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Quantitative and Qualitative Evaluation of *Sorghum bicolor* L. under Intercropping with Legumes and Different Weed Control Methods

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Received: 12 October 2020; Accepted: 6 November 2020; Published: 9 November 2020

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Abstract: In order to evaluate the quantity and quality of forage when intercropping forage sorghum (*Sorghum bicolor* L.) with lathyrus (*Lathyrus sativus*) and hairy vetch (*Vicia villosa*), and using different weed management methods such as double cropping, a factorial experiment in a randomized complete block design with three replications was carried out at the research station of the University of Zanjan over two growing seasons (2015 and 2016). In this experiment, the intercropping of forage sorghum with lathyrus and hairy vetch at six levels with single cropping of forage sorghum, lathyrus, and hairy vetch, and three weed management strategies (no weed control, full weed control, and single weed control) was evaluated. The results showed that most forage sorghum traits were significantly ($p \leq 0.05$) affected by different sowing ratios. The highest fresh forage yield of sorghum (77.9 ton/ha) and lowest (49.0 ton/ha) were obtained with sorghum + 33% hairy vetch and sorghum + 100% lathyrus, respectively. Forage qualitative traits were also affected by intercropping and weed management. The highest average acid detergent fiber (ADF), neutral detergent fiber (NDF), and total ash percentage (ASH) were obtained with 100% sorghum + 66% lathyrus and 33% hairy vetch. The results showed that sorghum intercropping with 33% lathyrus led to a significant reduction in dry matter intake and relative feed value with no weed control and single weed control. This study demonstrated that, by selecting the appropriate intercropping ratios and forage legumes, we could largely control sorghum weeds in addition to improving the quantitative and qualitative yield of sorghum forage.

Keywords: Fabaceae; *Sorghum bicolor*; forage quality; cover crops

1. Introduction

Shortage of forage is one of the main problems for livestock in Iran [1]. Forage crops are among the most important crops in livestock feeds and, consequently, for supplying livestock products for human consumption. Due to its unique morphological and physiological characteristics, sorghum has been introduced as a drought resistant crop and, as such, has fewer water requirements than other crops. It can be used in arid and semi-arid regions as a reliable source of forage [2]. Sorghum is also a major C_4 plant that has high growth potential and high production [3–8]. Due to the small size of sorghum seed, its seedlings are relatively weak and unable to compete with weeds [5,9,10]. Therefore, weed management is one of the most important aspects of sorghum farming. Without weed control, the loss of yield varies from 10% to 100%, depending on the competitive ability of the weeds and crops, their density, and the competition duration [11]. Herbicide application has not only led to many weeds becoming resistant, but also poses environmental hazards [12,13]. Moreover, seedlings from seeds are relatively weak and cannot compete with weeds [14,15]. Furthermore, manual weed control is a time-consuming method and is not cost-effective. However, an effective method for controlling weeds is the application of cover plants between rows of crops [16]. Cover crops inhibit the germination of weed seeds and reduce the growth and development of weed seedlings by the rapid occupation of open space between rows of the main plant [17]. Legume cover plants have the potential to compete with dominant weeds due to their rapid growth, in addition to supplying nitrogen for the next crop [18]. Intercropping gives more yield per area than monocropping for a variety of reasons, such as improved use of food sources, light, and water, as well as suppressing weed growth [19–21]. Research has shown that forage produced in intercropping is of a higher quality than sole cropping, especially when intercropping is used with legume and non-legume combinations, because Graminae are rich in carbohydrates and legumes are rich in protein and vitamins [22,23]. Researchers have demonstrated that yield, crude protein content, and total digestible dry matter in grass–legumes intercropping were higher than monocropping [24,25]. Naim (2013) found that forage production in sorghum and alfalfa (*Medicago sativa* L.) intercropping was more stable than the sole cropping of each of these plants, and this intercropping produced quality forage in addition to maximum forage production due to the mixing of grasses and legumes [26]. Other authors reported that sorghum–soybean (*Glycine max*) intercropping increased the qualitative traits of forage sorghum due to nitrogen contributions from legume intercrops resulting in increased crude protein and total ash contents, while crude fiber reduced significantly [27,28]. Sorghum is an appropriate plant for seed and forage production in regions with poor soil and warm and dry winters where corn (*Zea mays* L.) is unable to grow [29]. Sorghum intercropping with forage plants such as lathyrus and hairy vetch is a valuable method of increasing diversity, and it uses land more efficiently throughout the cropping season without reducing grain and forage yields. Considering the importance of this plant in terms of livestock nutrition and its possible cultivation in dry lands compared to similar plants, more research on its quantitative and qualitative characteristics is required. The aim of this study was to evaluate the effect of different ratios of forage sorghum intercropping with forage legumes and different weed management methods on some of the quantitative and qualitative traits of forage sorghum.

2. Materials and Methods

2.1. Experimental Area and Design

This study was conducted at the research station of the University of Zanjan (Latitude of 35°15′ North, Longitude of 47°52′ East) at 1664 m above sea level, over two growing seasons, 2015 and 2016. The area is characterized as a semi-arid region with a 50-year mean air temperature of 14.2 °C, and an annual rainfall of 379 mm. The meteorological data of the experimental field during the growing seasons are shown in Table 1. The soil texture of the research field was silty clay loam (Table 2).

Table 1. Meteorological data of the experimental site during the growing season in 2015 and 2016.

Year	Month	Average Temperature (°C)	Max. Temperature (°C)	Min. Temperature (°C)	Actual Evaporation (mm)	Precipitation (mm)	RH (%)
2015	July	26.6	34.6	18.5	300	0.04	41.2
	August	25.9	35.7	16.2	297	0	36.3
	September	21.5	30.3	12.6	207	0.11	50.4
	October	17.1	25.4	9.1	147	0.59	52.1
2016	July	24.7	32.8	15.7	301	0.05	41.2
	August	25.6	34.7	16.4	298	0	42
	September	22.6	32.5	12.7	240	0	42
	October	16.6	22.7	10.6	180	0.5	50.3

Table 2. Some physical and chemical characteristics of the field soil of the experimental site in 2015 and 2016.

Year	Potassium mg kg^{-1}	Phosphorus mg kg^{-1}	EC mS cm^{-1}	Sand (%)	Silt (%)	Clay (%)	Soil Texture	Organic Carbon (%)	pH
2015	220	22.63	3.14	42.2	34.4	23.4	Silty clay loam	1.3	7.72
2016	270	45.23	4.21	38.16	32	29.84	Silty clay loam	0.98	7.15

The experiment was carried out as a factorial based on a randomized complete block design with three replications. In this experiment, intercropping of forage sorghum with different ratios of *Lathyrus sativus* L. (lathyrus) and hairy vetch, included at nine levels (single cropping of sorghum, lathyrus and hairy vetch, sorghum intercropping with 33%, 66%, and 100% hairy vetch and lathyrus), and three weed management strategies (no weed control, full weed control, and single hand-weeding on day 35 after emerging) were evaluated. Land preparation for a second cultivation, including plowing and disking after harvesting of the first crop, was carried out. One hundred kilograms per hectare each of N, P, and K fertilizers were applied. Thereby, one third of N fertilizer was applied before planting and the rest was applied during the season, while P and K fertilizers were consumed completely before sowing. Seed sowing was done by hand in both years. Before planting and in order to prevent fungal diseases, seeds were disinfected with Vitavax (Bayer, Tehran, Iran) fungicide at a rate of one per thousand. The crop density of the forage sorghum cultivar Spidfid was 25 plants per m^2 for all treatments. Cultivation of the Zanjan cultivar of lathyrus and the Isfahan cultivar of hairy vetch was carried out in strip lines with sorghum at densities of 100–250 plants per square meter (sole cultivation), respectively. Sorghum, lathyrus, and hairy vetch plants were cultivated at the same time on July 10th in both years of the study. Each plot included five rows of 9 m length, 2.5 m width, and a row space of 0.5 m. The plot size of intercropped and monoculture sorghum was 22.5 m^2. The distances between plots and between experimental blocks were 0.5 and 1.5 m, respectively.

2.2. Plant Sampling and Measurements

The recording of sorghum forage and cover crop yield in each treatment was performed in a 2 m^2 area in the middle rows of the plot. To measure qualitative traits of sorghum forage, a sample from dried and milled samples was selected with a weight of approximately 50 g.

Qualitative traits including dry matter digestibility (DMD), water-soluble carbohydrates (WSC), crude protein (CP), acid detergent fiber (ADF), total ash percentage (ASH), crude fiber (CF), and neutral detergent fiber (NDF) were measured using a near-infrared spectrometer (NIR-8620) [30]. In order to calculate dry matter intake and relative feed value, the formulas DMI% = 120/ADF% and RFV = DDM% × DMI% × 0.775, respectively, were used.

2.3. Statistical Analyses

For statistical analysis, a two-way ANOVA was performed using the PROC GLIMMIX procedure in SAS version 9.1 (SAS Institute Inc., Cary, NC). Before analyses, data were tested for normality of residuals using the PROC UNIVARIATE procedure in SAS. When the ANOVA indicated treatment effects were significant, means were separated at $p = 0.05$ using Duncan's multiple range test. Since ANOVA indicated no significant differences between the years of the experiment for the majority of the variables, the values reported herein are averages over 2 years.

3. Results and Discussion

3.1. Dry Matter Digestibility (DMD)

The effect of year, year × intercropping, and year × weed management were significant (Table 3). In general, the percentage of digestible dry matter in the second year was greater than that in the first year. Sorghum cultivation with 66% and 100% hairy vetch had a significantly higher digestible dry matter than other treatments in both years, although in the second year, intercropping had no significant effect on DMD.

The lowest mean digestible dry matter content was obtained in sorghum mixed with 33% lathyrus in the first year (Table 4). Digestibility of forage depends on the ratio of intracellular content to the cell wall, and digestible energy is the most common limiting factor of forage quality [31]. The cell is mainly composed of carbohydrates and soluble proteins (which have high digestibility). It seems that the increase in DMD when intercropping sorghum with forage legumes can increase the nitrogen content of the soil and consequently increase leaf area and photosynthetic capacity. Environmental factors have an impact on digestibility. In this study, by increasing the percentage of hairy vetch, the percentage of soluble proteins increased and, as a result, digestible dry matter content increased. Researchers have argued that the reason for the increase in digestible dry matter content when intercropping with legumes is the increase in the amount of nitrogen in the soil and the leaf area of the plant, resulting in an increase in plant photosynthesis and dry matter [32]. Weed management did not cause significant differences between the experimental groups over the two years considered (Figure 1).

Table 3. Analysis of variance for qualitative traits of sorghum forage under increasing intercropping sorghum cultivation with vetch and lathyrus using combined data from 2015 to 2016

Source	DF	MS											
		DMD Dry Matter Digestibility	CP Crude Protein	WSC Water Soluble Carbohydrates	CF Crude Fiber	ADF Acid Detergent Fiber	NDF Neutral Detergent Fiber	ASH Total Ash Percentage	DMI Dry Matter Intake	RFV Relative Feed Value	Fresh Weight of Sorghum	Dry Weight of Sorghum	Dry Weight of Forage Legumes
Year	1	50.22	0.084ns	51.00 **	3.94 *	29.05 *	680.02 **	65.95 **	0.588 **	55205 **	6214.39 **	108105 **	23.59 **
Rep./Y	4	1.15ns [z]	2.14ns	3.04ns	0.98ns	1.37ns	2.21ns	0.343 *	0.003Ns	15.99ns	298.54 **	15.09 **	0.42ns
P.R [y] (A)	6	7.57ns	8.41 **	9.43 **	2.88 **	9.77ns	41.18 **	0.319 **	0.038 **	147.63 **	676.34 **	98.73 **	68.67 **
A × Y	6	9.79 *	5.07 *	8.33 **	3.49 **	7.19ns	33.97 **	0.163ns	0.032 **	179.96 **	99.38 **	42.96 **	4.24 **
W.M [y] (B)	2	1.76ns	1.2ns	13.81 **	0.289ns	2.05ns	43.68 **	0.198ns	0.034 *	210.43 **	1094.91 **	196.10 **	47.29 **
B × Y	2	22.93 **	1.89ns	0.98ns	3.42 *	37.84 **	0.203ns	0.015ns	0.001ns	3.44ns	1.54ns	0.45ns	0.45ns
A × B	12	6.42ns	3.62ns	3.13ns	2.91 **	10.48 *	19.21 *	0.523 **	0.019 *	87.03 *	20.76 **	6.47ns	3.36 **
B × A × Y	12	3.91ns	2.76ns	2.99ns	1.03ns	5.31ns	10.46ns	0.181ns	0.009ns	18.94ns	15.99ns	1.88ns	0.33ns
Error	80	4.22	2.15	2.45	0.798	4.72	8.19	0.102	0.008	36.66	20.08	4.16	0.41
CV		3.39%	14.62%	14.21%	2.51%	6.28%	4.48%	4.43%	4.70%	8.21%	7.28%	11.42%	19.72%

[Z] * is significant at $p < 0.005$, ** is significant at $p < 0.001$, and ns is not significant. [y] P.R Planting ratios. W.M; Weed management.

Table 4. Interaction effect of year and intercropping on quantitative and qualitative traits of sorghum in 2015 and 2016.

Year	Planting Ratios	NDF%	CF%	WSC%	CP%	DMD%	Dry Weight of Sorghum	Fresh Weight of Sorghum	DMI%	RFV%
First year	sole cropping of sorghum	63.97cd [z]	36.50a	9.90b–d	10.86a	59.37b–d	22.31b	75.14ab	1.88b–d	89.42b
	Sorghum with 33% vetch	63.23cd	35.59ab	12.112ab	11.28a	59.96d	27.16a	76.53a	1.89bc	92.56b
	Sorghum with 66% vetch	58.44e	34.32c	13.40a	9.07bc	62.14a	21.86bc	69.57bc	2.06a	103.0a
	Sorghum with 100 % vetch	60.74de	35.78ab	11.37a–d	10.11a–c	61.24a–c	19.23cd	65.36cd	1.98ab	95.22b
	Sorghum with 33% Lathyrus	61.48de	36.47a	11.91a–c	8.89c	58.80d	21.87bc	73.67ab	1.96ab	94.14b
	Sorghum with 66% Lathyrus	61.46de	35.96ab	10.87b–d	10.61ab	59.15cd	17.48de	63.04de	1.96ab	93.37b
	Sorghum with 100% Lathyrus	61.58de	35.94ab	11.93a–c	10.04a–c	60.12a–d	15.53e–g	56.58fg	1.96ab	94.93b
Second year	sole cropping of sorghum	68.18ab	35.44a–c	10.12b–d	8.67c	60.90a–d	15.97ef	58.75ef	1.76de	48.90d
	Sorghum with 33% vetch	68.30ab	34.76bc	9.94b–d	11.12a	61.48ab	16.37ef	62.68de	1.76de	48.92d
	Sorghum with 66% vetch	68.74a	35.90ab	9.72cd	9.11bc	61.92a	14.79e–g	56.18fg	1.75e	48.01d
	Sorghum with 100 % vetch	63.98cd	35.33a–c	10.74b–d	10.10a–c	61.79a	15.57e–g	57.27ef	1.88b–d	57.00c
	Sorghum with 33% Lathyrus	63.13cd	35.99ab	11.97a–c	9.98a–c	60.96a–d	14.22fg	51.15gh	1.90bc	58.91c
	Sorghum with 66% Lathyrus	66.26a–c	35.23a–c	9.30d	10.15a–c	60.36a–d	14.58fg	48.63h	1.81c–e	52.40cd
	Sorghum with 100% Lathyrus	64.81b–d	35.42a–c	10.79b–d	10.58ab	61.21a–c	12.93g	46.90h	1.87b–d	55.43cd

[z] Column means with the same letter are not significantly different by DMRT ($p < 0.05$).

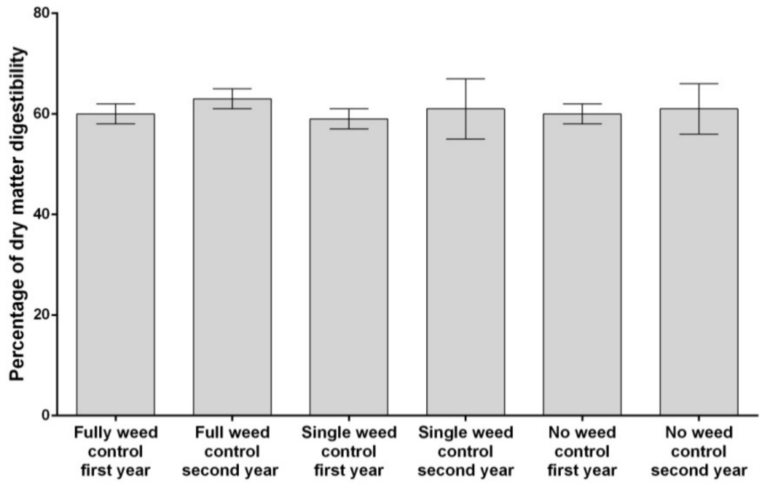

Figure 1. Mean comparison by year of the effect of weed management on percentage of digestible dry matter. All measurements were performed in triplicate. Data are shown as the mean ± standard deviation. There were no significant differences.

Phelam et al. [33] reported that by increasing the nitrogen fixation of forage legumes, digestible dry matter increased. Because an increase in the digestible dry matter is considered an advantage or positive factor, sorghum–hairy vetch intercropping was presented as a superior treatment. Digestibility is usually calculated based on dry matter, expressed as a percentage or coefficient, and digestion is defined as the preparation of the feed for absorption by the digestive system [34]. Restelatto et al. [35] reported that cover plants and nitrogen fertilizers increase the digestible dry matter of sorghum.

3.2. Crude Protein (CP)

The effects of intercropping and year × intercropping on percentage of crude protein were significant (Table 3). Intercropping significantly increased the crude protein content, although this difference was not significant in the first year (Table 4). The highest percentage of crude protein was observed in sorghum with 33% hairy vetch. Increasing the crude protein content of the sorghum plant with hairy vetch may be due to the semi-deep roots of sorghum, which can absorb nutrients from deep levels of soil, as well as nitrogen fixation by forage legumes that increase the nitrogen content of soil. In addition, legume plants increase the protein content of the forage compound, and their root bacteria increase the nitrogen content of soil, ultimately increasing the protein in seeds and forage [36]. Iqbal et al. [28] reported that forage legumes increased the percentage (14.9%) of crude protein in sorghum. An increase of 11–51% of crude protein in corn intercropped with other plants, compared to sole corn cultivation, has also been reported [37].

3.3. Crude Fiber (CF)

The effect of year, intercropping, year × weed control, year × intercropping, and intercropping × weed control were significant in terms of crude fiber content (Table 3). The percentage of crude fiber in the first year was higher than the second year. The highest average percentage of crude fiber was observed in sorghum monocropping with single weed control, although this treatment showed little difference from other treatments and the lowest value was obtained with 100% sorghum + 33% vetch. However, as shown in Figure 2, weed management gave no significant differences among treaments. Zandvakili et al. [38], by comparing the intercropping strip cultivation patterns of forage sorghum with beans (*Phaseolus vulgaris* L.) and soybeans, concluded that the highest percentage of crude fiber was obtained by sorghum monocropping, which was consistent with the results of this research. Intercropping increased forage quality by decreasing the crude fiber of grass [39].

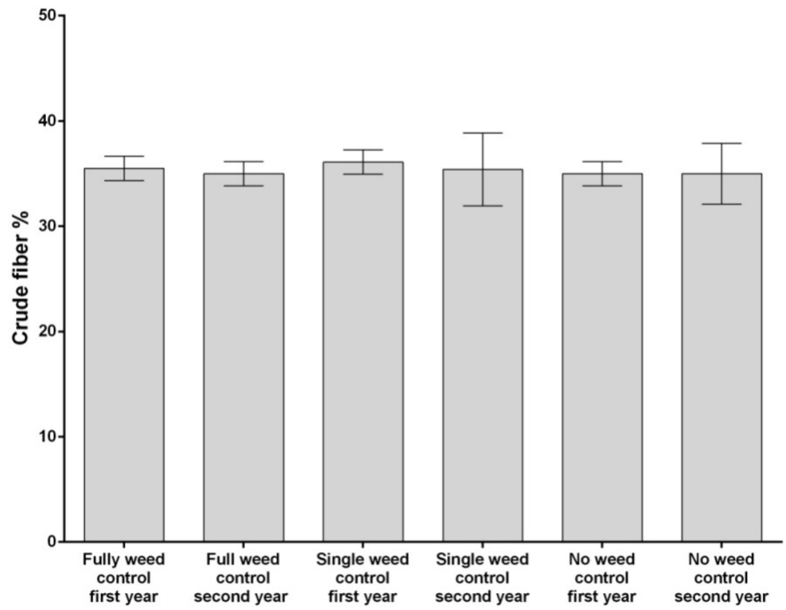

Figure 2. Mean comparison by year of the effect of weed management on crude fiber. All measurements were performed in triplicate. Data are shown as the mean ± standard deviation. There were no significant differences.

3.4. Total Ash (ASH)

The effects of year, intercropping and intercropping × weed management were significant at $p < 0.01$ (Table 3). The percentage of total ash showed that sorghum intercropping with 100% lathyrus and weed control had a positive effect on total ash. Single weed control and no weed control treatments had an increasing effect on total ash content compared to full weed control. Single weed control and no weed control treatments increased total ash content by 14% and 10%, respectively. The highest mean was recorded in sorghum with 33% hairy vetch in single weed control. The lowest percentage of total ash was obtained in sorghum with 100% lathyrus and full weed control (Table 5). The crude protein and ash content of forage maize improved under intercropping with legumes compared to sole-cropping [24].

Table 5. Interaction effects of intercropping and weed management on quantitative and qualitative traits of sorghum.

Planting Ratios	Weed	Fresh Weight of Sorghum (ton/ha)	ASH%	NDF%	ADF%	CF%	DMI%	RFV%
sole culture of sorghum	Full weed control	71.38ab[z]	7.15a–d	65.85a–c	35.15a–e	35.97a–e	1.82d–f	69.67e–h
	Single weed control	69.54bc	6.86de	65.57a–d	35.49a–c	36.89a	1.84c–f	70.72d–h
	No weed control	61.38d–h	7.52ab	66.82ab	35.77a–c	35.06c–e	1.80ef	67.10gh
Sorghum with 33% vetch	Full weed control	77.89a	7.17a–d	64.50a–e	33.06c–e	34.42e	1.87b–f	73.31a–h
	Single weed control	66.69b–e	7.61a	64.53a–e	34.29a–e	35.48a–e	1.86c–f	72.74b–h
	No weed control	62.78c–g	6.93c–e	68.27a	35.40a–d	35.63a–e	1.77f	66.17h
Sorghum with 66% vetch	Full weed control	68.92b–d	7.44a–c	61.65d–f	32.27e	34.67de	1.98ab	80.52ab
	Single weed control	61.53d–h	7.43a–d	62.90b–f	32.38de	34.74c–e	1.91a–e	77.00a–f
	No weed control	58.17f–i	7.42a–d	66.22a–c	35.31a–d	35.93a–e	1.82d–f	68.94f–h
Sorghum with 100 % vetch	Full weed control	65.55b–f	7.43a–d	60.40f	35.22a–e	34.83c–e	1.99a	78.38a–d
	Single weed control	60.99e–h	6.98b–e	61.61d–f	34.49a–e	36.25a–d	1.95a–c	78.62a–d
	No weed control	57.40g–j	7.31a–d	65.07a–d	33.47b–e	35.58a–e	1.84c–f	71.33c–h
Sorghum with 33% Lathyrus	Full weed control	67.94b–e	6.99b–e	64.39a–e	35.32a–d	36.77ab	1.87b–f	72.55b–h
	Single weed control	62.59c–g	7.08a–d	60.67ef	35.46a–c	36.03a–e	1.98ab	79.34a–c
	No weed control	56.69g–j	7.09a–d	61.85d–f	33.10c–e	35.90a–e	1.95a–d	77.69a–e
Sorghum with 66% Lathyrus	Full weed control	60.98e–h	7.26a–d	65.39a–d	36.54a	36.02a–e	1.84c–f	69.69e–h
	Single weed control	56.67g–j	7.50a–c	63.42b–f	35.23a–e	35.27b–e	1.89a–e	74.21a–h
	No weed control	49.87jk	7.09a–d	62.77c–f	34.53a–e	35.50a–e	1.92a–e	74.75a–g
Sorghum with 100% Lathyrus	Full weed control	54.12h–k	6.52e	60.76ef	33.16c–e	36.33a–c	1.99ab	81.52a
	Single weed control	52.09i–k	7.43a–d	64.43a–e	36.43ab	35.33a–e	1.87a–f	71.99c–h
	No weed control	49.01k	7.21a–d	64.40a–e	34.15a–e	35.38a–e	1.86a–f	72.03c–h

[z] Column means with the same letter are not significantly different by DMRT ($p < 0.05$).

These results may seem contradictory and this may be due to differences in legume species or variation in soil fertility conditions. Sorghum intercropping with hairy vetch increased soil nitrogen, which could lead to an increase in total ash content in sorghum. Saarsalmi et al. [40] reported that increasing the nitrogen fertilizer resulted in higher total ash. These findings are consistent with the results of this study and the results obtained by Palmer et al. [41] reported that returning the remnants of cover plants to the soil increased the total nitrogen and organic carbon content of the soil and consequently led to an increase in percentage of total ash in the plant. The percentage of total ash in forage represents the mineral content in the plant tissues [42]. Mineral elements in forage are important because they are involved in the metabolism of the animals who feed on it and are necessary for the activity of cells in the body. Mineral elements can also be effective in forage quality [43].

At the same time, in order to understand some contradictory results and complex correlations, it must be recognized that the data collected require further investigation.

3.5. Neutral Detergent Fiber (NDF)

All main and interaction effects, except year × weed control and year × intercropping × weed control, had significant effects on the percentage of neutral detergent fiber (Table 3). NDF averages among the treatments were higher in 2016 than in 2015. The highest mean of this trait was obtained with sorghum with 33% hairy vetch and weed control, and the lowest was obtained with sorghum with 100% lathyrus with full weed control (Table 5). In addition, the data in Table 5 show that sorghum–lathyrus intercropping had a greater effect on increasing the NDF content than intercropping with hairy vetch. No weed control led to an increase in NDF, which shows the negative effects of weeds on qualitative traits. The neutral detergent fiber (NDF) is an indispensable indicator of the digestibility and consumption of the plant by livestock [31]. Therefore, the higher the NDF content of the diet of livestock, the lower its digestibility and consumption [44]. Wheat (*Triticum aestivum* L.) intercropping with beans resulted in increased neutral detergent fiber compared to the sole cultivation of beans and wheat [37]. It seems that hairy vetch resulted in increased nitrogen in the soil. Some authors reported that nitrogen increment leads to an increase in percentage of soluble fiber in acid detergent and this leads to an increase in digestibility [45–47].

3.6. Water-Soluble Carbohydrate (WSC)

The effects of year, weed management, intercropping, and year × intercropping were significant at $p < 0.01$ for percentage of water-soluble carbohydrate (Table 3). There was a higher percentage of water-soluble carbohydrates in the first year than the second year. The results showed that in two years of study only sorghum cultivation with 66% hairy vetch could significantly increase the percentage of water-soluble carbohydrates in comparison to sole sorghum. However, in some treatments, this incremental trend was not significant. Furthermore, the lowest percentage of WSC was obtained in sorghum cultivation with 66% lathyrus in the second year (Table 4). In maize intercropping with common fava bean (*Vicia faba* L.), Stoltz and Nadeau [48] observed the highest amount of water-soluble carbohydrates with intercropping. Jahanzad et al. [49] stated that soybean intercropping with pearl millet (*Pennisetum glaucum* (L.) R.Br.) increased the amount of soluble carbohydrates in millet forage. Full control of weeds resulted in a significant increase in soluble carbohydrate content. However, there was no significant difference between single weed control and no weed control in terms of soluble carbohydrate content. Considering the reduction in weed density due to the increased percentage of hairy vetch with sorghum intercropping, it seems that the ability of vetch to release phytotoxin into the rhizosphere resulted in production of toxic substances and a change in the acidity of the soil [50]. As a result, because of decreased germination and weed establishment, weed density was reduced.

3.7. Dry Matter Intake (DMI)

In this study, year, intercropping and weed control, year × intercropping, and intercropping × weed management had significant effects on DMI. The first year resulted in a better DMI than the second year. The results demonstrated that no control and single weed control in sorghum intercropped with 33% lathyrus significantly reduced the DMI compared to sorghum monocropping (Table 5). The highest DMI in the first year belonged to sorghum cultivation with 66% hairy vetch, which showed a significant increase compared to sorghum monocropping and intercropping with 33% hairy vetch, while in other treatments this increase was not significant. In the second year, sorghum intercropped with lathyrus showed relative superiority compared to its cultivation with hairy vetch (Table 4). Assefa et al. [51] suggested that the increase in DMI of *Avena sativa* L. (oats) could be attributed to the increased amount of total CP (crude protein) due to intercropping legumes.

3.8. Relative Feed Value (RFV)

Year, intercropping and weed control, year × intercropping, and the interaction of intercropping and weed management had significant effects on RFV. The results showed that sorghum cultivation with 66% and 100% hairy vetch, as well as sorghum cultivation with 100% lathyrus, led to a significant increase in RFV under full weed control conditions compared to sole sorghum cultivation. On the other hand, the results showed that no weed control and single weed control in sorghum intercropped with 33% lathyrus could have a significant effect on weed control compared to sorghum monocropping (Table 5). The results indicated that the highest RFV belonged to sorghum intercropped with 66% hairy vetch in the first year. However, in the second year, sorghum with 100% hairy vetch, and 33% lathyrus significantly increased the percentage of relative feed value compared to sorghum monocropping, but this increase was not significant in the other treatment. This shows the positive effect of sorghum intercropping with cover crops (Table 4). Strydhorst et al. [52] reported an increase in RFV in barley intercropped with bean, white lupin (*Lupinus albus* L.), and pea (*Pisum sativum* L.).

3.9. Cell Wall Percentage Minus Hemicellulose (ADF)

ADF percentage was significantly different by year, year × weed control, and intercropping × weed control (Table 3). The second year showed a higher ADF than the first year. The results showed that in the first year, no weed control reduced the percentage of ADF, whereas in the second year, single weed control showed no significant difference compared to full control and it prevented a further decrease in the percentage of ADF compared to no weed control (Figure 3). In addition, the interaction of intercropping and weed management showed that the lowest mean was recorded in sorghum with 66% hairy vetch and full control of weeds (Table 4). These results were similar to the findings of other researchers who concluded that combined cereal legume forage had lower ADF content than sole cereal/legume [52,53]. Mosebi et al. [54] also reported that the highest ADF resulted from sole barley (*Hordeum vulgare* L.), followed by sole oat and sole alfalfa, while the lowest ADF was obtained with alfalfa + barley and alfalfa + oat intercropping systems. Acid detergent fiber (ADF) is an important parameter for evaluating forage quality. As the ADF increases, digestible energy content decreases [37].

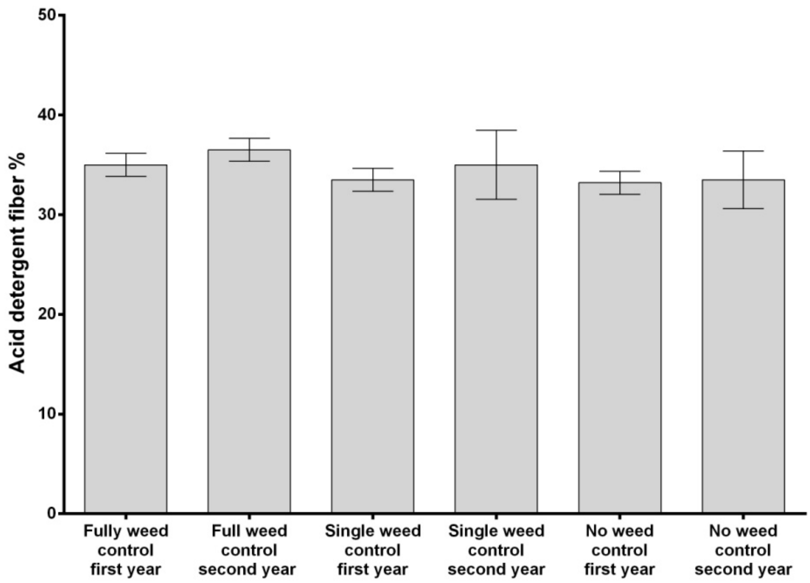

Figure 3. Mean comparison by year of the effect of weed management on acid detergent fiber. All measurements were performed in triplicate. Data are shown as the mean ± standard deviation. There were no significant differences.

3.10. Sorghum Forage and Forage Legumes Yield

Dry and fresh forage of sorghum and dry fodder of forage legumes were significantly affected by year, intercropping, and weed control. Intercropping × weed control had a significant effect on sorghum fresh forage and legume dry forage traits (Table 3). Sorghum and forage legumes gave a higher yield in the first year than the second year. The difference could be attributed, at least partially, to higher precipitation in 2015 compared to 2016. In addition, meteorology data show that average temperatures in 2015 for all months of the growing season were higher than averages in 2016. The high level of ambient temperature, particularly the minimum temperature, accelerated and increased leaf area and plant growth and, finally, enhanced the forage yield. Furthermore, the results of soil analysis showed that the cultivated land in the first year of the experiment showed better fertility (Table 2). The fresh and dry forage yield of sorghum in the first year was 25%, which was 39% higher than the second year. The highest fresh forage yield was obtained in sorghum intercropped with 33% hairy vetch and full control of weeds. The results showed that the intercropping of sorghum with 33% hairy vetch led to a significant difference between single weed control and full weed control, due to the lower density of this cover plant compared to the other ratios. Also, sorghum intercropped with 100% lathyrus and weed control had a positive effect on sorghum forage. No weed control and single weed control treatments in this mix showed no significant difference compared to full control (Table 5). Although with 100% lathyrus, due to the competitive principle, the sorghum yield was lower than with monocropping. Nevertheless, the total forage yield of this treatment (sorghum + lathyrus) was high and the total quality of the forage was better than that of the sorghum monocropping due to the high quality of lathyrus as a legume.

The highest forage of forage legumes was obtained with sole lathyrus cultivation with full weed control (Figure 4). The presence of a high density of lathyrus in intercropping with sorghum (sorghum + 100% lathyrus) inhibited the growth of weeds largely by competing with them and finally resulted in reducing weed growth in the no weed control treatment. One of the reasons for the higher yield of intercropping sorghum with 33% hairy vetch and full control of weeds can be that in intercropping, plants can use environmental resources in a better way with less competition for water, food and light. The ability of each plant to compete in intercropping is not constant, but rather a function of density variation [55]. Therefore, by the appropriate selection of forage legumes in the intercropping system and by increasing the diversity, the ability of weeds to compete for resource absorption can be reduced.

A previous study demonstrated that by mixed cropping of lima bean (*Phaseolus lunatus* L.) with sorghum, green forage yield was increased by 61% with an 80:20 sorghum–legume seed-blending ratio compared to other blending ratios. It was further discovered that multiple cropping was more effective than row intercropping systems in nitrogen transfer from lima bean to sorghum through roots intermingling, which enhanced mixed forage performance [38]. Aladesanwa and Adigun [56] also reported that living mulch increases crop yield due to less competition and its control effect on weeds. Some authors reported that, in incremental corn–mung bean (*Phaseolus radiates* L.) mixing treatments, not only was the yield of corn not reduced, but the yield of mung bean was increased, the weeds were controlled better, their negative effect was decreased, and the conditions for better growth of corn and mung bean were provided [57–59].

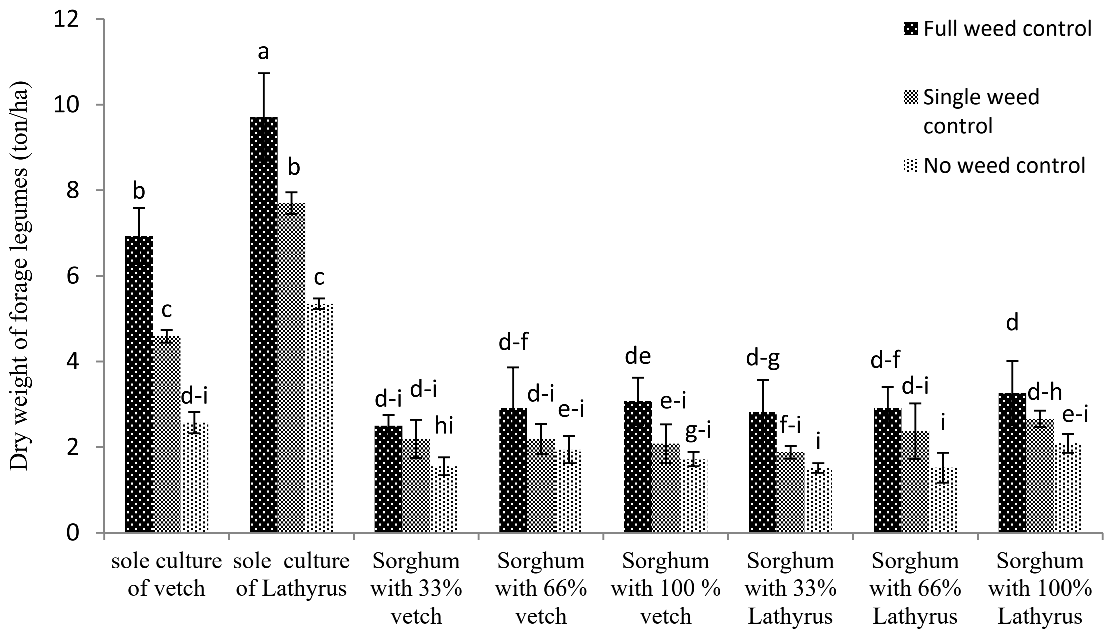

Figure 4. Means ± standard error for the interaction effect of planting density and weed management on dry weight of forage legumes. Different letters on the top of the bars indicate significant difference at $p \leq 0.05$ by DMRT.

4. Conclusions

Based on the results, it can be concluded that, by adding a minimum of 33–66% of hairy vetch to intercropping, the forage yield was increased. Forage quality was affected by intercropping and weed control treatments such that the crude protein and total ash were affected by sorghum intercropped with 33% and 66% hairy vetch under no weeding conditions. Furthermore, sorghum with 100% lathyrus had a positive effect on weed control and could greatly offset the negative effects of weed control on yield reduction. Therefore, it seems that sorghum mixing with cover plants could have a positive effect on weed control and sorghum forage yield.

Although some critical issues were highlighted in the discussion of the results, these data can give important indications on the dynamics associated with intercropping and the management of weeds. Further measurements in the field will have to be repeated to better define the results obtained.

Author Contributions: Conceptualization, S.V.R. and S.A.R.V.; methodology, S.V.R.; formal analysis, S.S. and H.R.Z.; investigation, H.R.Z.; resources, A.M.; data curation, S.V.R.; writing—original draft preparation, S.V.R.; writing—review and editing, A.M.; visualization, M.P.; supervision, A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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