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Forage Production of Sorghum and Alfalfa in Sole and Intercropping Systems

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Abstract: Field experiment was carried out for three years to investigate forage production in sorghum/alfalfa intercropping starting spring 2002 in Karaj region, Iran. In this experiment 3 mixing ratios of alfalfa with sorghum (including 75/25, 50/50 and 25/75%) were compared with sorghum and alfalfa sole cropping in a randomized complete block design with three replications. The results showed that the highest amount of forage was produced in 2nd year. Intercropping alfalfa/sorghum with 3:1 row ratio offered the highest mean forage production in 3 years of experimental period. In 2nd year of experiment, alfalfa sole cropping produced more forage than other treatments, followed by 3:1 alfalfa/sorghum treatment. Sorghum monoculture had the lowest total forage yield in 3 years. According to evaluating indices of intercropping profitability, LER in the first year was less than one due to the antagonistic effects of species on each other. Definite profitability of intercropping appeared in 3rd year, in such a manner that alfalfa/sorghum with 3:1 row ratio had LER = 1.22 and the minimum competition index (CI = 0.21). Aggressivity index indicated that alfalfa and sorghum in first year were the suppressed and dominant species, respectively. In 3rd year of experiment sorghum dominance decreased as its proportion increased in intercropping system. Overall, intercropping alfalfa/sorghum with 3:1 row ratio could be suggested as the superior treatment because of its higher total and available forage production system.

Key words: Alfalfa, sorghum, intercropping, forage, intercropping indices

INTRODUCTION

Intercropping is one of the common methods of multiple cropping which encourage sustainability in agriculture through increasing plant diversity (biodiversity) in agroecosystems, soil erosion control, soil fertility maintenance and more efficient use of resources.

This system has an important role in profitability and sustainability in crop production for low-input agricultural systems especially in arid and semi-arid regions. In simultaneous intercropping two or more crop species will be sown in the same time and grow with each other. If the partners have suitable morphological and physiological properties, the profitability of intercropping will be enhanced compared to pure stand of each crop. This is because of the reduced competition and the facilitation mechanisms to better use of environmental inputs. A review of intercropping literature shows that in many experiments, the performance of intercrops were better than the sole crops (Morris and Garrity, 1993). For instance intercropping of wheat/pea (Lauriault and Kirksey, 2004), cowpea/maize (Mandhal *et al*., 1996), alfalfa/timouthy (Zaeifizadeh *et al*., 1994) and berseem clover/lolium (Vaezzadeh, 1994) could be mentioned. Carouthers *et al*. (2000) reported that legume/grass intercrop has the most frequency in multiple cropping researches due to their ability for more efficient use of environmental resources.

There are several indices to evaluate superiority of intercropping compared to sole cropping systems. Findings of Zand and Ghaffari Khaligh (2002) indicated that intercropping cowpea and grain sorghum in 50:50 (1:1) ratios gave 19% preference to sole cropping. They investigated the Aggressivily index for intercrop treatment and stated that cowpea was the dominant species.

Homayouni (2004) studied forage sorghum intercropped with some legumes in different mixing ratios. They reported that intercropping of 2:1 sorghum and legume ratio increased fresh and dry forage yield. The highest Land Equivalent Ratio (LER) of 1.42 was obtained from 2:1 sorghum: soybean mixture.

Growth indices and yield affected by cropping patterns of grain sorghum and cowpea showed that

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sorghum was severely dominated by cowpea in 1:2 row ratio, whereas in 2:1 and 2:2 row ratio sorghum was more competitive than cowpea. The LER was highest (1.25) in 2:2 row ratio of sorghum/cowpea followed by 1:2 (LER = 1.23) (Deljoo and Sepehri, 2004). High LER of 1.78 in alfalfa/timothy intercropped in 1:1 sowing pattern was introduced as the most appropriate intercropping system for dry forage production (Ghaffari, 1996).

Mixed cropping of legumes and grasses for forage production is not a common practice among Iranian farmers, however, it is necessary to investigate the potential forage production (mixed and sole cropping) in both quantity and quality respects to introduce as alternative forage production system among farmers. The main objective of this research was to compare sole and intercropping of alfalfa and sorghum for potential forage production. This research was conducted to recommend the superior crop mixing ratio of sorghum and alfalfa in multiple cropping system.

MATERIALS AND METHODS

The experiment was carried out during growing season of 2002 and continued to 2005 in the Research Farm of College of Agriculture, University of Tehran in Karaj, Iran. In mixed cropping of an annual crop of sorghum (*Sorghum bicolor*, cv. Kimia) and a perennial crop of alfalfa (*Medicago sativa*, cv. Hamedani), sorghum was repeatedly sown on the same plots and rows after ridge cultivation every year during the experimental period. However, alfalfa produced its ratoons during the second and third year of the experiment after the first sowing in spring 2002.

The experimental site is located in 35°, 34′ (N) and 59°, 56′ (E), 1 160 m above sea level. Average annual rainfall and mean temperature in this area is 241 mm and 14°C, respectively. The representative soil samples from 0-30 cm soil depth were taken from the experimental site to measure and determine the chemical properties in March 2002. Soil chemical characteristics are presented in Table 1.

According to laboratory reports, to provide with required phosphorus levels in the soil, about 160 kg ha^{-1} of ammonium phosphate was applied at sowing time. Taken into consideration of 18% of nitrogen content in ammonium phosphate, no initial nitrogen fertilizer was applied to stimulate legume early growth in mixtures. This decision was made to prevent any interference in biological nitrogen fixation by alfalfa.

The experimental treatments were intercropped sorghum/alfalfa with 50/50; 75/25, 25/75 ratios along with their sole crops as control plots. Treatments were arranged in a split plot design in time (years of experiment) based on a RCBD with 3 replications.

Each experimental plot consisted of 6 rows of 8m length and 50 cm apart. Alfalfa (*Medicago sativa*, cv. Hamedani) and grain sorghum (*Sorghum bicolor*, cv. Kimia) were intercropped with different ratios in each plot in spring 2002. The experiment extended for three years (2002-2005). Alfalfa sowing rate in pure stand was 25 kg ha^{-1} and sorghum was sown at 45 kg ha^{-1} (180000 plants per hectare). Sorghum was replanted in the same rows with the same sowing density after ridge cultivation, every year.

The following indices were investigated to evaluate the intercropping performance (Mazaheri, 1998).

Land Equivalent Ratio (LER): This index introduce the ground area (ha) needed in sole cropping to produce the equal yield of intercropping (Eq. 1).

$$\text{LER} = \sum\nolimits_{c}^{n} \frac{Y_{ci}}{Y_{cm}} \tag{1}$$

Where,
Y_{ci} and Y_{cm} are private yield of each partner (crop) in intercropping and monoculture respectively. In LER = 1 there is no difference between intercropping and monoculture. LER = 1+x show that intercropping produce yield x percent more than monoculture and finally LER<1 indicates the dis-profitability of intercropping.

Competition Index (CI):

$$\text{CI} = \frac{(N'_A - N_A)(N'_B - N_B)}{N_A N_B} \tag{2}$$

Where:

N'_A = Yield of crop A in monoculture
N_A = Yield of crop A in intercropping

Table 1: Chemical properties of the soil at the experimental site at 0-30 cm depth

Sampling depth	pH	EC (ds m^{-1})	SAR (%)	Na (meq Lit^{-1})	Ca (meq Lit^{-1})	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	OM (%)	Mg (meq Lit^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})
0-30	7.8	0.6	7.5	1.13	2.25	0.62	8.9	183	1.17	3.2	6.5	1.2	8.5

N'_B = Yield of crop B in monoculture
N_B = Yield of crop B in intercropping

If CI<1, intercropping has been suitable and if CI>1, profitability of intercropping has been less than monoculture yield of crop A in monoculture.

Aggressivity Index (A): By using Eq. 3, dominance degree of species A in relation to species B could be investigated.

$$Aab = \frac{Yab}{Eab} - \frac{Yba}{Eba} \qquad (3)$$

Where,
Aab = Species A aggressivity in relation to species B
Yab = Actual yield of species A intercropped with B
Yba = Actual yield of species B intercropped with A
Eab = Expected yield of species A intercropped with B
Eba = Expected yield of species B intercropped with A

Relative Crowding Coefficient (RCC): Competition intensity of species A in relation to species B in an intercropped experiment with replacement arrangement could be calculated by Eq. 4 as follow:

$$Ka = \frac{Yab \times Zba}{(Yaa - Yab) \times Zab} \qquad (4)$$

Where:
Ka = Relative density coefficient of species A
Yaa = Yield of species A in monoculture
Yab = Yield of species A intercropped with species B
Zab = Mixing rate of species A
Zba = Mixing rate of species B

If Ka = 1, interspecific and intraspecific competition have been equal. If relative crowding coefficient for each intercropped species (Ka and Kb) differed from 1, dominant crop is the one which has higher RCC and other one with lower RCC is dominated. To evaluate intercropping profitability, using RCC Eq. (5) should be considered.

$$K = Ka \times Kb \qquad (5)$$

K >1 : There is no addition yield due to intercropping
K = 1 : There is no different between monoculture and intercropping
K<1 : Intercropping has produced more yield than monoculture

Forage sampling was carried out in 2 quadrate (2 m^2) samples consisting of 4 rows of sowing plants in each plot, regarding to border effects. Each sample was divided to sorghum and alfalfa forages and dried in an electrical oven (48 h in 72°C). The data were analyzed based on mean annual forage dry matter of each species (kg ha^{-1}). At the end of the experimental period, the accumulative forage production from each treatment was calculated and statistically analyzed and compared. The mean values of annual and accumulative forage production in different sowing mixtures were compared by F test (least significant difference). MSTATC statistical software was used for the analysis of the data.

RESULTS AND DISCUSSION

Intercropped forage production: Forage yields of sorghum and alfalfa in each year (Table 2) were considered to calculate the accumulative forage production in 3 years of experimental period.

As shown in Table 3, there is significant difference between years, treatments and interaction between year and treatments (p<0.05).

The highest forage yields were produced in 2nd year because of better establishment of alfalfa and better seasonal growth for sorghum (Table 4). This result was basically the same with the finding of Raei (1998) who

Table 2: Mean annual sorghum and alfalfa forage yield (kg ha^{-1})

	Year 1		Year 2		Year 3	
Treatments	Alfalfa	Sorghum	Alfalfa	Sorghum	Alfalfa	Sorghum
aaaa	4798.3^a	-	20888.1^a	-	17879.50^a	-
aaas	2049.5^b	8650.0^d	11585.7^b	6123.0^c	14802.90^b	1550.6^c
aass	871.6^c	11831.8^b	8597.7^c	6621.5^c	11525.60^c	1709.7^b
asss	544.1^d	15348.4^c	7385.8^c	9508.9^b	8830.35^d	2425.4^a
ssss	-	18815.7^a	-	15477.3^a	-	3976.0^d

Means with the same letter (s) in each column are not significantly (p<0.05) different, aaaa: (alfalfa 100%), aaas: (alfalfa 75%/sorghum 25%), aass: (alfalfa 50%/sorghum 50%)-asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

Table 3: Analysis of variance on intercropping forage production (mean squares)

SOV	df	Forage yield (kg h^{-1})
Time (year)	2	114518199.05*
Error	6	4971329.20
Factor A (mixing rates of alfalfa-sorghum)	4	10915180.04*
Time × A	8	93960621.04*
Error	24	2903820.3

*: p<0.05

Table 4: Total accumulative annual forage yield of alfalfa intercropped by sorghum

Years	Total annual forage yield (kg h^{-1})
Year 1	12580^b
Year 2	17540^a
Year 3	17950^b

Means with the same letter(s) in the column are not significantly (p<0.05) different produced the highest forage biomass in the 2nd cut of sorghum/bereseem clover intercrop, followed by the 1st and 3rd cuts, respectively.

Long term superiority of alfalfa/sorghum intercropping was obtained from 25/75 percent mixing ratio (asss). This treatment produced the highest total forage yield (Table 5). Beheshti (1995) reported that intercropping sorghum and soybean in 2:1 row ratio gave higher returns for sorghum and soybean compared to sole crops.

Year×sowing mixture interaction showed that the highest forage production was obtained in the 2nd year. This was probably due to the better establishment of alfalfa. In this year, alfalfa pure stand (100%) produced the highest forage yield followed by alfalfa/sorghum in 75/25 row ratio (aaas) (Table 6). Increment of sorghum rows in intercropped treatments decreased forage production probably due to sorghum autotoxicity effects. The superiority of alfalfa/sorghum in 25/75 row ratio treatment (asss) could be referred to its minimum yield variation in 3 years of experimental period. As shown in Table 6, other treatments undergo sever changes during three years of experimental period. These variations which could be related to autotoxicity or allelopathic effects of alfalfa and sorghum caused to yield loss in three years of forage production. It seems that alfalfa in 1:3 treatments (asss) not only increased total forage yield, but has an important role in decreasing the autotoxicity effects of sorghum as well. So this treatment could be recommended at least for a 3 year growing period.

To make a reliable decision to choose the superior treatment, some determining indices of intercropping profitability were evaluated as follows:

Land Equivalent Ratio (LER): In the 1st year due to antagonistic effects of two crops on each other, LER was less than one. However, in treatments with sorghum as dominant crop (75:25), LER was more than similar treatment with sorghum as dominated crop (0.92 compare to 0.89) (Table 7). Slow growth rate and poor establishment of alfalfa in 1st year might be the main reason for these results.

LER values in 3rd year of experiment clearly indicated the profitability of intercropping as compared to sole cropping. The highest LER (1.22) in 3rd year was obtained with intercropping alfalfa and sorghum in 75/25 row ratio (aaas) which was due to full establishment of alfalfa, whereas, LER reduced to 1.07 with increasing of sorghum proportion to 50%. The intercropping superiority in asss treatment was only 10% (LER = 1.10). In some local researches as Zand and Ghaffari Khaligh (2002) and Sharifi (2004) which studied green chop forage production

Table 5: Mean accumulative yield of alfalfa and sorghum intercropping treatments for three years

Treatments	Average yield of treatments (kg h^{-1})
aaaa	14970^{ab}
aaas	14980^{ab}
aass	13720^{bc}
asss	15380^{a}
ssss	12730^{c}

Means with the same letter in the column are not significantly ($p<0.05$) different, aaaa: (alfalfa 100%) (s) aaas: (alfalfa 75%/sorghum 25%), aass: (alfalfa 50%/sorghum 50%), asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

Table 6: Interaction between intercropping treatments of alfalfa and sorghum with time (years of experimental period) on accumulative forage yield

	Forage yields of treatments (kg h^{-1})		
Treatments	Year 1	Year 2	Year 3
aaaa	4798^{g}	22400^{a}	17710^{bc}
aaas	10700^{f}	17710^{bc}	16520^{bc}
aass	12700^{ef}	15220^{cde}	13240^{def}
asss	15890^{cd}	16890^{bc}	13360^{def}
ssss	18802^{b}	15480^{cde}	3910^{g}

Means with the same letter(s) in the columns and rows are not significantly ($p<0.05$) different, aaaa: (alfalfa 100%)-aaas: (alfalfa 75% /sorghum 25%), aass: (alfalfa 50%/sorghum 50%), asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

Table 7: LER indices for different intercropping ratios of alfalfa and sorghum during experimental period (2002-2005)

Treatments	LER (1st year)	LER (2nd year)	LER (3rd year)
aaas	0.89	0.94	1.22
aass	0.81	0.84	1.07
asss	0.92	0.96	1.10

aaaa: (alfalfa 100%), aaas: (alfalfa 75%/sorghum 25%), aass: (alfalfa 50% / sorghum 50%), asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

in sorghum/cowpea intercrop, reported LER values as 1.19 and 1.24, respectively. Whereas LER =1.42 for fresh forage was obtained in sorghum/soybean intercrop (Homayouni, 2004).

Aggressivity Index (AI): Based on CI values for alfalfa and sorghum in intercropped treatments (Table 8), in the 1st year, alfalfa was the dominated species in all treatments and sorghum was the dominant one because of fast establishment of sorghum. This situation resulted in poor performance alfalfa in all mixed sowing treatments with sorghum in the first year of the experiment. In a barley/common bean intercrop experiment, the dominance of barley was proved (Martin and Snaydon, 1982). They also emphasized on fast establishment of barley as the main reason for its dominance in intercropped plots, which the results corresponds to our finding in the first year of the experiment. Results of intercropping study of chickpea (desi type) with barley for forage production indicated that barley was dominant species in all treatments (Daryaei, 2005). In such a manner, chickpea yield decreased with increment of barley in intercropping mixture. According to Hauggaard-Nielsen and Jensen (2001), barley was a strong competitor in intercropping

Table 8: Agressivity indices (AI) for different intercropping ratios of alfalfa (AI a) and sorghum (AI S) during experimental period (2002-2005)

Treatment	AI (1st year) AI a	AI s	AI (2nd year) AI a	AI s	AI (3rd year) AI a	AI s
aaas	-1.24	1.24	-0.86	0.86	-0.40	0.40
aass	-0.84	0.84	-0.30	0.30	0.44	-0.44
asss	-1.45	1.45	0.58	-0.58	1.19	-1.19

aaaa: (alfalfa 100%), aaas: (alfalfa 75%/sorghum 25%), aass: (alfalfa 50%/sorghum 50%), asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

Table 9: Relative crowding coefficient for different intercropping ratios of alfalfa and sorghum during experimental period (2002-2005)

Treatments	RCC (1st year)	RCC (2nd year)	RCC (3rd year)
aaas	2.74	2.41	1.79
aass	1.92	1.45	2.55
asss	1.85	2.13	3.42

aaaa: (alfalfa 100%)-aaas: (alfalfa 75% /sorghum 25%)-aass: (alfalfa 50% / sorghum 50%)-asss: (alfalfa 25% / sorghum 75%) and ssss: (sorghum 100%)

Table 10: Competition indices for different intercropping ratios of alfalfa and sorghum during experimental period (2002-2005)

Treatments	CI (1st year)	CI (2nd year)	CI (3rd year)
aaas	1.6	1.2	0.21
aass	2.6	1.9	0.73
asss	1.8	1.1	0.75

aaaa: (alfalfa 100%), aaas: (alfalfa 75%/sorghum 25%), aass: (alfalfa 50%/ sorghum 50%), asss: (alfalfa 25%/sorghum 75%) and ssss: (sorghum 100%)

with chickpea; therefore its grain yield and nitrogen uptake was similar to barley in sole crop. Whereas these items for chickpea in intercropped plots were less than half of sole crop.

However, in the 2nd year of the experiment in asss treatment despite of lower ratio of alfalfa in intercropped stand, alfalfa was dominant partner mainly due to its better establishment on the ground. With increasing the sorghum ratio in intercropping, its dominance in intercropped stands decreased, it could be referred to probable autotoxicity effects of sorghum.

Relative Crowding Coefficient (RCC): RCC values above 1 throughout the experimental period indicate the sever inter-specific competition between alfalfa and sorghum (Table 9). So additive priority of intercropping including reducing weed population, soil fertility maintenance, soil erosion control and efficient use of resources should compensate the yield loss compared to monoculture.

Competition Index (CI): According to Table 10, aaas treatment which has higher LER in forage production showed the lowest Competition Index (0.21). In the other words, validity of our decision to introduce the superior treatment is confirmed. Therefore, intercropping alfalfa/sorghum with 1:3 row ratio should be chosen as the best treatment for forage production.

CONCLUSIONS

Forage production in alfalfa/sorghum intercropping system is more consistent compared to sole cropping of each species. The highest forage yield was obtained in asss treatment (1:3 alfalfa/sorghum row ratio). Since there is no statistically significant difference between asss and aaas (3:1 alfalfa/sorghum row ratio), so forage quality and economic prices would be determining factors to choose one of them as superior treatment in this experiment.

Sorghum forage yield in three years of experimental period followed a reducing trend, which could be referred to sorghum autotoxicity. This trend was clear in all intercropped treatments having sorghum at least up to 50% of population.

LER in all treatments followed an up going trend throughout the 3 years of experiment. The highest LER (1.22) and lowest CI (0.21) was obtained in aaas (3:1 alfalfa/sorghum row ratio), but since there was no significant difference between aaas and asss treatment (1:3 alfalfa/sorghum row ratio) in forage yield, one of them could be introduced as superior treatment based on forage prices and quality.

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