after emergence. Only one seedling was retained for each hole in the monocultured plots. The carrots, the main crop, were thinned to one plant per hole 25 days after sowing (DAS) in both cropping systems. A second planting of rocket was done on 23 September 2006, when the carrots were 69 days old.

The monocultured plots of rocket were broadcast at 15 DAS with 40 kg ha^{-1} N, in urea form. The monocultured and intercropped plots also received foliar fertilization at 25 and 30 DAS with 14% N, 4% P_2O_5, 6% K_2O, 0.8% S, 1.5% Mg, 2% Zn, 1.5% Mn, 0.1% B and 0.05% Mo at 30 mL 20 L^{-1} of water.

The carrots in the monocultured and intercropped plots received two N fertilizations, at 25 and 45 DAS, with 40 kg ha^{-1} of nitrogen. The first fertilization (25 DAS) also included 30 kg ha^{-1} of K_2O. Weeds were removed manually three times, and the plots were irrigated twice daily by a micro-sprinkler system with a water sheet of about 8 mm. The crops were sprayed twice with a solution of neem (*Azadiracta indica*) at 40 g of dried neem leaves for each liter of water to combat aphids in the rocket.

The rocket was harvested on 20 August and 27 October 2006. The carrots were harvested on 14 October 2006, 89 DAS.

2.4. Data collection and analysis

Along with the green mass yield of rocket (Y_r) and the marketable productivity of carrot roots (Y_c), the following agronomic and economic indices were evaluated in the intercropping systems.