Sorghum-Legume Mixed Cropping for High Yields of High Quality Forage

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Introduction

Mixed cropping is widespread on subsistence form in developing countries of the tropics[1]. Recently, however, the mixed cropping of grass and legume as forage has come to attract general interest[2]. The grass-legume mixed cropping is able to produce high quality forage for cows even in Japan.

Sorghum species are grown in large areas in warm regions of Japan, because they have high tolerance to high temperature, great adaptability to environments from wet to drought, resistance to lodging, and capability to regrowth. On the other hand, sorghum has some disadvantages — low digestibility, and low protein content — as balanced feed for cows. Mixed cropping of legumes to grasses makes a nutritious and palatable feed for cows.

Species of legume to be used for the mixed cropping must be compatible with sorghum in obtaining high yields of high quality forage due to efficient utilization of light and nutrients.

In the present study, three species of forage legumes were examined to find out a legume species to be combined with sorghum[3]. The result showed soybean is the best. Then, the superiority of sorghum-soybean mixed cropping over the pure stand or each crop was clarified by the physio-ecological approach[4,7] and the animal nutritional approach. Furthermore, the competitive relationship between the species in the mixed cropping was analysed in connection with the density effect under different conditions of cultivation[5,6,8].

Selection of legume species to be used for mixed cropping with sorghum

Three forage legume species, soybean (*Glycine max* Merrill cv. Kurosengoku), cowpea (*Vigna sinensis* Endl.) and Dolichos lablab (*Lablab purpureus* Sweet) were used for the mixed cropping with *Sorghum bicolor* Moench cv. FS401R.

Dry matter yield of the sorghum-soybean mixed cropping was significantly higher ($P < 0.05$) than that of the pure stand of sorghum (hereafter referred to sorghum pure cropping) at the late growth stage (Fig. 1).

Relative light intensity at the ground level in the canopy of the mixed cropping was lower than that of the sorghum pure cropping (Table 1), while total LAI in the mixed cropping was larger than in the respective pure cropping. On the other hand the relative light intensity at the middle portion of canopy of the sorghum-soybean mixed cropping was apparently higher than that of other kinds of mixed cropping, because of the upright plant-type of soybean, in contrast to the climbing type legumes used in other combinations. It was suggested that sorghum was able to utilize the more amount of solar radiation available in the upper portion of the canopy (above the soybean plants) in the sorghum-soybean mixed cropping.

Though mixed cropping of legumes to sorghum would enable to increase both dry matter and nutritive yields, the most suitable legume species to the mixed cropping with sorghum is considered to be upright

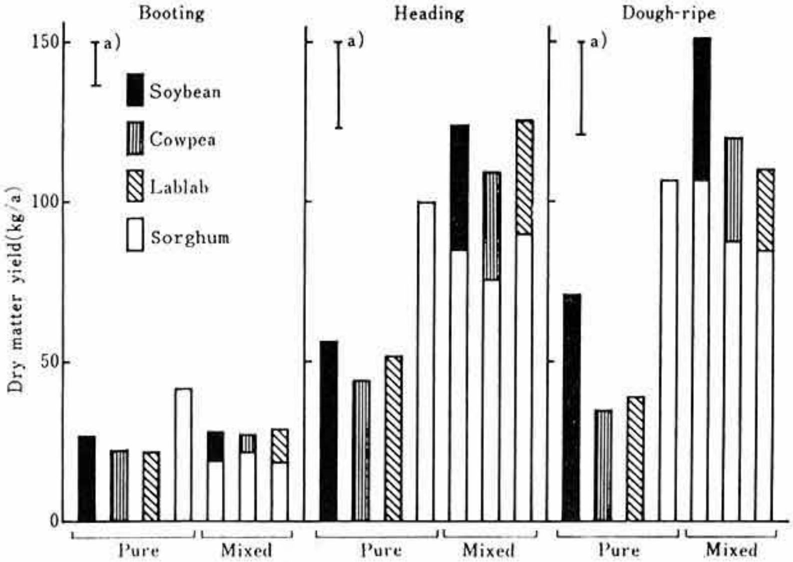

Fig. 1. Dry matter yields in pure and mixed cropping of sorghum and three kinds of legumes at three harvesting stages
a) Vertical bars: L. S. D. at 5 % level.

Table 1. Relative light intensity (%) in the canopy of pure and mixed cropping of sorghum and three species of legumes

Stage of sorghum at harvest	Height of measurement	Pure cropping				Mixed cropping		
		Soybean	Cowpea	Lablab	Sorghum	Sorghum/ Soybean	Sorghum/ Cowpea	Sorghum/ Lablab
Booting	Ground surface	17.5	21.4	19.3	32.2	18.2	21.6	24.4
	50 cm* above ground	—	—	—	50.3	58.6	52.2	53.3
Heading	Ground surface	12.2	14.4	12.4	36.4	13.3	14.2	13.6
	100 cm* above ground	—	—	—	43.8	44.0	28.8	18.8

* 50 cm and 100 cm represent the height of soybean at the booting and heading stage of sorghum, respectively.

type soybean, because the combination of sorghum and soybean enables to make an ideal canopy, which can utilize solar radiation most efficiently.

Mixed cropping advantage to crop growth

Table 2 shows the efficiency of solar energy utilization (Eu) in four different sorghum-soybean mixed croppings. At the late growth stage, Eu of each crop in the mixed cropping was higher than that of each crop grown in pure stand. The high values of Eu in mixed cropping brought about the high net photosynthesis per unit leaf area of the mixed-cropped sorghum.

The relative yield[11] of a species is obtained by taking the quotient (M/P) of the yield shown in the mixed cropping (M) and in the pure cropping (P). The relative yield total of two species grown together is the sum of

Table 2. Efficiency of solar energy utilization (Eu)* in four different sorghum-soybean combinations of mixed cropping

		Hy+Sk	Hy+Si	Pi+Sk	Pi+Si	Hy	Pi	Sk	Si
July 13 — July 27	Sorghum	2.39	2.34	2.28	3.47	2.37	4.20	—	—
	Soybean	0.32	−0.03	0.26	0.25	—	—	1.04	0.62
	Total	2.71	2.31	3.12	3.72	2.37	4.20	1.04	0.62
July 27 — Aug. 10	Sorghum	1.42	2.56	2.26	1.27	2.96	2.62	—	—
	Soybean	0.17	0.33	−0.08	0.19	—	—	1.12	1.32
	Total	1.59	2.89	2.18	1.46	2.96	2.62	1.12	1.32
Aug. 10 — Aug. 24	Sorghum	3.93	2.88	3.41	2.02	2.59	1.87	—	—
	Soybean	0.09	0.28	0.24	0.08	—	—	−0.53	0.21
	Total	4.02	3.16	3.65	2.10	2.59	1.87	−0.53	0.21

* Eu expressed in percentage.
Hy : Hybrid sorgo, Pi : Pioneer sorgo, Sk : Soybean Kurosengoku, Si : Soybean Iwatekurome.

their relative yields. In this experiment, the relative yield total in all mixed croppings exceeded 1.0 at the late stage of growth, even though the total dry matter yield of the mixed cropping did not out-yield the sorghum pure cropping.

Sorghum is usually tall with erectphile leaves and has the C_4 photosynthetic pathway, which is particulary efficient at high light levels, whereas the legume which has C_3 photosynthetic pathway is usually confined to the lower layer of the canopy, and it has planophile leaves and is well adapted to low light levels[10].

In the combination of sorghum and soybean, soybean is usually shaded by sorghum leaves. In this connection, a shading experiment was conducted.

The treatment of 50% shading and 70% shading retarded the growth of soybean, but the growth began to recover rapidly even though the shading treatment was continued. Especially plant height in 50%-shaded plot was higher than that of control at 41 days from the start of the shading treatment. The retarded growth was recovered with NAR and LAR. Nitrogen and digestible dry matter yield of 50%-shaded plants were higher than those of the control plants at 41 days from the start of the shading treatment.

Mixed cropping advantages to the nitrogen fixation and nitrogen uptake

Nodule formation and nodule activity (acetylen reduction activity) of soybean were compared between mixed cropping and pure cropping at different conditions of nitrogen supply (Table 3). Nitrogen supply only for the first 1 week, followed by no nitrogen (SN plot) stimulated the formation and activity of root nodules, while nitrogen supply for the whole experimental period (TN plot) inhibited the formation and activity of nodules. In the ON plot (no nitrogen applied for the whole period) and the SN plot, the mixed cropping increased the formation and activity of nodules. Such a favorable effect of mixed cropping was not clearly shown in the TN plot due to an inhibitory effect of nitrogen on root nodules. In addition to the advantage that the mixed cropping can promote the formation and activity of root nodules, sorghum plants have an advantage of absorbing some nitrogenous substance derived from the root nodules of soybean plants in the mixed cropping.

The relationship between sorghum and soybean described above is recognized as the complementary association, which is one of the major advantages of the mixed cropping.

Table 3. Formation and activity of root nodules of soybean in pure and mixed cropping

Treatment		Nodule number/plant	Nodule weight/plant (g)	Acetylene reduction activity SNA (μ mole C_2H_4/g・nodule/h)	Acetylene reduction activity TNA (μ mole C_2H_4/plant/h)
ON	Pure cropping	17± 3	0.13±0.02	149.4±24.8	19.4± 3.4
	Mixed cropping	31± 8	0.19±0.04	204.8±63.4	40.4±22.9
SN	Pure cropping	37± 8	0.23±0.05	139.0±58.1	31.5±14.4
	Mixed cropping	38± 7	0.30±0.03	183.8±68.0	55.7±19.2
TN	Pure cropping	28± 2	0.09±0.01	40.9± 5.7	3.8± 0.6
	Mixed cropping	22± 3	0.11±0.04	44.6±10.7	4.6±·0.9

Values are mean±S. E.
SNA and TNA indicate specific nodule activity and total nodule activity, respectively.
ON : N-free nutrient solution for the whole experimental period.
SN : Nutrient solution with N for the first 1 week, followed by N-free solution until the end of the experiment.
TN : Nutrient solution with N for the whole period.

Competitive relationships in the mixed cropping

To maximize advantages of mixed cropping, such as the increased dry matter production with improved nutritional value, competitive relationship specific to the mixed cropping was analyzed.

Firstly, the effect of planting dates on growth and competitive relation in mixed cropping was examined.

The yield of sorghum combined with soybean which was planted 12 or 24 days ahead was markedly decreased, and that of soybean planted 12 days after the planting of sorghum was also decreased remarkably (Fig. 2). Thus, the relative yield of sorghum is negatively correlated with that of soybean. It was suggested that the simultaneous planting of both crops or the planting of sorghum earlier than soybean by only few days may cause high photosynthesis ability of sorghum plants, and enhanced the advantage of mixed cropping in dry matter production.

Secondly, the sorghum-soybean mixed cropping was conducted at four different levels of planting density combined with two different planting patterns to evaluate the effect

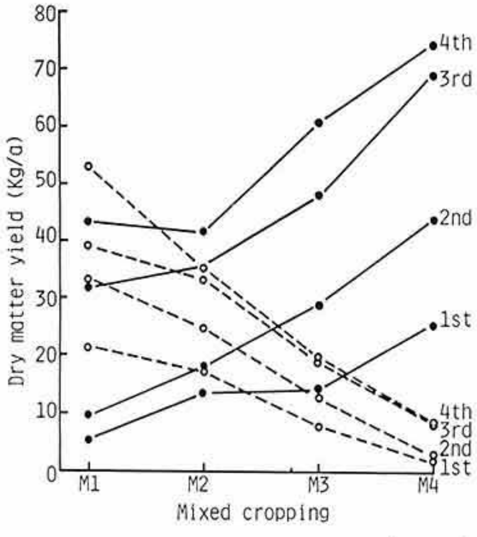

Fig. 2. Dry matter yield of sorghum (—・—) and soybean (····∘····) as influenced by different combinations of planting time of two crops in mixed cropping
1st, 2nd, 3rd and 4th indicate the harvesting time: July 14, July 23, Aug. 7 and Aug. 22.
M1, M2, M3 and M4 indicate the sowing date of soybean: April 28, May 9, May 21 and June 3.
Sorghum was sown on May 21 only.

Table 4. Dry matter yield (DM), ratio of soybean in mixed cropping, relative yield (RY) and relative yield total (RYT) of pure and mixed cropping at different levels of planting density

	5.6 plants/m²			11.1 plants/m²			16.7 plants/m²			33.3 plants/m²		
	DM (kg/a)	Ratio of soybean	RY, RYT	DM (kg/a)	Ratio of soybean	RY, RYT	DM (kg/a)	Ratio of soybean	RY, RYT	DM (kg/a)	Ratio of soybean	RY, RYT
Sorghum pure cropping												
Sorghum	108.32			163.83			196.64			222.41		
Soybean pure cropping												
Soybean	42.39			45.89			48.64			55.46		
AWR mixed cropping												
Sorghum	65.54		0.61	91.61		0.56	125.49		0.77	173.88		0.77
Soybean	12.08	15.6	0.28	22.30	19.6	0.49	23.89	16.0	0.49	26.50	13.2	0.48
Total	77.62		0.89	113.91		1.05	149.38		1.26	200.38		1.25
AR mixed cropping												
Sorghum	66.63		0.62	89.70		0.55	111.81		0.57	156.73		0.70
Soybean	13.92	17.3	0.33	16.05	15.2	0.35	18.19	14.0	0.37	17.73	10.2	0.31
Total	80.55		0.95	105.75		0.90	130.00		0.94	174.18		1.01

AWR: Two crops alternated in a row.
AR: Rows of each crop alternated.

of planting density and planting pattern on growth and competitive relation in the mixed cropping.

Dry matter yield of sorghum pure cropping increased from 100 kg to 222 kg, as the planting density increased from 5.6 plants/m² to 33.3 plants/m². That of soybean increased from 42 kg to 56 kg. Total dry matter yield in AWR system was higher than that of AR system at the same planting density as shown in Table 4.

All the values of relative yield of sorghum in both systems exceeded 0.5, showing high values at relatively high planting density. On the other hand, the values of relative yield of soybean were not influenced by planting density. From the values of relative yield, positive mixture effect (mixed cropping advantage) was recognized at high planting density in mixed cropping.

To evaluate the relationship between mixed cropping advantage and planting density in detail, the concept of density exchange rate[9] was introduced.

The respective relationship between planting density and plant weight for sorghum and soybean was described by the reciprocal equation of density effect ($1/w = A\rho + B$; w=plant weight, ρ=planting density, A, B=constant) significantly ($P<0.01$).

Density exchange rate was calculated as follows:

$$q_{Hy} = (\rho^*_{Hy} - \rho_{Hy}) / \rho_{Soy},$$

$$q_{Soy} = (\rho^*_{Soy} - \rho_{Soy}) / \rho_{Hy},$$

where q_{Hy} is an equivalent ratio of density effect of soybean (Soy) to that of sorghum (Hy) in mixed cropping, ρ^*_{Hy} (equivalent density) is a value of total density effect of both Hy and Soy in mixed cropping, ρ_{Hy} is a population density (plants/m²) of sorghum in mixed cropping. Also, q_{Soy}, ρ^*_{Soy} and ρ_{Soy} are the same definitions as to Hy. Density exchange rate, which is the criteria for assessing mixed cropping advantages, is suggested as follows. In the case of $q=1.0$, the effect of the companion species is the same as the density effect of the own species. If q is less than 1.0, the density effect of the own species is stronger than the effect of the other species.

The density exchange rate, calculated from the measured values in Table 4, is given in Table 5.

The value of q_{Hy} showed below 1.0 even in all the densities and two mixed cropping systems, and for soybean over 1.0. This

Table 5. Density exchange rates(q) of sorghum and soybean and products of them in AWR and AR mixed cropping

	5.6 plants/m²		11.1 plants/m²		16.7 plants/m²		33.3 plants/m²	
	AWR	AR	AWR	AR	AWR	AR	AWR	AR
qsorghum	0.46	0.61	0.27	0.37	0.20	0.29	0.14	0.21
qsoybean	1.58	2.28	1.20	2.28	1.08	2.28	0.95	2.28
qsorghum × qsoybean	0.72	1.38	0.32	0.84	0.22	0.65	0.13	0.47

AWR and AR: See Table 4.
qsorghum: Number of sorghum plant equivalent to one soybean plant in competitive effect.
qsoybean: Number of soybean plant equivalent to one sorghum plant.

suggested that sorghum was dominant to soybean. And also, inter-specific competition was dominant for sorghum, while for soybean intra-specific competition showed the greater effect on dry matter production of individual plants. Mixed cropping advantage was greater in AWR mixed cropping than in AR mixed cropping.

Nutrient uptake in the mixed cropping

The content of nutrients (N, P, K, Ca, Mg) of sorghum in the mixed cropping tended to be higher than those in pure sorghum cropping under low and high nitrogen and potassium fertilization (Table 6).

Table 6. Effects of nitrogen and potassium fertilization on dry matter(DM) weight(g/plant) and nutrients content(% in DM) in pure and mixed cropping of sorghum (Hy) and soybean (Soy)

		DM	N	P	K	Ca	Mg
L-NK	Hy*	88.8	1.06	0.37	1.25	0.37	0.18
	Hy	119.5	1.09	0.35	2.16	0.40	0.16
	Soy	22.9	2.77	0.42	1.79	1.01	0.34
H-N	Hy*	116.0	1.33	0.29	1.64	0.35	0.21
	Hy	141.9	1.49	0.33	1.99	0.42	0.22
	Soy	22.0	2.70	0.43	2.27	0.96	0.41
H-K	Hy*	86.2	0.96	0.42	2.49	0.32	0.17
	Hy	112.5	1.01	0.43	2.54	0.37	0.18
	Soy	23.1	2.91	0.48	2.45	0.93	0.29

Hy*: Sorghum pure cropping.
L-NK: 0.5 kg/a of $N-K_2O$ applied.
H-N: 1.0-3.0 kg/a of N applied.
H-K: 1.0-3.0 kg/a of K_2O applied.

Therefore, the yields of these nutrients were higher in the mixed cropping than those in pure cropping, even if the dry matter yield of sorghum in the mixed cropping was a little less than in pure sorghum cropping.

Nutritional value of sorghum in the mixed cropping

As described above, it was made clear that the nitrogen-uptake of sorghum was increased by association with soybean. It was assumed that the nutritional value of sorghum also changed with increase of soil nitrogen uptakes.

Protein content of sorghum was higher in the mixed cropping than in the pure stand. As mentioned above, this tendency became

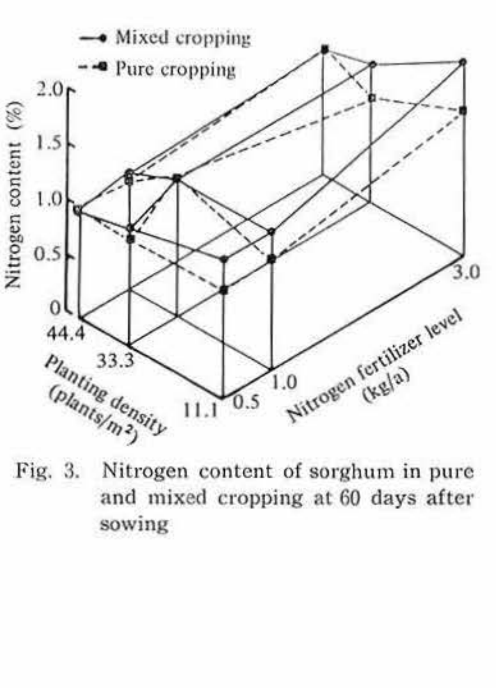

Fig. 3. Nitrogen content of sorghum in pure and mixed cropping at 60 days after sowing

Table 7. ***In vitro*** **dry matter digestibility (%) of sorghum in pure and mixed cropping harvested on different days**

	July 31	Aug. 16	Sep. 3	Mean difference* ($P<0.05$)
Pure sorghum	54.9	52.1	42.7	2.1
Mixed sorghum	57.7	53.1	45.3	

* Difference between the mean values obtained from all of the sorghum pure and mixed cropping experiments in which various treatments were given. The difference is significant at 5% level.

remarkable at low planting density and with nitrogen application (Fig. 3).

In vitro dry matter digestibility of sorghum grown by mixed cropping was higher by two percentage unit ($P<0.05$) than that of sorghum in pure cropping (Table 7). The effect of planting density and nitrogen fertilization on *in vitro* dry matter digestibility of sorghum was small both in mixed cropping and pure cropping.

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