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*Production of aerial biomass and equivalent land use in alfalfa (*Medicago sativa *L.) intercropping*

T. W. Pereyra, H. R. Pagliaricci, A. E. Ohanian y M. J. Bonvillani
Facultad de Agronomía y Veterinaria, Universidad Nacional de Río Cuarto,
Ruta Nacional 36 km 601, Córdoba, Argentina
E-mail: tpereyra@ayv.unrc.edu.ar

ABSTRACT

Productivity increase has traditionally been associated to yield increase through breeding and crop management practices. Nevertheless, if production is considered per area and time unit, the intercropping system may be another way to improve cost-effectiveness. The objective of the experiment was to determine the produced biomass and the equivalent land use in alfalfa (*Medicago sativa* L.) monocrop and intercrops with sorghum Sudan (*Sorghum sudanense* L.) and oat (*Avena sativa* L.). The aerial biomass of all the treatments (expressed per surface unit) and the equivalent land use were determined. The design was completely randomized, arranged in blocks with two repetitions. The results were subject to an ANOVA and the means were compared through Duncan's test, by means of the statistical pack INFOSTAT. The alfalfa-sorghum intercrop triplicated the alfalfa production with regards to the monocrop, while alfalfa-oat did not exceed the production of pure alfalfa in the winter months. The alfalfa-sorghum intercrop was 57 % more efficient in land use than the respective monocrops, while alfalfa-oat did not surpass the unit.

Key words: biomass, *Medicago sativa*, multiple land use

INTRODUCTION

The agriculturalization process –specially the expansion level of the soybean crop (*Glycine max* L.)–, from its prices in the international market and the excellent economic results, has caused the displacement of livestock production to less adequate zones for agriculture; initially towards the central region of Argentina, mainly the subhumid pampa, and then towards the semiarid region. Probably in the future, with the incorporation of such technologies as irrigation and genetic materials –which are capable of producing with lower water requirements-something similar will occur in arid regions. This phenomenon seems irreversible, because the entire surface occupied by agriculture is not likely to be used by other production systems, especially if the displaced activity is livestock production (Pagliaricci, Sacido and Herrero, 2008).

In mixed production systems, the competition generated between agriculture and livestock production limits to the maximum the surface destined for annual crops, because they compete for the land use with agricultural crops, due to the long occupation times of the lots –since their selection and preparation until the moment of first utilization (Pereyra, 2005).

The increasing interest in the sustainability of agricultural systems has led, in recent years, to significant development of agricultural practices in North America (zero and minimum tillage systems, reductions in summer agricultural practices, etc.). There is also growing interest in the alternative forms for nutrient management, particularly the role of legumes in the supply of nitrogen to other crops through their rotation and intercropping techniques (Thiessen-Martens, Entz and Hoeppner, 2005).

The increase of productivity has traditionally been associated to yield increase through breeding and crop management practices. Yet, if production is considered per area and time unit, the intercropping system may be another way to improve cost-effectiveness (Calviño, Cirilo, Caviglia and Monzón, 2005).

Intercropping is a production system in which two or more species are simultaneously cultivated during part or the whole life cycle (Ofori and Stern, 1987). The success of this practice is based on the differentiated utilization of resources by the integrating crops (Li *et al*., 2001). Likewise, some combinations of intercropped species achieve higher efficiency in the capture or utilization of the available resources than traditional crops (Morris and Garrity, 1993; Caviglia, Sadras and Andrade, 2004).

The intercropping of winter annual grasses with alfalfa has been suggested as a solution to the problems of scarce winter growth (Vartha, 1976). On the other hand, Fernández, Vergara, Virnolo and Laterra (1997) state that sowing an annual crop along with perennial forage species not only offers economic advantages, but also represents a contribution to ecological sustainability, because of the lower requirements of cultural operations and biocides, and to the rational and efficient soil use.

According to the above-described premises, the objective of this work was to compare the aerial biomass yield and the equivalent land use in alfalfa intercropping with sorghum Sudan and oat, with regards to their respective monocrops.

MATERIALS AND METHODS

Location of the experimental area. The study was conducted at the experimental field of the School of Agronomy and Veterinary Medicine of the National University of Río Cuarto, located in the Río Cuarto Department, Córdoba, Argentina (32º 33' LS and 63º 10' LE).

Climate and soil. The climate is temperate subhumid, with monsoon rainfall regime (80 % of the rainfall concentrated in the October-April period) and with mean annual rainfall of 850 mm. The water balance presents a deficit between 50 and 300 mm/year, according to the rainfall regime. The main climate adversities are: droughts, extemporaneous frost, hail and rainfall intensity.

The mean annual temperature (1977-2006) is 15,8 ºC; the coldest month is July (9,9 ºC), and the warmest, January (22,8 ºC) (Degioanni, 1998). During the studied period the recorded temperature and rainfall values were in accordance with the historical means (fig. 1).

The soil is classified as typical Hapludoll, without problems of internal or external drainage, and has plain relief, with slopes lower than 2 %. The original material is mainly constituted by very fine loess loamy-sandy sediments of the Formation la Invernada (Cantú, 1992).

The chemical composition (table 1) shows that there are no restrictions for nutrient availability due to its neutrality. The organic matter value (OM) is in correspondence with the zonal mean, the cations maintain a balanced relation with regards to the cation exchange capacity (CEC) and the value of phosphorus (P) availability is in accordance with the requirements of the crops used in the experiment.

Experimental design. A completely randomized design was used, arranged in blocks with two repetitions. The treatments were: 1) alfalfa in monocrop, 2) intercrop of alfalfa-annual species, and 3) monocrop of annual species. The size of each experimental plot was 108 m^2 and they

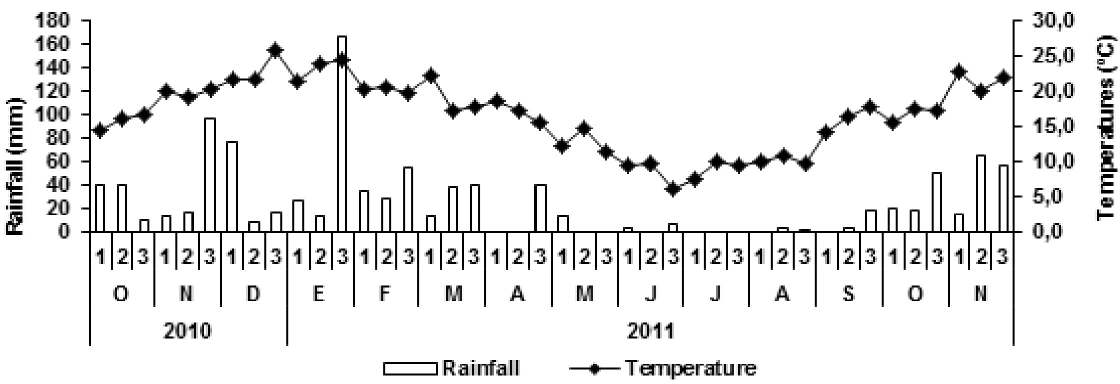

Fig. 1. Monthly rainfall (per decade) (mm) and mean temperature (ºC) of the studied period. Río Cuarto, Córdoba. Argentina.

Table 1. Soil chemical composition of the experimental area.

pH (2,5/L)	Total N (%)	OM (%)	CEC (meq/100 g)	Exchangeable cations (meq/100 g)				P (ppm)	K_2O (cmol/kg)
				Ca	Mg	K	Na		
6,9	0,32	2,2	19,34	12,19	2,57	3,02	0,1	17,2	1,35

were separated at a distance of 1,5 m. The results were subject to an ANAVA and the averages were compared through Duncan's test (Di Rienzo *et al*., 2012).

Experimental procedure. On an alfalfa pasture (*Medicago sativa* L.) cv. La Sureña, of grade 7 of winter rest –planted in March, 2009, with a density of 12 kg/ha and distance between rows of 0,175 m–, three treatments were established: 1) monocrop: pure alfalfa; 2) intercrop: alfalfa-sorghum (spring-summer 2010-2011) and alfalfa-oat (autumn-winter, 2011). After a cutting with reaper, with a direct planter the following species were inter-planted: sorghum Sudan cv. F 700, on November 18, 2010, at a rate of 18 kg of viable seed per hectare and at 0,52 m between rows, and oat cv. Cristal-INTA, on April 7, 2011, with a density of 90 kg/ha and at 0,175 m between rows. The third treatment was constituted by sorghum and oat monocrops, which were sown on a surface without alfalfa.

The treatments were not fertilized and complementary irrigation was applied, in order to minimize the probability of water restrictions; for such purpose monthly applications of 30 mm were made, with self-propelled equipment of lateral advance. The aerial biomass was determined through sampling close to the soil, with a surface unit of 0,25 m^2. The samples were separated into components (alfalfa and annual grasses) and were introduced in a forced-air stove until reaching constant weight. The values were expressed in kilograms per surface unit (kg DM/ha). Six samples were taken per treatment and the sampling frequency was determined from 10 % of flowering or emergence of basal shoots in alfalfa (Cangiano, 1997).

The equivalent land use (ELU) was estimated with the biomass values, according to the following expression:

$$ELU = \sum Ci/Cp$$

Where:

Ci: biomass production of each of the components of the intercrop.

Cp: biomass production in pure stand (Willey and Osiru, 1972).

To determine the effect of interplanting on the alfalfa crop, cover (%), plant density (number of plants per square meter), root and crown diameter (cm), and dry weight (g) were measured. The cover percentage was determined in the field through the method of free spaces, counting in the planting row the quantity of empty spaces higher than 10 cm (Spada, 2001). Plant number and size were determined by means of the extraction of all the individuals in 50 cm on the planting row, for which 10 samples were taken in each treatment.

RESULTS AND DISCUSSION

Winter-summer period

The aerial biomass was obtained from three cuttings performed during the growth period of sorghum Sudan. Table 2 shows the values of biomass production per cutting and the cumulative biomass, from January 11 to April 1st, 2011 (sum of three sampling dates).

The aerial biomass production of the alfalfa-sorghum intercrop was statistically higher (P≤0,05) than that of the alfalfa monocrop in the three cuttings and the total production of the cycle; nevertheless,

Table 2. Aerial biomass production of intercrops of alfalfa with *Sudan sorghum* and their respective monocrops (t DM/ha).

Treatment	Cutting date			Cumulative
	11/01/2011	25/02/2011	01/04/2011	
Alfalfa monocrop	$1,88 \pm 0,64^a$	$1,76 \pm 0,60^a$	$1,41 \pm 0,42^a$	$5,05 \pm 1,32^a$
Alfalfa + sorghum	$5,92 \pm 1,17^b$	$5,01 \pm 1,30^b$	$2,86 \pm 1,00^b$	$13,81 \pm 2,53^b$
Sorghum monocrop	$6,33 \pm 1,22^b$	$11,01 \pm 2,11^c$	$2,43 \pm 0,93^b$	$19,85 \pm 2,73^c$

Different letters in the same column differ significantly (P≤0,05) it did not exceed the sorghum monocrop, which did not have significant differences in the January and April cuttings. The sorghum monocrop was statistically higher (P≤0,05) than the alfalfa-sorghum intercrop only in the February cutting and the cumulative.

The alfalfa-sorghum intercrop triplicated the alfalfa monocrop production in January and February and in the total of the cycle, with average values of 5,4 t DM/ha for the association and 1,8 t DM/ha for the pure alfalfa in each cutting, and a total of 13,8 and 5,1 t DM/ha (respectively) for the sum of the three cuttings. The sorghum monocrop expressed its highest potential in the February cutting, with an aerial biomass production that duplicated that of the intercrop (11,01 vs. 5,01 t DM/ha); however, when the total production of the cycle was compared the difference was 6,04 t DM/ha in favor of sorghum (table 2).

The alfalfa-sorghum association showed that on a same surface between 120 and 150 % more of aerial biomass could be produced than that of pure alfalfa and 75 % with regards to the production of sorghum in monocrop. In this regard, in the Livestock Production Experimental Station of Paraná soybean and corn intercrops were planted for forage production in order to make silage, and it was found that the association produced 75 % of the production obtained in the corn monocrop and duplicated that of the soybean monocrop (Díaz, López and Peltzer, 2012).

The initial competition for light and nutrients during the emergence stage, caused by the regrowth of alfalfa, could explain the lower production of sorghum in the intercrop with regards to the monocrop; this occurred because of a less vigorous growth of the plants, which decreased the biomass production capacity. Caviglia (2007) stated that intercrops show competitive aspects when they grow simultaneously, due to the high competition generated for light.

The equivalent land use allowed to calculate the average surface needed by the monocrops to produce what the alfalfa-sorghum association generated in the same area. For the elaboration of this index the biomass values obtained in all the treatments during the period of sorghum growth were used. Table 3 shows the ELU values for the alfalfa-sorghum intercrop, between January 11 and April 4, 2011.

Table 3. ELU in alfalfa-sorghum intercrops and their respective monocrops.

Treatment	ELU
Alfalfa + sorghum	1,57
Alfalfa monocrop	1,00
Sorghum monocrop	1,00

The alfalfa-sorghum intercrop showed an ELU value of 1,57; taking as reference the unit for a monocrop, this value allows to state that– as average– pure sorghum and alfalfa need 57 % more surface than the association between them to produce the same quantity of aerial biomass. In this regard, in intercrops of *Zea mays* and *Vigna sinensis*, Eskandari (2012) found that in all the possible combinations of rows between both species, the ELU was always higher than the unit. Similar results were reported by Al-Suhaibani (2010) with the association of alfalfa and white clover in different combinations of spatial arrangement, in which the ELU always exceeded the unitary value.

Autumn-winter-spring period

The aerial biomass was obtained from four cuttings performed during oat growth. The values of biomass production per cutting and the total of the period comprised between June 27 and November 10, 2011 (sum of four cuttings) are observed in table 4.

Table 4. Production of aerial biomass of alfalfa-oat intercrops and their respective monocrops (t DM/ha).

Treatment	Cutting date				Cumulative
	27/06/2011	28/07/2011	13/09/2011	10/11/2011	
	Winter		Spring		
Alfalfa monocultivo	1,04 ± 0,28[a]	0,79 ± 0,30[a]	2,80 ± 0,62	2,56 ± 0,63[a]	7,17 ± 1,72[a]
Alfalfa + avena	0,72 ± 0,23[a]	1,29 ± 0,33[ab]	3,11 ± 1,10	4,18 ± 1,50[c]	9,31 ± 1,83[b]
Avena monocultivo	1,74 ± 0,43[b]	1,51 ± 0,39[b]	2,96 ± 0,72	3,20 ± 1,12[b]	9,40 ± 1,93[b]

Different letters in the same column significantly differ (P≤0,05)

The production of aerial biomass of the intercrop was significantly higher (P≤0,05) than the alfalfa monocrop only in the November cutting and in the total production of the cycle; likewise, the production of the intercrop significantly exceeded (P≤0,05) pure oat in this season.

The alfalfa-oat association was very variable in production, with average values close to one ton in winter and 3,6 t DM/ha in spring, and a total of 9,31 t DM/ha in the cycle, which exceeded the production of pure alfalfa and equaled the oat monocrop. When the production per cutting was compared, the intercrop did not improve the distribution of the biomass production with regards to pure alfalfa in the June, July and September cuttings (table 4).

The results showed that it is possible to improve the total autumn-winter-spring production when alfalfa is associated with oat, but the offer per cutting is not modified with regards to an alfalfa monocrop, mainly in winter. Pagliaricci, García and Vignolo (2000), in the same ecological area and with winter cereals –with and without competition of alfalfa– performed two cuttings of biomass production (July and October), with a distribution of 25 % in the first and 75 % in the second one. Similar results were obtained by Pridham and Martin (2008) in Clearwater, United States, with intercrops of wheat and red clover, in which the legumes-cereal association exceeded in 20 % the biomass production in pure red clover.

The equivalent land use for the alfalfa-oat intercrop reached a value of 0,97, very close to the unit, which is the reference that must be taken into consideration for a monocrop (table 5).

These values indicate that, from the point of view of land use, the alfalfa-oat association is not more efficient than the respective monocrops. Ofori and Stern (1987) stated that in the associations of legumes with temperate grasses high competition is generated among grass individuals for growth factors, because the same planting densities as those recommended for the monocrops are used.

Effect of intercropping on the alfalfa plants

At the end of the studied period related to the aerial biomass (January to November, 2011) the effect of the sorghum intercropping and, later, the oat intercropping, on alfalfa, was determined. The measurements made were: cover, quantity and size of the alfalfa plants.

- Cover and number of alfalfa plants

Table 6 shows the cover values of the alfalfa plants for the intercropped alfalfa treatments (alfalfa-sorghum and alfalfa-oat intercrops) and non-intercropped alfalfa (alfalfa monocrop).

The cover percentage of the alfalfa plants for the monocrop significantly exceeded (P≤0,05) that of the alfalfa which was intercropped with sorghum and oat, with values of 75,5 and 52,0 %, respectively. On the other hand, the number of plants did not significantly differ.

- Size of the alfalfa plants

The size values of the alfalfa plants in intercrop and monocrop are shown in table 7.

The root diameter of the alfalfa plants was not significantly affected (P≤0,05) by the intercropping, unlike the diameter and dry weight. The alfalfa plants which were not intercropped had a higher crown diameter and dry weight in 60 % with regards to the intercropped plants. These results showed that, although the number of plants did not differ in both treatments,

Table 5. ELU in alfalfa-oat intercrops and their respective monocrops.

Treatment	ELU
Alfalfa + oat	0,97
Alfalfa monocrop	1,00
Oat monocrop	1,00

Table 6. Percentage of cover and number of alfalfa plants intercropped with sorghum Sudan and oat.

Treatment	Cover (%)	No. of plants/m^2
Intercropped alfalfa	52,00 ± 7,29^a	55,00 ± 8,67
Alfalfa monocrop	75,50 ± 10,12^b	60,00 ± 9,23

Different letters in the same column significantly differ (P≤0,05)

Table 7. Size values of alfalfa plants in intercrops with sorghum Sudan and oat.

Treatment	Root diameter (cm)	Crown diameter (cm)	Dry weight (g)
Intercropped alfalfa	1,20 ± 0,31	6,35 ± 1,91[a]	7,93 ± 2,11[a]
Alfalfa monocrop	1,55 ± 0,42	9,55 ± 2,70[b]	12,95 ± 3,92[b]

Different letters in the same column significantly differ (P≤0,05)

the highest cover percentage of alfalfa in monocrop was due to the higher size of the plants, expressed in their mass and crown diameter. Such performance indicated that the intercropped alfalfa showed lower growth throughout the trial, due to the competition generated by the association with the grass. In this regard, Busqué and Herrero (1995) reported that the associations between forage legumes and grasses show interspecific interactions related to the higher efficiency in the use of resources –especially light– by the grass, and to a higher extent if it is a C_4 plant. Sánchez and Salinas, Veiga and Ferrufino (cited by Duarte, Pezo and Arze, 1994) reported that the magnitude of the interspecific interactions, in associations of forage crops, are regulated by climate conditions, nutrient availability and spatial arrangement of each species type.

CONCLUSIONS

The alfalfa-sorghum Sudan association generated high production volumes of aerial biomass with regards to the alfalfa monocrop, which improved the distribution per cutting and the seasonal production, and also produced a more efficient land use. The alfalfa-oat association improved the total production of the cycle, but not the distribution of the aerial biomass offer in the autumn-winter-spring period or the efficient land use. Intercropping did not affect the number of alfalfa plants, but it did affect their vigor and productive performance.

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