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Full Length Research Paper

Effect of proportion of component species on the productivity of *Solanum aethiopicum* and *Amaranthus lividus* under intercropping

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In central Uganda, 'garden egg' (*Solanum aethiopicum*) is commonly intercropped with 'spleen amaranth' (*Amaranthus lividus*) but the productivity of this mixture is unknown. The objective of the experiment was to determine the yield advantage from this mixture. Treatments tested included pure stands of *Solanum aethiopicum* and *Amaranthus lividus*, locally called nakati and ebugga, respectively, 'additive mixtures', and several 'replacement series' mixtures. Generally, pure stands gave the highest total and edible DM yields. For each species, DM yield in mixtures was significantly higher (P<0.05) in mixtures in which it constituted the highest proportion, that is 75:25% *Solanumi*:*Amaranthus* replacement series mixture in the case of *S. aethiopicum*, and 25:75% mixture in the case of *A. lividus*. Intercropping reduced total *S. aethiopicum* DM yield by 72% in the 25:75% *Solanum*:*Amaranthus* mixture, while *A. lividus* yield was reduced by 68% in the 75:25% mixture. There was high correlation between *S. aethiopicum* and *A. lividus* plant population and edible DM yield (r = 0.71 and 0.98, respectively).The difference in yield between pure stand *S. aethiopicum* and the 75:25% *Solanum*:*Amaranthus* mixture was not significant yet it was associated with 93 kg ha^{-1} of edible DM yield of *A. lividus* as a 'bonus' yield, equivalent to 27% of the edible DM yield of pure stand *A. lividus*. Generally, the additive mixtures gave higher *S. aethiopicum* DM yield than the replacement series mixtures with less than 50% *S. aethiopicum*. The 37% lower edible DM yield of *S. aethiopicum* in the double compared to the single additive mixture was attributed to greater competition against *S. aethiopicum* by the double *Amaranthus* rows compared to the single *Amaranthus* rows but the double additive mixture had about 55% more edible *Amaranthus* DM yield than the single additive. Most mixtures gave yield advantages, with the double (47%) and single (39%) additive mixtures giving higher yield advantages than the replacement series mixtures. On the basis of gross returns, most mixtures were more profitable than the pure stands.

Key words: Garden egg (*Solanum aethiopicum*), spleen amaranth (*Amaranthus lividus*), proportion of component species, plant population, intercropping, yield advantage.

INTRODUCTION

There are over 160 species of local vegetables in Uganda (Goode, 1989). Local vegetables are the indigenous vegetables in the country and those that were introduced into the country a long time ago, without clear existing evidence of when, where and by whom they were introduced (Rubaihayo, 1995a). Many of these local vegetables have been grown by generations of farmers and propagated as local land races (Grubben and Almekinders, 1997). In central Uganda, garden egg, which is locally called nakati (*Solanum aethiopicum*) is ranked the most important local vegetable species that is commercially grown, and is allocated larger land acreage than the others (Ssekabembe et al., 2003ab) . *Solanum aethiopicum* is also one of the five most important vegetable species in West and Central Africa (Schippers, 2000). The other important local vegetables in Uganda include *Amaranthus lividus* (locally called ebugga), *Gynandropsis* (*Cleome*) *gynandra* (Ejobyo) and *Solanum gilo* (Entula enganda) (Goode, 1989). These local green vegetables are important for food security and some of them can be harvested piecemeal for home consumption or to spread the marketing season (Schippers, 2000);

have high nutrient content (FAO, 1988; Numfor, 1997), low production costs (Schippers, 1997; Attere and Guarino, 1997); some have short growth duration (Rubaihayo, 1995b); and cultivars adapted to local soils and climate may be available (Rubaihayo, 1994; Chweya, 1997). Early maturity of some species like *Amaranthus lividus* may facilitate intercropping.

Despite their importance, the local vegetables have generally received little research attention. Therefore, their productivity has remained relatively low or is unknown (Rubaihayo, 1996; Schippers and Budd, 1997). In the case of *S. aethiopicum*, the crop is commonly grown in intercropping systems with *A. lividus* being the commonest intercrop in central Uganda (Ssekabembe, 2003a). Unfortunately, the productivity of the *S. aethiopicum* + *A. lividus* mixture, hereafter referred to as the *Solanum*:*Amaranthus* mixture, is largely unknown. Farmers intercrop the two species partly because *Amaranthus* is earlier maturing and the income derived from its sale can support production of *S. aethiopicum* which is later maturing and also the preferred component species. Research on intercropping with other crops indicates that the proportion of the component species in crop mixtures or spatial arrangement often has an important effect on the nature and magnitude of competition among the component crops in the mixture (Chowdhury and Bhargava, 1986). Furthermore, the best spatial arrangement for crop mixtures appears to differ with different intercrops (Ssekabembe and Sabiiti, 1997). Therefore, it was important to determine the effect of proportion of component species in the *Solanum* + *Amaranthus* mixture, on the yield advantages from this mixture. This intercropping system had previously not received any research attention.

Mixtures can be formed by adding together the plant populations used in the pure stands (Agboola and Fayemi, 1971). This means that in such additive intercropping the total plant population of the mixtures is doubled when two crops are intercropped in this manner (Ebwongu et al., 2001). In other words, an inherent feature of additive intercropping is that the total plant population of the mixture is greater than that of the pure stands, which may contribute to its yield advantage (Willey and Osiru, 1972). The alternative method of forming crop mixtures is the 'replacement series' technique which was described in detail by Willey and Osiru (1972). Briefly, in this method mixtures are formed by replacing a certain proportion of one species by another while keeping the total plant population pressure constant. The technique allows formation of a range of mixtures with different proportions of the two species. As Willey and Osiru pointed out, an important feature of replacement series is that a single plant of one species is not necessarily equivalent to a single plant of the companion species. Rather, equivalence is calculated according to the ratio of their optimum plant populations in pure stand. Therefore, if the optimum plant population of the first crop species is 10 plants m $^{-2}$ and that of the companion species 5 plants $^{-2}$, then is forming the mixtures two plants of the first species are regarded as equivalent to one plant of the companion species. In the replacement series system total plant population pressure is conveniently expressed in terms of 'plant units'. Thus, in the example used above two plants of the first species or one plant of the companion species is equivalent to one 'plant unit'.

MATERIALS AND METHODS

The experiment was carried out at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) (0^o 28'N, 32^o 37'E), which is 17 km northeast of Kampala. The soils in the area are Oxisols, which are highly weathered and low in soil fertility although they may be deep and well drained. The mean daily maximum and minimum temperature of the area are about 27 and 17^oC, respectively. The annual average rainfall is about 1300 mm but its reliability fluctuates a lot in the recent past. It is bimodal in distribution with April and November as the usual wettest months.

In the present experiment, the treatments included various proportions of the two component species formed by either the replacement series method or the additive method. *A. lividus* is a short-lived annual plant that can grow up to 100 cm in height under favourable conditions. It is erect and has 'bush' growth habit and its above-ground part is often thick and fleshy. The leaves are green or purple. It can be recognized by its distinct long clusters of red flowers in the axils of the lower leaves and a longer spike, branched or not, in the terminal parts. It can be harvested in 30 - 50 days after sowing (NAP, 1984). On the other hand, un-harvested *S. aethiopicum* plants can reach about 80 cm. Its plants develop a much-branched architecture with weak stems and many small leaves. Both green and purple-stemmed varieties are available but consumers prefer the green-stemmed varieties because they tend to be sweeter (Schippers, 2000). According to the 'replacement series' treatments (except 50:50%b), one row of *S. aethiopicum* was taken as equivalent to two rows of *Amaranthus* because the pure stand *S. aethiopicum* was sown on 50 cm rows as reported by Schippers (2000) and pure stand *Amaranthus* on 25 cm rows. The intra-row spacing was 10 cm for both species, and this was attained during thinning the crops 2 weeks after emergence. The following was the full range of treatments:

1. Pure stand *S. aethiopicum* grown on 50 cm rows and thinned to 10 cm within the rows two weeks after emergence. The expected total plant population was 200,000 plants ha^{-1}.

2. Single additive *Amaranthus* rows in which one *Amaranthus* row was planted in the middle of each two adjacent *S. aethiopicum* rows planted 50 cm apart as in the pure stand. Both species were thinned to 10 cm within the rows. The expected plant population was 200,000 plants ha^{-1} of either species giving a total plant population of 400,000 plants ha^{-1}.

3. Double additive *Amaranthus* rows in which two rows of *Amaranthus* themselves 25 cm apart were planted between each pair of *S. aethiopicum* rows planted 50 cm apart as in pure stand *S. aethiopicum*. The expected plant population was 200,000 plants ha^{-1} for *S. aethiopicum* plus 400,000 plants ha^{-1} of *Amaranthus*.

4. 75:25% *Solanum*:*Amaranthus* 'replacement series' treatment, in which three rows of *S. aethiopicum* alternate with two rows of *Amaranthus* (the latter is equivalent to one row of *S. aethiopicum*), that is, two rows of *Amaranthus* replaced every fourth row of pure

Table 1. Mean number of plants of each species in the sample at harvesting time.

Treatment (*Solanum aethiopicum* : *Amaranthus lividus*.	Number of rows in harvest sample (2.5 m^2)		Number of plants per hectare at harvest time	
	Solanum aethiopicum	***Amaranthus lividus***	***Solanum aethiopicum***	***Amaranthus lividus***
Pure *S. aethiopicum*	6	-	135,556	-
Single additive	6	5	124,444	156,444
Double additive	6	10	148,000	310,222
75:25% replacement	5	2	107,556	56,000
50:50% replacement	3	5	80,889	163,111
50:50b% non-replacement	3	3	55,111	58,222
33:67% replacement	2	7	27,111	220,444
25:75% replacement	2	7	30,667	268,000
Pure *Amaranthus*	-	11	-	260,000

stand *S. aethiopicum* while maintaining the total 'plant units' as in pure stand *S. aethiopicum*. Thus, in this treatment the expected plant population was 150,000 plants ha^{-1} of *S. aethiopicum* plus 100,000 plants ha^{-1} of *Amaranthus*. The two rows of *Amaranthus* were 25 cm apart while those of *S. aethiopicum* were 50 cm apart but the first *Amaranthus* row was 37.5 cm away from the third *S. aethiopicum* row.

5). 50:50% *Solanum*:*Amaranthus* 'replacement series' treatment, in which one row of *S. aethiopicum* alternates with two rows of *Amaranthus* , that is two rows of *Amaranthus* replaced one row of *S. aethiopicum* in alternate order. The two rows of *Amaranthus* were 25 cm apart while *S. aethiopicum* was 37.5 cm away from the first *Amaranthus* row.

6). 50:50%b, which was a 1:1 *Solanum*:*Amaranthus* row arrangement (not replacement series), assuming *S. aethiopicum* and *Amaranthus* to be equal in terms of population pressure, that is both planted on 50 cm rows and had one row of *Amaranthus* replacing one row of *S. aethiopicum* rather than two *Amaranthus* rows replacing one *S. aethiopicum* row as in treatment 5 above. Neither species was at the pure stand row spacing. Thus, total plant population was 100, 000 plants ha^{-1} for *S. aethiopicum* and 100,000 plants ha^{-1} of *Amaranthus* with the latter being half of the recommended pure stand population.

7). 33:67% *Solanum*:*Amaranthus* 'replacement series' mixture in which one row of *S. aethiopicum* alternates with four *Amaranthus* rows that are equivalent to 2 *S. aethiopicum* rows. The Amaranthus rows were 25 cm apart and the spacing between *S. aethiopicum* and the first *Amaranthus* row was 37.5 cm. The expected total plant population was 66,000 plants ha^{-1} of *S. aethiopicum* plus 268,000 plants ha^{-1} of *Amaranthus*.

8. 25:75% *Solanum*:*Amaranthus* 'replacement series' mixture in which one row of *S. aethiopicum* alternates with six rows of *Amaranthus* that are equivalent to 3 *S. aethiopicum* rows. The Amaranthus rows were 25 cm apart and the spacing between *S. aethiopicum* and the first *Amaranthus* row was 37.5 cm. The expected total plant population was 50,000 plants ha^{-1} of *S. aethiopicum* plus 300,000 plants ha^{-1} of *Amaranthus*.

9). Pure stand *Amaranthus* grown on 25 cm rows and thinned to 10 cm within the rows two weeks after emergence. The expected total plant population was 400,000 plants ha^{-1}.

The treatments were laid out in a randomized complete block experimental design with three replications. Each plot measured 4 x 4 m. The experiment was planted on 30th September in the second rains of 2005 and repeated twice in the same plots in the first and second rains of 2006. Local landraces of the two species were used in the study, and locally available seed for both species was used. The inter -row spacing and species arrangement depended on treatment as described above. During seedbed preparation each plot received a blanket application of poultry manure from the same source each season, and the application (broadcasting followed by incorporation into the soil with a rake) was done by the local farmers in order to mimic the traditional practice in which a little amount of manure, about 1.5 t ha^{-1}, is applied in the seedbed before or at the planting time. The plots were kept relatively weed free with application of roundup or glyphosate, isopropylamine salt of N-(phosphonomethyl) glycine at a rate of 3 l of roundup ha^{-1} applied by mixing 150 ml of the herbicide in 20 l of water, before seedbed preparation. This was followed by preparation of a fine seedbed before planting, and hand weeding whenever it became necessary. Sampling for dry matter (DM) yield was restricted to the middle 2.5 m^2 of each plot. The number of plants for each species in the sample varied with spatial arrangement and survival of plants in the treatments, and these are indicated in Table 1. Total above-ground DM production was partitioned into the edible portion consisting of leaves and soft parts of the stem at the top of the plants, and the reject or inedible portion which consisted of the fibrous part of the stem. *Amaranthus* was harvested 30 days after planting and *S. aethiopicum* two weeks later. Five sub samples at harvest time were used to determine the moisture content of the species, by drying the 2 kg fresh weight samples in an oven at about 60^{o}C until constant dry weight. The dry mater content was used to calculate total DM yield, edible DM yield and inedible DM yield per hectare. Partial and total land equivalent ratios were computed by dividing the edible yield in the mixture by the corresponding edible pure stand yield in the respective replications, which was then averaged over the seasons. Using the average of the price of the crop species in the local market, the gross returns from each treatment was computed in order to get an idea on the monetary benefit of intercropping the two crops in different proportions. The data was analyzed for variance using the Genstat computer programme Release 7.1, and means separated using the Fisher's Protected LSD test at 5% level of significance.

RESULTS AND DISCUSSION

Total *Solanaum aethiopicum* DM yield

The results on total aboveground DM yield of nakati are

Table 2. Effect of intercropping *Solanum aethiopicum* with *Amaranthus lividus* on the total DM yield of *S. aethiopicum* over three seasons at MUARIK

Treatments	Seasons			Mean
	2005b	2006a	2006b	
	kg ha^{-1}			
Pure *S. aethiopicum*	259.2	835.2	1137.6	744.0
Single additive	86.4	444.8	1092.8	542.4
Double additive	41.6	259.2	638.4	313.6
75:25% replacement	128.0	702.4	1468.8	766.4
50:50% replacement	72.0	382.4	1123.2	526.4
50:50b% non replacement	70.4	363.2	588.8	340.8
33:67% replacement	25.6	142.4	441.6	203.2
25:75% replacement	22.4	100.8	289.6	137.6
Mean	88.0	403.2	848.0	446.4
$LSD_{(0.05)}$	39.5	215.7	436.5	154.9
CV	25.6	30.5	29.4	36.5

shown in Table 2. Total DM yield was markedly greater in the 2006 second rainy season compared to the other seasons. The low total DM yield in the 2005 second rainy season is partly attributed to drought. While the 4 months growing season (October 2005 to January 2006) received a total of 197.9 mm of rainfall that of the third season (September 2006 to December 2006) received a total of 552.1 mm of rainfall. Since organic matter decomposes slowly, it takes time to release nutrients for the benefit of the first crop (Kalumuna, 2001). In one trial in Kenya, use of organic manure had little or no effect on maize yield in the first two years, but in the third year use of compost almost doubled the farmer's maize yields (Kamidi et al., 1999). In the present experiment, poultry manure was added every season to the same plots in which the crops were grown in the various seasons. Therefore, the third season can be expected to have benefited from better accumulated soil fertility following the gradual release of nutrients.

Except in a few cases in the 2006 first and second rainy seasons, the significant differences in total *S. aethiopicum* DM yield between the treatments were similar in the various seasons. As indicated in Table 2, pure stand *S. aethiopicum* gave the highest total DM yield followed by the 75:25% *Solanum*:*Amaranthus* replacement series mixture but the difference between these two treatments was significant only in the 2005 season (P<0.05) . This indicates that in terms of total *S. aethiopicum* DM yield, the 75:25% mixture did not reduce *S. aethiopicum* yield remarkably, and the *Amaranthus* yield associated with it is a desirable 'bonus' yield. In almost all the seasons, the 25:75 and 33:67% *Solanum*: *Amaranthus* mixtures gave significantly lower total DM yield (P<0.05), which reduces their appeal to farmers who prefer *S. aethiopicum* to *Amaranthus* (Ssekabembe et al., 2003ab) . Overall, intercropping reduced total nakati DM yield by 72 and 82% in the 33:67 and 25:75% *Solanum*: *Amaranthus* mixtures, respectively. The higher *S. aethiopicum* population in the 75:25% *Solanum*: *Amaranthus* mixture contributed to its higher total DM yield compared to the other mixtures given the high correlation between *S. aethiopicum* plant population and *S. aethiopicum* total DM yield (r = 0.66) (P <0.05) . On the average, the single additive followed by the double additive gave higher total *S. aethiopicum* DM yield than the mixtures with less than 50% *S. aethiopicum* in the replacement series treatments. The significantly lower total DM *S. aethiopicum* yield in the double compared to the single additive mixture could be attributed to greater competition against *S. aethiopicum* by the double *Amaranthus* rows compared to the single *Amaranthus* rows.

Edible (leaves) and inedible (stem) DM yield of *Solanum aethiopicum*

The results on the edible DM yield of *S. aethiopicum* are given in Table 3. The effect of season on edible *S. aethiopicum* DM yield was similar to that of total DM yield. As with total DM yield, the 25:75 and 33:67% *Solanum*:*Amaranthus* replacement series mixtures but also the 50:50%b (non replacement series) mixture and the double additive mixture gave significantly lower edible DM *S. aethiopicum* yield than the pure stand in all seasons (P<0.05). Compared to the pure stand, the edible DM yield of *S.aethiopicum* in the 25:75% and 33:67: *Solanum*:*Amaranthus* mixture was on average reduced by 81 and 73%, respectively. As with total DM yield of *S. aethiopicum*, the edible yield of *S. aethiopicum* realized from the 75:25% *Solanum*:*Amaranthus* replacement series mixture, but also the 50:50% replacement series mixture was similar to that from the pure stand. The results show that the replacement series mixtures

Table 3. Effect of intercropping *Solanum aethiopicum* with *Amaranthus lividus* on the edible and inedible portion of *S. aethiopicum* over three seasons at MUARIK.

Treatments	Seasons			Mean
	2005b	2006a	2006b	
	kg ha^{-1}			
Pure *S. aethiopicum*	178.7 (80.5)	537.1 (298.7)	637.0 (501.3)	450.9 (293.4)
Single additive	63.84 (23.2)	296.2 (149.3)	651.0 (442.4)	337.1 (205.0)
Double additive	30.56 (10.9)	197.9 (61.3)	404.8 (234.2)	211.0 (102.1)
75:25% replacement	83.04 (45.0)	470.2 (231.8)	804.0 (665.0)	452.5 (313.9)
50:50% replacement	55.36 (17.0)	248.0 (134.6)	662.7 (460.6)	322.1 (204.0)
50:50b% non replacement	47.84 (22.4)	209.0 (153.6)	309.8 (279.8)	189.0 (152.0)
33:67% replacement	18.08 (7.0)	97.4 (45.0)	244.6 (196.3)	120.2 (82.7)
25:75% replacement	15.84 (6.6)	73.0 (28.0)	171.2 (118.4)	86.7 (51.0)
Mean	61.6 (26.6)	266.1 (137.8)	485.6 (362.2)	271.2 (175.5)
$LSD_{(0.05)}$	28.64 (19.0)	138.2 (87.2)	254.2 (209.8)	158.8 (124.7)
CV	26.6 (40.9)	29.7 (36.1)	29.4 (33.1)	35.6 (43.2)

Table 4. Effect of intercropping *Solanum aethiopicum* with *Amaranthus lividus* on total *Amaranthus* DM yield over three seasons at MUARIK.

Treatment	Seasons			Mean
	2005a	2006a	2006b	
Pure stand *Amaranthus*	2561.6	1000.0	424.0	1328.0
25:75% replacement	2616.0	907.2	318.4	1280.0
33:67% replacement	2361.6	742.4	323.2	1142.4
50:50% replacement	2270.4	593.6	275.2	1046.4
50:50b% non replacement	1224.0	169.6	83.2	492.8
Double additive	3056.0	832.0	395.2	1427.2
Single additive	2232.0	473.6	272.0	992.0
75:25% replacement	945.6	262.4	75.2	427.2
Mean	2158.4	622.4	270.4	1017.6
$LSD_{(0.05)}$	543.8	354.6	176.2	305.6
CV	14.4	32.5	37.1	31.7

with a higher proportion of *S. aethiopicum* (or lower proportion of *Amaranthus*) produced more edible *S. aethiopicum* DM yield than the mixtures with a low proportion of *S. aethiopicum*. This is also confirmed by the other finding that, overall, the double additive mixture had 37% less edible DM yield of *S. aethiopicum* than the single additive mixture. The correlation between *S. aethiopicum* plant population and the edible DM yield of *S. aethiopicum* was strong (r = 0.71) ($P<0.05$) indicating the strong effect of plant density on the edible yield of the crop species in the respective mixtures. Plant population has long been recognized as one of the major factors that influences the performance of crop mixtures (Willey, 1979; Alofe and Ayotade, 1997).

Mixtures with a higher proportion of *S. aethiopicum*, such as the 75:25% *Solanum*:*Amaranthus* also had a significantly higher proportion of inedible *S. aethiopicum* than those with a lower proportion of *S. aethiopicum*, such as the 25:75% and 33:67% mixtures (Table 3). The correlation between plant population and inedible *S. aethiopicum* yield was positive though not very strong (0.58) ($P<0.05$). Usually, as plant density increases, the crop canopy expands more rapidly, more radiation is intercepted and more dry matter produced, especially during the early stages before the canopy closes. As density increases, the amount of dry matter in vegetative parts also increases (Yellamanda and Sankara, 1995).

Total amaranthus DM yield

Unlike *S. aethiopicum*, the total yield of *Amaranthus* was highest in the 2005 season and declined significantly in the subsequent seasons (Table 4). In general, in all the seasons the 75:25% *Solanum*: *Amaranthus* mixture and the 50:50%b non replacement series mixture which had a

Table 5. Effect of intercropping *Solanum aethiopicum* with *Amaranthus lividus* on the edible and inedible portion of *Amaranthus* over three seasons at MUARIK.

Treatments	Seasons			Mean
	2005b	2006a	2006b	
	kg ha $^{-1}$			
Pure *Amaranthus*	441.8 (2118.4)	387.4 (612.8)	191.8 (232.0)	340.3 (987.2)
25:75% replacement	462.4 (2153.6)	358.6 (548.8)	85.0 (233.6)	302.1 (977.6)
33:67% replacement	393.0 (1969.6)	296.8 (446.4)	79.8 (243.2)	256.5 (886.4)
50:50% replacement	363.4 (1907.2)	238.9 (355.2)	73.8 (201.6)	225.3 (820.8)
50:50b% non replacement	2468.8 (1009.6)	70.4 (99.2)	21.8 (60.8)	102.6 (390.4)
Double additive	587.4 (2468.8)	327.2 (504.0)	93.4 (302.4)	336.0 (1091.2)
Single additive	388.0 (1844.8)	195.0 (278.4)	67.8 (204.8)	217.0 (776.0)
75:25% replacement	151.8 (793.6)	100.2 (163.2)	26.1 (48.0)	92.6 (334.4)
Mean	375.4 (1782.4)	246.9 (376.0)	80.0 (190.9)	234.1 (784.4)
$LSD_{(0.05)}$	93.7 (466.6)	137.1 (225.0)	NS (72.1)	86.7 (238.7)
CV	14.3 (14.9)	31.7 (34.2)	95.4 (21.6)	39.0 (32.1)

*Figures in brackets are the *Amaranthus* inedible DM yield

lower proportion of *Amaranthus* gave significantly lower *Amaranthus* yield than the other treatments (P<0.05). Overall, the double additive intercrop had 30% more *Amaranthus* yield than the single additive intercrop further indicating a role of plant population in influencing total DM yield in the mixture. On average, the double additive intercrop, the 25:75% *Solanum*: *Amaranthus mixture* and the pure stand *Amaranthus* had similar total *Amaranthus* DM yield, and gave the higher *Amaranthus* yield than the other mixtures. On average, compared to the pure stand, intercropping reduced *Amaranthus* yield by 68% in the 75:25% *Solanum*: *Amaranthus* mixture and by only 4% in the 25:75% mixture, which has a significantly higher proportion of *Amaranthus*. Since the 75:25% *Solanum*: *Amaranthus* mixture gave the highest *S*. *aethiopicum* yield, the 'bonus' yield of *Amaranthus* from this mixture was an average of 427 kg ha^{-1}, which would be in addition to an average of 766.4 kg ha^{-1} of *S*. *aethiopicum* total DM yield from this mixture. In this *Solanum:Amaranthus* mixture, the bonus of *Amaranthus* yield is realized about 30 days after planting the mixture simultaneously, while the main *S*. *aethiopicum* crop may be harvested two weeks later depending on growing conditions. Some growing conditions, such as drought and the heat associated with it, could reduce the difference in maturity period as a result of accelerated maturity. In Mexico increasing air temperature by 1.7^{0}C accelerated crop development and in turn shortened the time to flowering of wheat by 11 days. This resulted in a reduction of total biomass and grain yield (Asieng et al., 2004).

Edible (leaves) and inedible (stem) *Amaranthus* DM yield

As with total *Amaranthus* yield, the edible yield of *Amaranthus* was significantly higher in pure stand, 25:75% mixture and double additive intercrop, but these mixtures did not differ significantly among themselves (P<0.05) (Table 5). Compared to the pure stand, the average reduction in edible *Amaranthus* DM yield due to intercropping was 73% for the 75:25% mixture compared to only 11% in the 25:75% *Solanum*: *Amaranthus* mixture with the highest proportion of *Amaranthus*. The double additive intercrop had 55% more edible DM yield than the single additive intercrop that has half its *Amaranthus* population. The correlation between plant population and edible *Amaranthus* yield was generally strong and positive (r = 0.97) (P<0.05). However, in other studies, excessively high seed rate reduced herbage yield of some *Amaranthus* species (Svirskis, 2003). On the basis of the edible portion of *Amaranthus*, an average bonus yield of 92.6 kg ha^{-1} was obtained from the 75:25% *Solanum*: *Amaranthus* replacement series mixture which gave an average of 452.5 kg ha^{-1} of the main *S*. *aethiopicum* crop yield. The inedible portion of *Amaranthus* was also significantly higher in the double additive intercrop, pure stand *Amaranthus* and the 25:75% *Solanum*: *Amaranthus* mixture (P<0.05).

Land equivalent ratio and gross returns

Partial LER for each species was highest in the mixtures in which it constituted a higher proportion, i.e., higher in the 75:25% *Solanum*:*Amaranthus* mixture in the case of *S*. *aethiopicum*. The double and single additive mixtures gave higher total LER (1.47 and 1.39, respectively) than the replacement series mixtures (Table 6). This suggests that *Amaranthus*, which matures earlier than *S*. *aethiopicum* made effective use of the space between the wide *S*. *aethiopicum* rows, earlier in the cropping season. The contribution of *Amaranthus* to total LER was greater

Table 6. Effect of intercropping *Solanum aethiopicm* with *Amaranthus lividus* on yield advantages measured in terms of total LER, at MUARIK (average of three seasons).

Treatments	Partial LER (average of 3 seasons)		Total LER
	Solanum aethiopicum	*Amaranthus lividus*	
25:75% replacement	0.17	0.94	1.12
33:67% replacement	0.23	0.80	1.03
50:50% replacement	0.60	0.76	1.36
50:50%b non-replacement	0.39	0.31	0.70
75:25% replacement	0.91	0.29	1.21
Double additive	0.40	1.07	1.47
Single additive	0.68	0.71	1.39
Mean	0.49	0.70	1.18

in the double additive intercrop than in the single additive intercrop indicating a possible role of plant population in influencing yield advantages from this mixture. Similarly, Ebwongu et al. (2001) reported that LER in the maize + potato mixture tended to increase with increase in maize population. In this intercropping system, it was the additive mixture, in which a maize row was imposed between potato rows rather than the replacement series treatments, which gave the highest yield advantage of 58% compared to less than 10% for the other mixtures. This advantage is attributed to the higher plant population density of both component species in the additive mixture (Ifenkwe et al., 1989; Ebwongu et al., 2001). The inherently higher plant population of the additive mixtures could enable them attain more efficient light interception because of better coverage of the land with the crop canopy, especially during the early growth period. Often, the high productivity of some intercrops is partly explained by an increase in accumulated light interception per unit of cultivated area (Zhang et al., 2008), and this could result from the high plant population in the additive intercrops. Sometimes, differences in growth patterns of the intercrops also improve light interception pattern, leaf area index and leaf area duration (Yellamanda and Sankara, 1995). The component crops in mixtures ought to be planted in such a way as to minimize competition for light and other resources, and manipulating spatial arrangement is one way of attaining this (Trenbath, 1976).

Usually, when intraspecific competition is greater than interspecific competition, it is more advantageous for mixed cropping because the plants of different species compete less with each other than plants of the same species (Beets, 1982). In the *Solanum:Amaranthus* mixture, only the 50:50%b non replacement series mixture failed to give a yield advantage, which could be due to failure to capture resources more efficiently than the pure stands rather than greater interspecific competition in this mixture. The failure of this 1:1 row arrangement (not replacement series) mixture to give a yield advantages could also be partly attributed to low plant population of *Amaranthus* in this mixture in which it was planted at half its theoretical population when compared to the pure stand spacing used for *Amaranthus*. The attained population of *Amaranthus* in the said treatment was 58,222 plants ha^{-1} compared to 163,111 plants ha^{-1} in the 50:50% replacement series mixture which gave a yield advantage.

In the present study, the partial LER for *Amaranthus* was more than expected in most mixtures suggesting that it utilized more sources than allocated to it, in terms of spatial arrangement, at planting time. However, it did not dominate *S. aethiopicum* in all the mixtures such as the 50:50% and 75:25% *Solanum:Amaranthus* replacement series mixtures. Perhaps, dominance over *S. aethiopicum* by *Amaranthus* during the early growth period was overcome by the time of *S. aethiopicum* maturity, which often occurs several weeks after *Amaranthus* harvest. In general, while early-maturity crops benefit from intercropping, late-maturing crops usually suffer growth penalties during the intercropping phase but recovery or compensation of the late-maturity crops can occur after the harvest of the early-maturing crops. For example, in a wheat + maize and wheat + soybean mixtures there was recovery of soybean and maize growth after wheat harvesting especially under good soil conditions (Long Li et al., 2001) . In the case of the *Solanum:Amaranthus* mixture, this area requires more specific study. On the other hand, in some mixtures, a high population of the earlier maturing crop species combined with a high population of the later maturing species gives high yield advantages or may even be a requirement for this to happen (Willey, 1979ab). However, supra-optimal but also sub- optimal plant population proportions could reduce or even negate the possibility of realizing yield advantages from some intercropping systems, such as the rice + cowpea intercropping system (Fischer et al., 2001) . It is also noteworthy that besides spatial arrangement, the population of each of the component species in the mixture has a marked effect on their yield and contribution to land equivalent ratio, hence yield advantage (Tariah and Wahua, 1985; Niringiye et al.,

Table 7. Gross returns from the *Solanum aethiopicum* + *Amaranthus lividus* mixture, based on the DM yield of the edible portion of each species*.

Treatments	Mean yield of the 3 seasons, kg ha^{-1}		Gross returns from each species (Shs)		Total Gross returns (Shs) from each mixture
	***S. aethiopicum*i**	***A. lividus***	***S. aethiopicum***	***A. lividus***	
Pure *S. aethiopicum*	450.88	-	2,012,728.3	-	2,012,728.3
Single additive	337.12	217.0	1,504,903.7	1,356,250	2,861,153.7
Double additive	211.04	336.0	942,082.6	2,100,000	3,042,082.6
75:25% replacement	452.48	92.6	2,019,870.7	578,750	2,598,620.7
50:50% replacement	322.08	225.3	1,437,809.8	1,408,125	2,845,934.8
50:50b% non replacement	188.96	102.6	843,517.4	641250	1,484,767.4
33:67% replacement	120.16	256.5	536,394.2	1,603,125	2,139,519.2
25:75% replacement	86.72	302.1	387,118.0	1,888,125	2,275,243.0
Pure *Amaranthus*	-	340.3	-	2,126,875	2,126,875

*A survey in a market near the experimental site in the third season indicated that on a dry weight basis, one kg of edible *S. aethiopicum* cost Shs. 4464 and that of *A. lividus* Shs6250. About Shs.1700 is equivalent to one US dollar.

2005).

Since most of the intercropping treatments of *Solanum:Amaranthus* mixtures in the present study gave yield advantages, intercropping the two species was generally beneficial. The reduction in the DM yield of either species in the mixtures was not strong enough to negate the advantage of intercropping the two species. The earlier maturity of *Amaranthus* gives early food and income to the farmers followed later by that from the main *S. aethiopicum* crop. Theoretically, a wide difference between the maturity periods of the intercrops would be expected to result in greater yield benefits from crop mixtures partly because the peak growth requirements may occur at different times (Willey, 1979a; Sssekabembe, 1986; Niringiye et al., 2005). Thus, Osiru (1974) attributed the 55% yield advantages from sorghum + beans mixture to differences in maturity periods of the two species. Combination of the early maturing millet genotype, 'engenyi', and the late maturity, taller 'namateera' sorghum genotype, resulted in up to 40% yield advantage (Ssekabembe, 1983, 1986). While a sole crop of a long-season crop like cassava does not efficiently use the available light, water and nutrients during its early growth stages due to its slow initial development, a short-duration legume intercrop may make more efficient use of these growth factors and even improve soil fertility through biological nitrogen fixation and the addition of crop residues (Ashokan et al., 1985). The greater the difference in maturity periods and growth factor demands of the component crops, either because of genetic differences or manipulation of planting dates, the more opportunity for greater total exploitation of growth factors and over-yielding (Willey, 1979b).

As indicated in Table 7, gross returns from the double and additive intercrop were higher than that from either pure stands. Banik (2006) also recommended wheat (*Triticum aestivum*) + chickpea (*Cicer arietinum*) additive intercropping mixtures for their higher net income besides more efficient utilization of resources and weed suppression. Most other *Solanum:Amaranthus* mixtures were also more profitable than the pure stands. However, since crop prices can fluctuate from season to season and year-to-year (Mead, 1986), more market study is needed to determine the effect of fluctuation in the price of either crops on the profitability of growing these two species in mixtures. Often, the possibility of maintaining a consistent income with relatively lower investment depends on the relative prices and cost of production of the component crops (Francis and Sanders, 1978). In the present study, the crops health did not warrant prophylactic protection with chemicals. Should pests attack *S. aethiopicum* severely, the profitability of growing this mixture could change remarkably. When attacked by pests, failure to spray *S. aethiopicum* in time can make the farmer lose 30 - 60% of the potential yield, which affects profits (African Agriculture, 2007) . For most small scale farmers, net income advantage appears to be secondary to risk reduction (Lynam et al., 1986). It is not yet clear which of the present two species is more prone to risks of weather and pests but differences in maturity periods makes likelihood of complete crop failure less likely.

Conclusion

The *Solanum aethiopicum* + *Amaranthus lividus* mixture that is commonly grown in central Uganda is advantageous, biologically and economically. The DM yield of each species was reduced significantly in the mixtures in which it constituted a low proportion, by up to 82% for *S. aethiopicum* in the 25:75% mixture and 68% for *Amaranthus* in the 75:25% *Solanum*:*Amaranthus* mixtures. However, yield advantages were obtained in almost all mixtures with the double additive intercrop giving the highest yield advantage of 47%, and this mixture was the most profitable. It is recommended that farmers can impose a relatively high plant population of *Amaranthus* into *S. aethiopicum* stands with biological and economic benefits. Among the replacement series mixtures, the 75:25% *Solanum:Amaranthus* mixture with a higher population of the more desirable species, was the best in terms of DM yield. In terms of total and edible DM yield, the 75:25% mixture did not reduce *S. aethiopicum* yield significantly, and the *Amaranthus* yield of 427 kg ha^{-1} total DM or 93 kg ha^{-1} edible DM yield constitutes a desirable 'bonus' yield. This bonus yield is equivalent to 32% of the total DM or 27% of the edible DM yield of the *Amaranthus* pure stand.

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