World Journal of Agricultural Research, 2022, Vol. 10, No. 3, 70-75
Available online at http://pubs.sciepub.com/wjar/10/3/2
Published by Science and Education Publishing
DOI:10.12691/wjar-10-3-2

Biomass Production of *Brachiaria ruzizienzis* and *Crotalaria retusa* in Different Cropping Systems on an Andic Ferralsol in Western Highlands of Cameroon

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Received September 08, 2022; Revised October 10, 2022; Accepted October 22, 2022

Abstract Benefits associated with cover crops in direct seeding mulch-based cropping systems (DMC) often depend on the establishment of a highly productive cover crop community. The objective of this study was to assess biomass production for the implementation of DMC and its efficiency based on Land Equivalent Ratios (LER) of *Brachiaria ruziziensis* and *Crotalaria retusa* grown in different cropping systems on an Andosol in the Western Highlands of Cameroon. The six treatments were pure stands and combinations of one or two lines of each cover crop. These were assigned to experimental units in a randomized complete bloc design with four replications. Biomass production, ability to start DMC and Land Equivalent Ratios (LER) were used to compare treatments. *B. ruziziensis* produced 10.51 t DM ha^{-1} in pure stands and 2.9 to 5.37 t DM ha^{-1} in intercropping. *C. retusa* produced 5.03 t DM ha^{-1} in pure stands and 2.88 to 5.28 t DM ha^{-1} in intercropping. There were highly significant differences ($p < 0.01$) among treatments for total biomass production. Biomass production was significantly higher when two lines of *B. ruziziensis* were associated with a single line of *C. retusa*. Intercropping one line of *B. ruziziensis* and one line of *C. retusa* was the only combination that could not allow the implementation of DMC the following season. LER larger than 1 for the other intercropping indicated their superiority compared to pure stands. Growing *B. ruziziensis* and *C. retusa* during the first season with one line of one species and two lines of the other species, or two lines of each crop species were considered appropriate for the implementation of DMC. Results provided a basis for DMC implementation using intercropping of *B. ruziziensis* and *C. retusa* as cover crops during the first cropping season. Further studies are necessary to evaluate the residual effects of the biomass produced.

Keywords: *direct seeding mulch-based cropping systems (DMC), Brachiaria ruziziensis, Crotalaria retusa, intercropping, cover crops, biomass, LER (Land Equivalent Ratio)*

Cite This Article: Beyegue Djonko H., Tatang Tadjufo A., Mvondo-Awono J.P., Gafe Pelap H., and Tankou C.M., “Biomass Production of *Brachiaria ruzizienzis* and *Crotalaria retusa* in Different Cropping Systems on an Andic Ferralsol in Western Highlands of Cameroon.” *World Journal of Agricultural Research*, vol. 10, no. 3 (2022): 70-75. doi: 10.12691/wjar-10-3-2.

1. Introduction

The inclusion of cover crops such as *Brachiaria ruziziensis* and *Crotalaria retusa* in cropping systems provides a number of agronomic and environmental benefits, such as restoration of soil fertility, increasing soil productivity and crop performance [1,2,3]. Achieving these benefits often depends on the establishment of a highly productive cover crop community either in pure stands or in mixtures [4]. Planting multi-species cover crops may be a viable solution for increasing the ecological stability and resilience of cover crop communities, which can contribute to higher and more consistent productivity [5,6], especially with direct seeding mulch-based cropping systems (DMC).

The DMC introduced in the Northern part of Cameroon [2,7,8] is an approach of Conservation Agriculture based on three principles: minimum soil tillage, permanent soil cover and crop rotations [1,9]. Biomass production by cover crops is followed by the cultivation of the desired crop with the mulches serving as nutrient sources and humus [10,11]. The minimum biomass to start a successful DMC in Northern Cameroon was estimated at 7 t DM ha^{-1} [12]. Both the quantity and the quality of biomasses are important for the efficiency of the systems [13]. Cover crops species are chosen on the basis of their ability to produce abundant biomasses and their capacity to improve soil properties [8,14]. Increasing cover crop biomass was positively correlated with several ecosystem services, namely weed suppression, prevention of nitrate leaching, and aboveground biomass N [4]. Plant mulches improve soil fertility by constant organic inputs, protect the soil from erosion and stimulate the biological activity [15,16].

Among available cover crops in Cameroon, *Brachiaria ruziziensis* and *Crotalaria retusa* are commonly used in pure stands [2,3,11]. The intercropping of the two plant species may allow a better performance of the system in terms of mulch persistence and soil properties improvement [17,18]. Intercropping systems typically include the production of two crop species within a given field in the same season, most commonly oriented in alternating rows or strips of rows [13,19]. There are many examples of intercropping systems that have demonstrated greater grain or forage yield compared to sole-cropping systems on an equivalent land area basis [19,20,21,22,23]. However, the performances of the systems vary according to several factors including plant species, cultural practices and growing conditions [24].

The agricultural system practiced in the Highlands of West Cameroon is based on two cultural seasons within the same year. It is important to adapt the DMC procedures to farmers' needs and growing conditions [11]. This study aims to assess the implementation of DMC on a Ferrasol with andic character. The objectives of the study are the following: (1) to evaluate the amount of biomass produced in the first agricultural season by *B. ruziziensis*, and *C. retusa* grown in pure stands or intercropped; (2) to evaluate the ability to start DMC the next campaign and (3) to determine efficiency of *B. ruziziensis* and *C. retusa* intercropped during the first growing season using LER.

2. Material and Methods

2.1. Location of the Experimental Area

The experiment was carried out in 2015 at the Faculty of Agronomy and Agricultural Sciences (FASA) Teaching and Research Farm of the University of Dschang in Bansoa, in the West region of Cameroon. The geographical coordinates of the experimental site are as follows: latitude, 5°27'48''N; longitude, 10°15'30''E and altitude, 1420 m. The amount of rainfall during the study period was 1558.6 mm and temperatures oscillated between 15 and 35°C. The soil is a Ferrasol with an andic character. The soil characteristics determined by the soil analysis laboratory are presented in Table 1.

2.2. Planting Material

Brachiaria ruziziensis is an herbaceous grass; semi erected or creeping that grows in tufts with a height ranging from 1 to 1.5 m at flowering. Its root system is composed of numerous roots, dense and able to grow to more than 1.8 m deep [25,26]. The plant can be propagated either by seeds or by cuttings. Biomass production of 7.5 to 25.6 t DM ha^{-1} have been reported [3,27]. The germination rate of the seed lot used was 25%.

Crotalaria retusa is an erect annual plant that grows to a height of between 1 and 1.40 m. It has a taproot system. The plant is propagated by seeds. *C. retusa* is leguminous plant that fixes atmospheric N_2. Its biomass production varies according to the ecologies. Yields of 3 to 12 t DM ha^{-1} have been reported [28,29]. The germination rates of the seed lot used was 70%.

Table 1. Soil Characteristics of the Experimental Site

Chemical characteristics of the soils	Values of soil characteristics
Texture (%)	
Sand	74
Silt	17.6
Clay	8.4
Acidity	
pH-water	5.6
pH-KCl	4.9
Organic matter	
Organic carbon (%)	4.00
Organic matter (%)	6.9
Total N (g/kg)	2,94
C/N	14
Exchangeable cations (meq/100g)	
Calcium	14.28
Magnesium	5.28
Potassium	0.49
Sodium	0.47
Sum of cations	21.52
Exchange capacity (meq/100g)	30.40
Available phosphorus Bray II (mg/kg)	26.38

Source: Laboratory of Soil Analysis and Chemistry of Environmental (LSACE), FASA, UDs, 2016.

2.3. Treatments and Experimental Design

The six treatments were pure stands of *B. ruziziensis* (BP) and *C. retusa* (CP) and mixtures of one line and two lines of each cover crop in a randomized complete bloc design with four replicates. The four spatial arrangements of intercropped species determining the treatments were: one line of *B. ruziziensis* and one line of *C. retusa* (1B1C); one line of *B. ruziziensis* and two line of *C. retusa* (1B2C); two lines of *B. ruziziensis* and one line of *C. retusa* (2B1C) and two lines of *B. ruziziensis* and two lines of *C. retusa* (2B2C).

2.4. Cultural Practices

The experimental plots measured 20 m^2 (4 m x 5 m). Cover crops were sown in lines distant of 30 cm. The seeding rate was 15 kg per hectare for both cover crops. The fertilizer rates applied to cover crops during the first season were 100 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} for *B. ruziziensis* and 50 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} for *C. retusa*. Cover crops were weeded 27 days after sowing.

2.5. Determination of Aboveground Biomass and Ability to Implement DMC

The aerial biomass produced by cover crops was obtained from sub plots of 0.45 m^2 or 0.60 m^2 depending on the number of lines of each species involved in the mixture. After harvest, biomasses of both plants were separated and sun dried. Samples were subsequently oven dried at 70°C until constant weight for dry matter (DM) determinations. The evaluation of the ability to start DMC on the basis of biomasses produced was made following the recommendations by [7] and [2]. These authors proposed that cover crops should produce a minimum of 7 t DM ha^{-1} before any successful DMC could be expected.

2.6. Land Equivalent Ratio Determination

The land equivalent ratio (LER) was used to compare the productivity of sole and intercropped cover crops. The LER indicates the relative amount of land required when growing sole crops to achieve the productivity observed in the mixture [30]. The LER is a robust and useful indicator of mixture productivity relative to sole crops [5]:

$$LER = LERi + LERj + \ldots + LERn \quad (1)$$

Where LER*i* is the partial LER of species *i*, LER*j* is the partial LER of species *j*, and so forth for *n* number of species.

Partial LER is calculated as:

$$LERi = YMIi / YSCi \quad (2)$$

where *YMIi* is the yield of species *i* planted in mixture and *YSCi* is the yield of species *i* planted as a sole crop.

A total LER > 1.0 indicates the mixture was more productive than the component sole crops, whereas a value <1.0 suggests sole crops were more productive.

2.7. Statistical Analysis

Cover crops biomass data were statistically analysed using appropriate SAS software procedures. Analysis of variance and single degree of freedom orthogonal contrasts to compare the productivity of mixtures and mixtures *vs.* sole crops were carried out. Means were separated using least square difference method at 5% probability level.

3. Results and Discussion

3.1. Aboveground Biomass Produced by Cover Crop

Brachiaria ruziziensis produced 2.9 to 5.37 t DM ha^{-1} when intercropped with *C. retusa*, depending on the number of lines involved in the mixture (Table 2). The amount of biomass harvested was higher (5.37 t DM ha^{-1}) when two lines of *B. ruzizensis* were associated with one line of *C. retusa* and lower (2.9 t DM ha^{-1}) when one line of *B. ruziziensis* was associated with two lines of *C. retusa*. There was a significant difference among treatments ($p < 0.05$) for biomass production (Table 3). The amount of biomass produced by *B. ruziziensis* in pure stands (10.51 t DM ha^{-1}) was significantly larger compared to biomasses produced in intercropping (Table 2 and Table 3). *B. ruziziensis* alone can produce 5 to 25 t DM ha^{-1} depending on the duration of the cropping cycle, fertilization and ecology [3,10,11,13,27,31,32,33].

Crotalaria retusa produced 2.88 to 5.28 t DM ha^{-1}, depending on the number of lines involved in the association with *B. ruziziensis* (Table 1). The higher biomass of *Crotalaria retusa* (5.28 t DM ha^{-1}) was obtained when two lines of C. *retusa* were associated with a single line of *B. ruziziensis*. The differences observed were highly significant (Table 3). 5 t DM ha^{-1} were obtained in Brazil with *C. juncea* in sole cropping [13] *C. retusa* can produce up to 11 t DM ha^{-1} with a longer growing period [10,11,29]. This species is very sensitive to irregular rainfall during the early stages of growth.

In mixtures, the highest total biomass (9.01 t DM ha^{-1}) was obtained when two lines of *B. ruziziensis* were associated with two lines of *C. retusa.* In general, the total biomass produced ranged from 6.84 t DM ha^{-1} to 9.01 t DM ha^{-1} depending on the number of lines of the two species involved in the intercropping (Table 2). Differences among treatments are highly significant ($p < 0.01$). Amounts of biomasses obtained in this experiment are similar to those obtained by [13] on mixtures of *B. ruziziensis* with *C. juncea* or pearl millet in Brazil. However, the quality of biomasses could be different according to the proportion of each species in the mixture. Differences in the qualitative value of biomasses of cover crops mixtures have been reported [13,34,35,36,37].

It is recommended to produce a minimum of 7 t DM ha^{-1} biomass before starting typical DMC [2,7]. In this experiment, only *C. retusa* in pure stands and intercropping of one line *C. retusa* and one line *B. ruziziensis* did not produce enough biomass for starting DMC. They produced 5.03 and 6.84 t DM ha^{-1}, respectively. The other plant intercropping or sole crop produced enough biomasses (8.18 to 10.51 t DM ha^{-1}) and DMC could be started the next campaign [10,11]. However, these biomasses may not remain longer on the soil surface and need to be renewed. Establishing mixtures of *B. ruziziensis* and *C. retusa* for three months during the first campaign in the highlands of West Cameroon needs to be repeated every year and the sustainability of the system have to be assessed. The relatively low amounts of biomass obtained in this experiment can be explained by fact that cover cops were allowed to grow only for three months during the first campaign of the growing season. In a context of intensive use of soils for food crop cultivation, where soils are depleted in organic matter and request proper care to offset their degradation, allowing cover crops to grow all year round could contribute to substantially increase the biomass production for a more efficient establishment of a DMC system.

Table 2. Biomass production of *B. ruziziensis* and *C. retusa* in mixtures or in pure stands

Treatment	Biomass production of *B. ruziziensis* (t DM ha^{-1})	Biomass production of *C. retusa* (t DM.ha^{-1})	Total biomass production (t DM ha^{-1})
1B1C	3.46 ± 0.94bc	3.38 ± 0.34bc	6.84 ± 0.74cd
1B2C	2.90 ± 0.94c	5.28 ± 0.57a	8.18 ± 0.74bc
2B1C	5.37 ± 0.94b	2.88 ± 0.48c	8.25 ± 0.51bc
2B2C	4.72 ± 0.90bc	4.29 ± 0.47ab	9.01 ± 0.56ab
CP	0.00d	5.03 ± 0.30a	5.03 ± 0.30d
BP	10.51 ± 0.87a	0.00d	10.51 ± 0.87a

Means followed by the same letter(s) are not significantly different at the 5% probability level.

Table 3. Summary of the analysis of variance from data of biomass production of *Brachiaria ruziziensis* and *Crotalaria retusa* in mixture or in pure stands

		B. ruziziensis			*C. retusa*			Total biomass		
Sources of variation	Df	MS	FCAL	PR > F	MS	FCAL	PR > F	MS	FCAL	PR > F
Bloc	3	2.76	1.24	0.32	2.10	4.84	0.01*	1.89	0.32	0.80
Treatments	5	48.67	21.86	< 0.0001**	15.00	34.40	< 0.0001**	70.38	7.17	< 0.001**
Error	15	2.22			0.43			29.43		
Total	23							101.71		
Contrasts										
1B1C vs 1B2C	1	0.61	0.28	0.60	7.23	16.60	0.001**	3.59	1.83	0.19
1B2C vs 2B1C	1	12.20	5.48	0.03*	11.49	26.36	< 0.0001**	0.01	0.01	0.94
2B1C vs 2B2C	1	0.86	0.39	0.54	3.93	9.02	< 0.008**	1.11	0.57	0.46
CP vs 1B1C, 1B2C, 2B1C, 2B2C	1	54.10	24,29	< 0.0002**	3.65	8.38	< 0.01 *	29.67	15.12	< 0.001**
BP vs 1B1C, 1B2C, 2B1C, 2B2C	1	131,09	58,86	<0.0001**	50.08	114,84	<0.0001**	19.09	9.73	< 0.007**

*: Significant at the 5% probability level, **: significant at the 1% probability level.

Table 4. Theoretical and observed partial and total land equivalent ratios (LER) for mixtures of *B. ruziziensis* and *C. retusa*

Treatments	Theoretical LER_B	Theoretical LER_C	Observed partial LER_B	Observed partial LER_C	Observed Total LER
1B1C	0,50	0,50	0,33	0,67	1.00
1B2C	0,33	0,66	0,27	1,05	1.32
2B1C	0,66	0,33	0,51	0,57	1.08
2B2C	0,50	0,50	0,45	0,85	1.30

3.2. Land Equivalent Ratio (LER)

The computed LER varied from 1.00 to 1.34 for the various intercropping systems (Table 4). Theoretically, if the agro-ecological characteristics of each crop in a mixture of two are exactly the same, the total LER should be 1.0 and the partial LERs should be 0.5 for each [30]. LER value of 1.0 indicates no difference in yield between the mixture of *B. ruziziensis* and *C. retusa* compared to monocultures of the same species. The LER higher than 1.0 indicates the presence of positive inter-specific interference in the mixtures which provides an advantage to the intercrop.

The other mixtures with LER > 1 (Table 4) suggest that they were more beneficial compared to sole crops of each species in terms of the efficiency in land use. There is an increase in the biomass production in mixtures including Fabacae perhaps by the extra nitrogen supplied through the biological nitrogen fixation, which favors the development of the Poaceae species [13]. The partial LER of *C. retusa* range from 0.57 to 1.05. These values indicate that this species is more efficient for land use in mixtures with *B. rusiziensis*. In general, it is observed that grasses dominate legumes in mixtures [38,39] because of grasses relative fast growth at the early stages. The performance of *C. retusa* can be explained by its fast growth rate and its known allelopatic effects [40]. Delay planting of *C. retusa* may improve *B. ruziziensis* performance, if the need is to get more grass in the mixture.

4. Conclusion

This study was designed to assess biomass production of intercropped *B. ruziziensis* and *C. retusa*, their ability to implement DMC on a Ferrasol with andic character in the highlands of West Cameroon. Only the combination of one line *B. ruziziensis* and one line *C. retusa* did not produce sufficient biomass to start typical DMC the following season. The combination of two lines of *B. ruziziensis* and two lines of *C. retusa* provided higher and fairly balanced total biomass production. The LER for all cover crops mixtures were equal or greater than 1. There is an advantage of intercropping these two plants compared to their cultivation in pure stand. However, *C. retusa* tends to dominate over *B. ruziziensis* and delay sowings can be practiced if more grass is needed in the mulch. Results provide a basis for intercropping *B. ruziziensis* and *C. retusa* as cover crops for DMC in the Highlands of West Cameroon. But establishing mixtures of *B. ruziziensis* and *C. retusa* in three months during the first season in the Highlands of West Cameroon needs to be repeated every year and the sustainability of the system have to be assessed.

Acknowledgments

The authors are thankful to the Department of crop sciences of Faculty of Agronomy and Agricultural Sciences of the University of Dschang for the technical and financial support, and to the many Agronomy students who were involved in field work.

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