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Changes in *Clitoria ternatea* Canopy Cover and its Relation to Forage Productivity under *Leucaena leucocephala* Alley Cropping and NPK Fertilization in Arid Agroforestry Systems of Saudi Arabia

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ABSTRACT

Background: There is an increased need for intercropping practice in drylands to increase land-use efficiency. Canopy cover is a great tool to assess agricultural yield, as it is an indicator of plant health and productivity.

Methods: The smartphone-based application Canopeo was used to measure the canopy cover (CC) of *Clitoria* under mixed intercropping with *Leucaena* and with four (4) fertilization levels (Control, 200 kg, 300 kg and 400 kg of NPK). Forage yield and (CC) were measured during six (6) consecutive harvests. Moreover, forage quality (NPK and protein) was analyzed.

Result: The results revealed a high positive correlation between (CC) with crop yield and quality. Also, the application of fertilizers produced higher (CC) associated with higher yield and forage quality. The relatively low correlation of (CC) with yield in intercropping may be due to the high competition of the *Leucaena* tree. However, the whole intercropping system was positive (with an LER of 2.4), indicating better land-use efficiency. The results concluded that intercropping in drylands would result in better land use. While the application of NPK fertilizers will increase crop (CC), which in turn will reflect in higher forage yield and quality.

Key words: Agroforestry, Alley cropping, Canopy cover, Competition, Yield.

INTRODUCTION

Alley cropping, also known as “inter-cropping,” is the practice of planting rows of trees and/or shrubs to form alleyways where agricultural or horticultural crops are grown (USDA, 2021). This system improves soil nutrient accessibility in many ways: The integration of woody species on farmlands enhances soil fertility and increases soil organic matter content via leaf litterfall and other materials from trees. Moreover, trees usually offer other efficient nutrients cycling within the system (Grau *et al*., 2017). In addition, this system offers a more appropriate environment for the enlarged activity of valuable microorganisms in the root zone (Lee and Jose, 2003). Recently, the effect of the trees in alley cropping gained growing interest due to the nutrient capture mechanism, in which trees’ deep roots play the role of a “safety net” for capturing and leaching nutrients below the crops root zone (Pierret *et al*., 2016), recycled to the topsoil part of these through litterfall and fine roots decomposition (Liu *et al*., 2019).

Various indicators such as spectral vegetation indices and fractional green canopy cover (FGCC) have been developed to assess the extent of canopy growth (Meyer and Neto, 2008). FGCC has come up as a non-destructive and relatively simple-to-measure variable used in ecology, environmental science and agronomy to assess active green land cover at different spatial and temporal scales (Patrignani and Ochsner, 2015).

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Among the two categories of software packages regarding FGCC, are manual pixel and automatic colour threshold classifications (Patrignani and Ochsner, 2015). Canopeo’s pixel classification method, which employs red-to-green and blue-to-green colour value ratios, has been demonstrated to differentiate green vegetation from non-green backgrounds (Wang and Naber, 2018).

The resulting image is black and white, with white pixels referring to the percentage of green cover and black to non-green. The smartphone-based app. Several researchers have used Canopeo App. such as Lollato *et al*. (2016); Chung *et al*. (2017); Graham *et al*. (2019) and Abreu (2019) for diverse purposes.

Clitoria ternatea L., Fabaceae is a well-known Ayurvedic medication used for various illnesses that have been thoroughly researched scientifically (Mukherjee *et al*., 2008). *C. ternatea* is a palatable fodder legume favoured by cattle above other legumes with good regrowth characteristics after cutting or grazing and produces large yields. Whereas the *L. leucocephala* family of Fabaceae, a fast-growing and evergreen tree, is one of the highest qualities and most palatable fodder trees of the tropics (Ecoport, 2009) with nitrogen fixation potentiality (150 to 300 kg/ha).

This paper is focused on the assessment of the effect of *L. leucocephala* alley cropping on *C. ternatea* L. canopy cover and its relation to the yield using Canopeo App.

MATERIALS AND METHODS

Site sescription

The experiment was conducted in an agroforestry system site located at the Agricultural Research Station of King Abdulaziz University in Hada Al-Sham, approximately 80 km north-east of Jeddah (Latitude 21°48′3″N, Longitude 39°43′25″E, elevation 240 m.a.s.l). The site receives minimal annual rainfall (less than 100 mm/annum) with poor sandy loam and pH ranging from 7.1 to 7.99 (Al-Solimani *et al*., 2003). The experiment was conducted in the field under a drip irrigation system. The agroforestry system was established, with 10 m between rows and 4.5 m within row distances, with a row length of 17.5 m.

Experimental design

The experiment was designed as replicated split-plot design in a randomized complete block design. The main plot was represented by *Leucaena* × *Clitoria* intercropping, while the subplots were occupied with fertilization treatments (0, 200, 300 and 400 kg/ha). The experiment was monitored for the whole year to account for all seasonal variations.

The canopeo app.

The Canopeo app. used in this study is an Automated Colour Threshold picture analysis tool using colour values in the red-green-blue (RGB) developed by Oklahoma State University for CC measurement (Shepherd *et al*., 2018). It grants access to the operator to take managerial choices while in the field. The FGCC ranges from 0-1 (no green to 100% green CC) (Fig 1).

Measurements

Six (6) cuttings were conducted throughout the experiment (17th February 2020 to 13th April 2021). In each cutting harvest, a one-meter square (1 m^2) quadrat was thrown randomly over the growing plants in each plot/treatment in a total of 24 plots. Within each plot, plant height was measured on 3 sampled plants; then the shoots inside the quadrat were trimmed and fresh weighted; afterwards, samples were oven-dried to estimate the dry weight and forage yield per hectare. The forage yield was estimated by converting the 1 m^2 fresh forage weight/quadrat into tons/ha. In each plot, downward-facing images were captured from random spots using the Canopeo App. on an android smartphone. The camera was kept at approximately 60 cm from the top of the canopy to maintain an appropriate distance between it and the plant top, essential to minimize the overestimation of FGCC due to canopy leaves being too close to the lens of the camera (Hoyos Villegas *et al*., 2014).

Then leaves samples were collected to determine N, P, K and protein. Nitrogen was analyzed using automated micro-Kjeldahl and multiplied by 6.25 to estimate the protein content (Miller and Horneck, 1998). The phosphorus was determined by the U.V. visible spectrophotometric method (Pradhan and Pokhrel, 2013). While potassium was determined by atomic absorption spectrophotometry (Adelantado *et al*., 1991).

Statistical analysis

The analysis of variance was conducted using SAS (Statistical Analysis System, SAS System) and the means were obtained and tested by Duncan's multiple range test.

RESULTS AND DISCUSSION

Crop canopy cover

In this study the measurements of FGCC with Canopeo app. during six consecutive measurements resulted in significantly different canopy cover (CC) percentage between plants grown under the trees and monoculture in four measurements out of six (Table 1). The highest CC of 71.7% was obtained in intercropping systems during harvest six and 67.9% was reported in monocropping in the same period. Similar to the cropping system, the data showed that the addition of NPK fertilizers produced a significantly higher CC percentage in plots treated with fertilizer compared to the control untreated plots (Table 2). Higher doses of fertilization (400 kg/ha) resulted in higher CC in all six measurements followed by 300 and 200 kg/ha and the least was reported in control untraded plots. A similar study conducted by Elfeel and Elsafori (2014), reported positive effects of NPK addition to *Clitoria* on LAI with CC measurement based on a similar theory using Canopeo app. In addition, in the same climatic condition, Elfeel and Abohassan (2016) find the alike results, linking different doses of NPK to the increase of various parameter of a plant such as LAI and diameter growth. It is well known that the addition of fertilizers, especially N leads to better growth and green matter production.

Forage yield

In this study effects of the alley cropping system and NPK fertilization on forage yield were assessed. In addition to the correlation of CC with forage yield. Analysis of variance showed that intercropping system was significantly affected by forage yield parameters measured, including plant height (m), fresh weight and forage yield (tons/ha) at

Table 1: Mean differences of *Clitoria ternatea* plant length (cm), fresh weight (tons/ha), yield (tons/ha) and canopy cover (%) between intercropping (I) and Mono-cropping (M) under the effects of *Leucaena leucocephala* alley cropping system across 6 cutting harvests.

Harvest	Cropping	Variables			
		Plant length	Fresh weight	Yield	Canopy cover
Harvest 1	I	0.98^{b}	0.72^{b}	2.36^{b}	58.79^{a}
	M	1.11^{a}	1.39^{a}	5.47^{a}	48.33^{b}
Harvest 2	I	1.06^{b}	0.83^{b}	3.66^{b}	65.97^{a}
	M	1.26^{a}	1.29^{a}	5.19^{a}	63.91^{a}
Harvest 3	I	1.57^{a}	0.79^{b}	2.43^{b}	65.99^{a}
	M	1.53^{a}	1.29^{a}	4.45^{a}	64.46^{a}
Harvest 4	I	1.28^{a}	0.69^{b}	1.78^{b}	32.04^{a}
	M	1.28^{a}	1.22^{a}	3.27^{a}	61.57^{a}
Harvest 5	I	0.75^{a}	0.42^{b}	1.08^{b}	59.29^{a}
	M	0.67^{b}	0.71^{a}	1.80^{a}	59.46^{a}
Harvest 6	I	0.99^{a}	1.17^{b}	3.38^{b}	71.77^{a}
	M	0.94^{b}	1.86^{a}	7.66^{a}	67.99^{b}

Using duncan's multiple range test, the means within each column by harvest, crop and cropping with the same letter are not significantly different at p=0.05.

Table 2: Mean values of *Clitoria ternatea* plant length (cm), fresh weight (tons/ha), yield (tons/ha) and canopy cover (%) under the effects of four NPK fertilization (T0=0 kg, T1=200 kg, T2=300 kg and T3=400 kg) across 6 cutting harvests.

Harvests	Fertilization level	Variables			
		Plant length	Fresh weight	Yield	Canopy cover
Harvest 1	T 0	0.95^{c}	0.76^{b}	2.81^{c}	40.51^{b}
	T 1	1.00^{c}	0.96^{b}	3.58^{b}	46.79^{b}
	T 2	1.08^{b}	1.18^{a}	4.41^{a}	59.03^{a}
	T 3	1.16^{a}	1.31^{a}	4.87^{a}	67.90^{a}
Harvest 2	T 0	0.99^{c}	0.74^{b}	2.79^{c}	52.27^{d}
	T 1	1.10^{bc}	1.10^{ab}	4.18^{bc}	60.18^{c}
	T 2	1.19^{b}	1.19^{a}	4.80^{ab}	69.18^{b}
	T 3	1.37^{a}	1.22^{a}	5.93^{a}	78.14^{a}
Harvest 3	T 0	1.34^{c}	0.70^{c}	2.30^{c}	59.02^{b}
	T 1	1.51^{b}	0.90^{c}	2.98^{c}	60.23^{b}
	T 2	1.62^{ab}	1.18^{b}	2.84^{b}	71.28^{a}
	T 3	1.73^{a}	1.39^{a}	4.64^{a}	72.39^{a}
Harvest 4	T 0	1.14^{c}	0.75^{b}	1.96^{c}	56.81^{b}
	T 1	1.26^{b}	0.92^{ab}	1.35^{bc}	59.60^{b}
	T 2	1.31^{ab}	1.02^{a}	2.71^{ab}	64.47^{a}
	T 3	1.41^{a}	1.11^{a}	3.05^{a}	66.36^{a}
Harvest 5	T 0	0.58^{b}	0.43^{c}	1.12^{d}	50.80^{c}
	T 1	0.66^{b}	0.56^{b}	1.34^{c}	56.86^{b}
	T 2	0.79^{a}	0.59^{b}	1.52^{b}	60.24^{b}
	T 3	0.82^{a}	0.68^{a}	1.78^{a}	69.60^{a}
Harvest 6	T 0	0.80^{c}	1.04^{c}	3.52^{c}	61.27^{c}
	T 1	0.98^{b}	1.49^{b}	5.35^{b}	70.22^{b}
	T 2	1.00^{ab}	1.69^{ab}	6.09^{b}	73.38^{ab}
	T 3	1.07^{a}	1.84^{a}	7.12^{a}	74.66^{a}

Using duncan's multiple range test, the means within each column by harvest, crop and fertilization with the same letter are not significantly different at p=0.05.

($p<0.05$). The monocrop plots produced significantly higher yield values than the intercrop plots in all harvests and across most of the measured parameters. This is similar to Elfeel *et al*. (2014), who reported adverse effects of *Leucaena* trees on Clitoria yield. This may be attributed to the fast and prolific growth of the Leucaena tree, leading to high competition. However, concerning the whole system, the net gain of *Clitoria* intercropped with *Leucaena* trees in the dry site of Hada Ash-Sham produced a positive effect with an LER value of 2.4 (Table 3) indicating better land-use efficiency under intercropping.

In the same way, the intercropping system significantly ($p<0.05$) affected the yield production in tons ha^{-1} over the six harvests (Table 1). The highest total yield production per year (28.4 tons ha^{-1} y^{-1}) was reported in the combination of NPK 400kg/ha under monocrop plots, while the lower yield was reported in the 100 kg/ha and control untreated plots under intercropping (Fig 2). Similar results were obtained by Riste *et al*. (2017) studying the response of local rice (*Oryza sativa* L.) cv. to different doses of NPK (60:30:30 kg NPK/ha), they find differents yield respctively compared to the control. In general, the combined effects of NPK and monocrop planting produced higher yields compared to intercropping and NPK. The reduction in forage yield under alley cropping was near 50%; however, looking at the whole system, the effect was positive.

Table 3: Land equivalent ratio of the total yield for the 6 cutting harvests.

	Intercrop yield (t/ha)	Monocrop yield (t/ha)	Partial LER
Clitoria	14.69	27.84	14.69/27.84=0.53
Tree	22.59	11.87	22.59/11.87=1.90
Total	-	-	2.43

LER>1 means intercropping is yield advantage regarding monocropping.

This was related to the very high effect of intercropping on tree growth. This may call for future investigation of the addition of *Leucaena* forage as a supplement to *Clitoria* forage in certain percentages in order to increase the forage output of the intercropping system. It is well known that the production of Leucaena forage is very high; however, due to the toxic effects of Mimosine in high quantities, it is highly needed to investigate the best *Clitoria*: *Leucaena* ratio that will not affect the forage quality.

The data represented in Table 4 revealed a very high positive correlation of CC with crop dry matter production and yield (especially in monocrop). This is similar to Bakhashwain and Elfeel (2012), who found a positive relationship between canopy and *Clitoria* productivity. Despite the higher CC in intercropped plots compared to the monocrop, however, the correlation of CC with yield is lower under intercropping. This confirms the competitive effects of the *Leucaena* tree, occurring between the crop and trees roots for nutrients resulting in heavy competition and a reduction in crop yield (Jose *et al*., 2000). This positive correlation of the fast smartphone CC with forage yield and quality highlighted the importance of CC measurement as an indicator of crop yield and quality.

Regarding the application of NPK fertilizer, it was found that fertilization had highly significant ($p<0.05$) effects on crop yield and quality (Table 2 and Fig 3). Also, there are observed strong relations between CC with yield under the corresponding fertilization level (Table 2). The NPK level 400 kg/ha (T3) resulted in a high canopy cover percentage as well as the yield (ton ha^{-1}) compared to the control, followed by T2 (300 kg/ha) and T1 (200 kg/ha). This result is similar to Umami *et al*. (2019); Adhikari (2009) and Sarfraz *et al*. (2021), who reported the positive effect of fertilization on crop yield. The positive correlation of NPK addition with CC may be attributed to the fact that the addition of fertilizers, especially N would lead to better growth and green matter production and consequently to high crop forage yield and

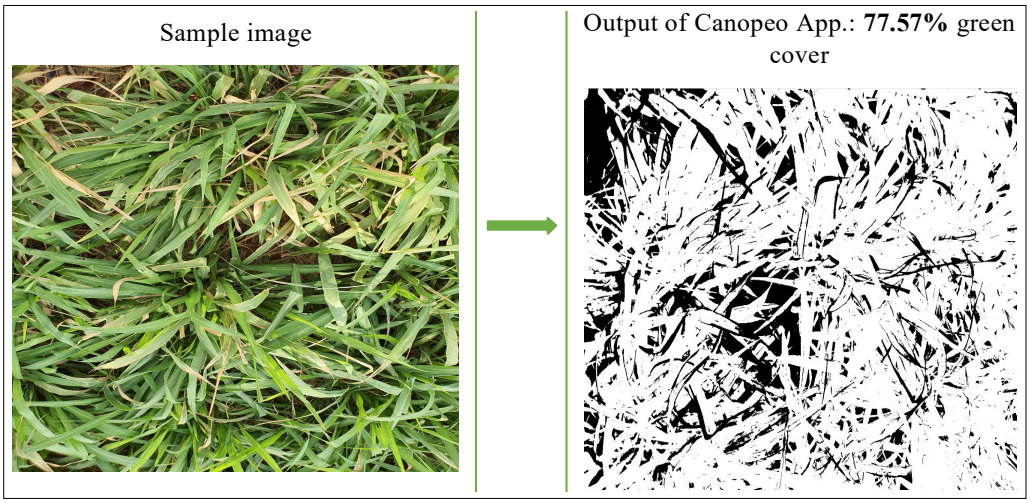


Fig 1: A sample GCC percentage measurement recorded on 28/08/2021 at 9h28 AM.

quality. NPK fertilizers substantially enhance productivity and increase numerous parameters that contribute to yield and quality (Bakhashwain and Elfeel, 2012; Li *et al*., 2010).

Forage quality

The data presented in Fig 3 revealed that the effects of intercropping and fertilization on forage quality (protein and N, P, K contents) were high. Protein contents in *Clitoria* leave ranged from 18.5 to 21.7%, the nitrogen (N) ranged from 3 to 3.5%; meanwhile, the phosphorus (P) varied from 0.59 to 0.52% in intercropping and monocropping, respectively. No difference was observed between monocropping and intercropping for potassium (K) with 0.02% for both monocropping and intercropping. Similar

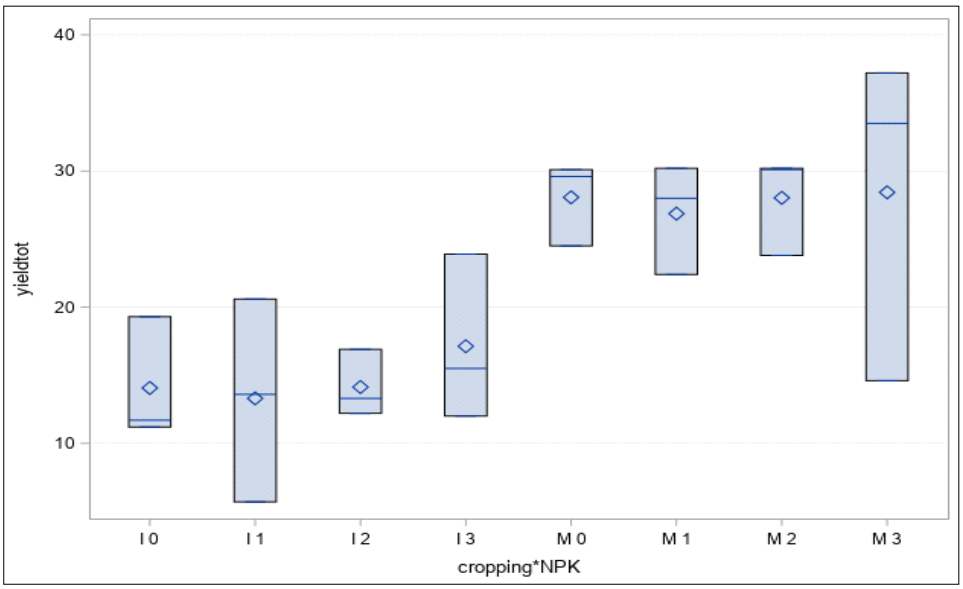


Fig 2: Mean value (Mean±SD) distribution of total yield (Tons ha^{-1} y^{-1}) of *Clitoria Ternatea* grown between alleys of *Leucaena Leucocephala* and different NPK concentrations under arid land agroforestry system.

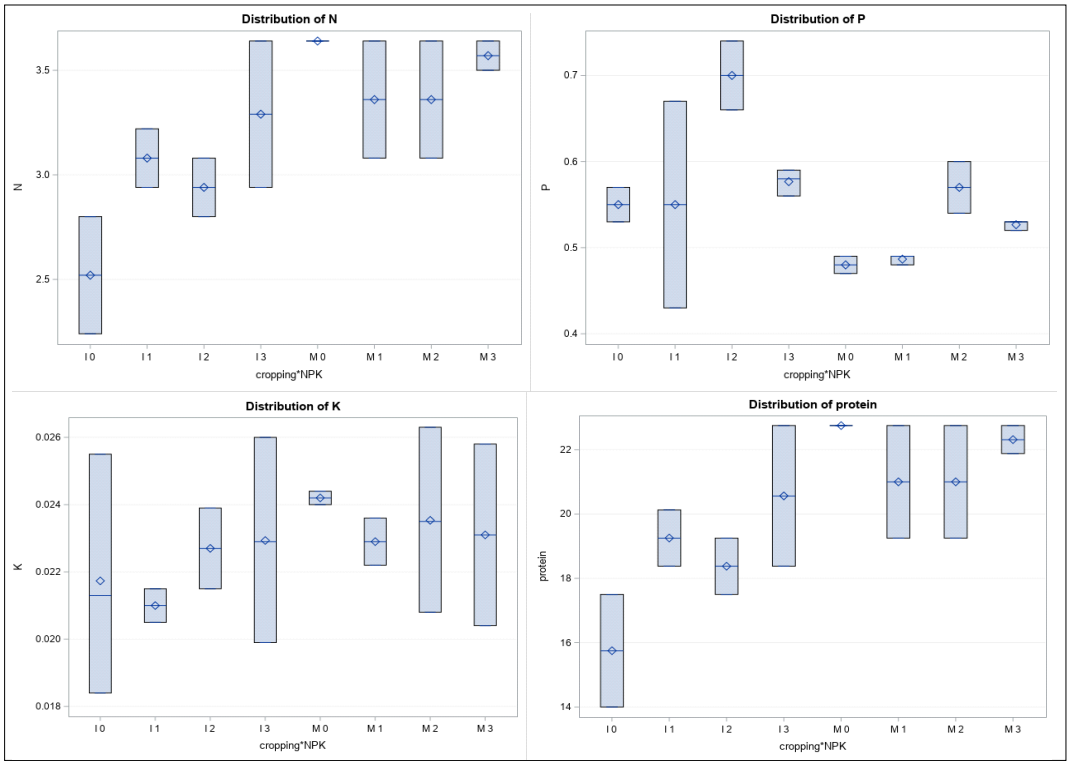


Fig 3: Mean value (Mean±SD) distribution of forage quality percentages (N, P, K and protein) of *Clitoria ternatea* grown between alleys of *Leucaena Leucocephala* and different NPK concentrations under arid land agroforestry system.

Table 4: Pearson correlation coefficient of clitoria *Ternatea* canopy cover with fresh weight and yield in intercropping and monocropping plots across 6 cutting harvests.

Harvests	Intercropping		Monocropping	
	Canopy cover correlation with variables			
	Fresh weight	Yield	Fresh weight	Yield
Harvest 1	0.53 (p<0.08)	0.59 (p<0.04)	0.85 (p<0.0005)	0.88 (p<0.0002)
Harvest 2	0.18 (p<0.58)	0.16 (p<0.63)	0.60 (p<0.04)	0.65 (p<0.02)
Harvest 3	0.41 (p<0.19)	0.38 (p<0.22)	0.68 (p<0.01)	0.68 (p<0.01)
Harvest 4	0.82 (p<0.001)	0.87 (p<0.0002)	0.84 (p<0.0006)	0.86 (p<0.0004)
Harvest 5	0.90 (p<0.0001)	0.57 (p<0.05)	0.81 (p<0.001)	0.77 (p<0.004)
Harvest 6	0.16 (p<0.61)	0.65 (p<0.02)	0.92 (p<0.0001)	0.92 (p<0.0001)

to the forage yield, the combined effects of monocropping and NPK fertilization resulted in higher forage quality values than the intercropping and NPK fertilization combination.

The two-way means distribution value of total yield (Tons/ha/year) with different NPK concentrations displayed in Fig 2 indicates that the different NPK doses positively impacted the yield throughout the experiment. This graphic confirms the result obtained in Table 2, which indicates the positive difference in yield obtained under the levels of fertilization compared to the control plot. High is the dose of NPK and high is the yield obtained regarding the control (0NPK). In several studies, Yamika *et al*. (2021); Murthy *et al*. (2015); Dhinesh and Santhi (2016), similar results were obtained correlating the high level of NPK fertilization with high yield. Meanwhile, the yield obtained in monocropping is high than the yield under intercropping at all levels of NPK.

CONCLUSION

Leucaena leucocephala intercropped with *Clitoria ternatea* increased crop canopy cover, reflecting better forage yield and quality. Although the yield, in general, is higher in monocrop compared to the sole crop, however, the whole intercropping system is positive. This result may be attributed to the light shaded of *Leucaena* L., which reduces the light competition between the understory crop (Clitoria ternatea) and *Leucaena* L. trees. In addition to the mentions, the young stage growth of *Leucaena* L. trees may also be another explanatory factor to its positive effect.

Conflict of interest

All authors declare that they have no conflicts of interest.

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