Tropentag, October 6-8, 2009, Hamburg
"Biophysical and Socio-economic Frame Conditions
for the Sustainable Management
of Natural Resources"

Yield and Nutritive Value of Maize-amaranth Mixtures for West African Dwarf Sheep

Olusola Olorunnisomo[1], Olufemi Julius Ayodele[2], Tolulope Ososanya[3]

[1] *University of Ibadan, Animal Science, Nigeria*
[2] *University of Ado-ekiti, Crop, Soil and Environment Sciences,*
[3] *University of Ibadan, Department of Animal Science, Nigeria*

Introduction

The high yield and high concentration of water-soluble carbohydrates in maize has made it the silage crop per excellence in both temperate and tropical regions (Phipps, 1996; Njoka *et al.*, 2005). Typically maize has a CP concentration of 80–90 g kg^{-1} DM (Carruthers *et al.*, 2000; Darby and Lauer, 2002). This makes it necessary to supplement ruminants fed this basal diet with oilseed cakes.

The amaranth plant is gaining attention as a forage crop. Previously its use as a grain or vegetable in human foods had been studied. Its potential as a forage for ruminants was reported by Sleugh *et al.* (2001). Although the yield is reported to be high (up to 9·5 t ha^{-1} DM; Svirskis, 2003), the main attraction of this crop as a livestock feed is its high concentration and quality of CP. The CP concentration of amaranth fodder is two to three times higher than that of maize, with values ranging from 150 to 240 g kg^{-1} DM (Kadoshnikov *et al.*, 2001; Pisarikova *et al.*, 2006). It is rich in lysine and sulphur-containing amino acids which are lower in cereal crops (Sleugh *et al.*, 2001; Svirskis, 2003). It is also suspected that this plant has a high proportion of rumen-undegradable protein (Cheeke and Bronson, 1980) which can be of great value in the nutrition of ruminants. The concentration and quality of CP of amaranth, and its growth habit, suggest that it can play a complementary role to maize in traditional crop-livestock systems in the south-west of Nigeria. The presence of anti-nutritional factors, such as oxalates, saponins, phenols, trypsin inhibitors and nitrates in some species of amaranth, however, poses a limitation on its usefulness as a livestock feed (Cheeke and Bronson, 1980; Gupta and Wagle, 1988; Pisarikova *et al.*, 2006). Heat treatment has been suggested as an effective means of reducing the effects of anti-nutritional factors in plants (Andrasofszky *et al.*, 1998). Pond and Lehmann (1989) showed that the inclusion of up to half of the diet as amaranth in growing lambs had no ill-effect on their productivity since the vegetative part apparently contained little toxic compounds. Anti-nutritional factors in amaranth seem to be associated with certain species and varieties of the plant, and management practices during cultivation. The raw seed also contain significant levels of anti-nutritional factors.

This study tested the hypothesis that intercropping amaranth with maize would increase yields of dry matter (DM), improve the efficiency of land use and the nutrition of ruminants fed a combination of these fodders in a crop-livestock system.

Materials and Methods

This study was conducted at the Teaching and Research Farm of the University of Ado-Ekiti (7°37′N, 5°13′E) which lies within the rainforest and experiences a tropical climate with distinct wet and dry seasons, high temperatures and high humidity. Mean annual rainfall is 1367 mm and is spread over 8 months (April–November). Mean annual temperature is 27°C and varies little throughout the year.

A landrace variety of maize (*Zea mays*) and grain amaranth (*Amaranthus cruentus*), cultivated for fodder production, were used in two experiments. Maize, amaranth or their mixtures were evaluated in the growing seasons of 2 years, 2006 (Experiment 1) and 2007 (Experiment 2). In both experiments, samples of soil in the top 15 cm were taken from experimental plots before the commencement of the study. Available nutrients were determined using standard chemical methods (SSSA, 1996). The soil at the experimental site was classified as Oxic Paleustalf by Fasina *et al.* (2005).

Experiment 1

In August–November 2006, the effects of fertilizer application and intercropping on yield and chemical composition of maize and amaranth forage, and efficiency of land use, were considered. The area of the experiment had previously been used for maize for several years without application of fertilizer. The area was ploughed, harrowed and divided into three blocks across the slope of the land. Each block was divided into six plots measuring 4 m × 6 m each. The study consisted of six treatments [three forages × two levels of fertilizer, that is; maize (M), amaranth (A) and intercropped maize–amaranth (MA)], with or without fertilizer application. Each treatment was replicated three times. A randomized complete block design in a factorial arrangement was used. Treatments were randomly assigned to plots within a block. Guard rows of maize (4 m wide) were planted around the experimental plots to deter rodents from accessing and damaging main plots and a row of unharvested maize was planted around each plot to avoid or minimize border effects. Intercropped plots consisted of a 50:50 mixture of maize and amaranth. Planting was on 25 August, immediately after the break in rainfall which lasted from late July to mid-August. Maize was seeded directly into the plots by hand at a spacing of 100 cm × 25 cm with two plants per stand while amaranth seeds were broadcast on a nursery bed on the same day, and transplanted into the plots 21 d later at a spacing of 50 cm × 25 cm (one plant per stand) such that on intercropped plots, the distance between a row of maize and amaranth was 25 and 50 cm between two rows of amaranth (i.e. intra-row spacing was 25 cm for both species while inter-row spacing was 100 cm for maize and 50 cm for amaranth). Plant population on plots containing maize or amaranth was

80 000 plants ha^{-1} while intercropped plots contained 160 000 plants ha^{-1}. Fertilized plots received a total of 91 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1} in a split application at 24 and 56 d after planting, using the band application method. The plots were weeded twice at 20 and 54 d after planting, using a hoe. Plants were harvested at the dough stage (85 d after planting) by cutting at 15 cm above ground using a large knife. At this stage, both maize and amaranth had reached an advanced stage of maturity and a similar height of 2·1 m, with amaranth seed rubbing off easily from the seed-head. Whole plants of maize and amaranth were harvested separately and weighed using a spring balance. Maize ears and amaranth seed-heads were separated from the stover and weighed. Total plot DM yield of ear/seed-head, stover and whole plants was determined for maize, amaranth and the intercropping mixture. Land-use efficiency under intercropping was measured using the land-equivalent ratio (LER).

This compares the advantage in yield from growing two or more species together in intercropping with yields from growing the same species in pure stands (Balasubramanian and Sekayange, 1991). The ratio (LER) was calculated as:

$$LER = (I_m/S_m) + (I_a/S_a),$$

where I_m = DM yield of maize in intercropping, S_m = DM yield of maize in a pure stand, I_a = DM yield of amaranth in intercropping and S_a = DM yield of amaranth in a pure stand.

Whole plants, harvested from the plots, were bulked for each treatment and chopped using a forage chopper. Samples of chopped fodder collected from each treatment were analysed for composition of proximate constituents and detergent fibre using AOAC (1995) methods.

Experiment 2

In July–October, 2007, an adjacent area, which had been used for several years for maize production without any fertilizer applications, was used. The proportion of maize:amaranth populations in the mixture was varied to give twelve treatments (six forages × two levels of fertilizer application). Treatments consist of: maize (M), amaranth (A), 50:50 maize:amaranth (MA50:50), 60:40 maize:amaranth (MA60:40), 70:30 maize: amaranth (MA70:30) and 80:20 maize:amaranth (MA80:20), with or without fertilizer application. Each treatment was replicated three times, giving a total of thirty-six plots. Plant populations were 80 000; 80 000; 160 000; 133 333; 114 286 and 100 000 plants ha^{-1} for the six forages: M, A, MA50:50, MA60:40, MA70:30 and MA80:20 respectively. The same levels of fertilizer were used as in Experiment 1. A randomized complete block design in a factorial arrangement was adopted. Maize and amaranth seeds were planted on 10 July (amaranth seedlings were transplanted into the plots 21 d later). The same management practices were applied as in Experiment 1 except that plots received supplementary water twice weekly (using watering cans) during the August break. Both maize and amaranth were harvested at 85 d after planting as in Experiment 1. Yield and LER were determined for each treatment.

Proximate constituents and detergent fibre of whole plants was determined using the methods described in AOAC (1995) for the with-fertilizer treatments only.

Experiment 3

In December 2007, the digestibility of conserved maize, amaranth and maize–amaranth fodders was estimated in a study using male West African dwarf (WAD) sheep. Whole plant maize and amaranth were harvested at the dough stage from an area cultivated specifically for fodder production. The forages were chopped to approximately 3-cm lengths using a forage chopper. Equal proportions (50:50) of chopped maize and amaranth were mixed (weight for weight) to form a mixed forage. Chopped maize, amaranth and the maize–amaranth mixture were then sun-dried or ensiled. Sun-dried forages were made by spreading the chopped fodders thinly on polythene sheets under the sun for 4 d. Sun-dried forages were stored in a barn until commencement of the digestibility study. Ensiled forages were made by packing and compressing wet and chopped forage into 120-L plastic drums manually. The compressed mass was then sealed with polythene and weighted with a 15-kg sand bag for 21 d. No additives were added to the silages.

Treatments were sun-dried maize (SDM); sun-dried maize–amaranth (SDMA); sun-dried amaranth (SDA); ensiled maize (EM); ensiled maize–amaranth (EMA); ensiled amaranth (EA). Eighteen matured WAD rams approximately 12 months old with a mean live weight (s.e. of mean) of 17·3 (2·70) kg were put in metabolic cages with facilities for feeding, watering and separate collection of faeces. The rams were divided into three groups according to their live weight and randomly assigned to one of the six diets. Experimental diets were offered *ad libitum* for 14 d. Feed offered, feed refused and faeces were weighed and recorded in the last 7 d. Feed intake and faecal output were determined. A representative sample of feeds and faeces were taken daily, dried at 65°C to a constant weight, milled and kept in air-tight containers for chemical analysis. Dry matter content and chemical composition of feed and faeces were determined using the methods described by AOAC (1995). Apparent digestibilities of the diets were calculated as the difference between nutrient intake and excretion in the faeces, expressed as a proportion of nutrient intake. The randomized complete block design was adopted for this experiment.

Statistical analyses

Data obtained in the experiments were subjected to analysis of variance and Duncan's multiple range tests using the procedures of SAS (1995).

Results and Discussion

Yield of dry matter

Table 1 shows that the soils were moderately acid with low total N and available P contents and a very low exchangeable K content based on existing soil test criteria

(ANON, 2006). The components of yield for maize, amaranth and the maize–amaranth intercropping plots in Experiments 1 and 2 are presented in Table 2 and show that the application of fertilizer increased the DM yield of maize two-fold, amaranth by about 1·2 and the intercrop by 1·6–1·9 in both experiments. In Experiment 2 the response in DM yield of intercropping mixtures generally increased with the higher proportion of maize in the mixture. These responses were expected since the limiting soil nutrients (N, P and K) were supplied by the fertilizer applied.

The effect of intercropping on DM yield was more pronounced when fertilizer was applied to the plots. With fertilizer application, DM yield varied significantly ($P < 0 \cdot 05$) among the various treatments in the two experiments. In Experiment 1, there were significant ($P < 0 \cdot 05$) differences in DM yield of maize (treatment M), amaranth (treatment A) and the maize–amaranth mixture (treatment MA) with maize having the highest yield, followed by the maize–amaranth mixture (proportionately 0·30 lower than maize) and amaranth (proportionately 0·19 lower than the mixture). This shows that intercropping had advantage only for amaranth and not for maize. In Experiment 2, a slightly different trend was observed. DM yield of maize was significantly higher than that of amaranth but there was no significant difference in DM yield between maize and the various intercropping mixtures. The highest DM yield in Experiment 2 was recorded for the 70:30 maize–amaranth mixture while the lowest DM yield was recorded for amaranth.

There was no significant difference in DM yield of maize, amaranth or intercropping mixtures when no fertilizer was applied to the plots in either experiment. Given the higher response in DM yield of maize to fertilizer application than that of amaranth and, since DM yields of maize and amaranth were similar when soil fertility status was low, amaranth or maize–amaranth mixtures may be the preferred crop when soil fertility is a limiting factor to DM yield. Hence, in parts of Nigeria where reduced fallow periods, poor soil fertility and the high cost of fertilizer has led to low DM yields, use of amaranth, with its high CP concentration, would serve to augment livestock production in crop-livestock systems. Although DM yield of maize was generally higher than amaranth or maize–amaranth mixtures, CP yield ha^{-1} (Table 2) was higher in amaranth or maize–amaranth mixtures, especially when no fertilizer was applied. This further suggests that amaranth can play a complementary role to maize when soil fertility is adequate or can replace maize when soil fertility is low.

Land use efficiency

Land equivalent ratios for maize–amaranth mixtures are given in Table 3 for Experiments 1 and 2. In Experiments 1 and 2, LER values without fertilizer were <1·0 which shows that there is little or no advantage in land use efficiency from the maize–amaranth combinations. The results show that intercropping either reduced or maintained land use efficiency under conditions of poor soil fertility due to competition among component species for limited soil nutrients.

In Experiment 1, with application of fertilizer, LER values were higher than 1·0 for stover and whole plants. In Experiment 2, LER values of fertilized whole plants in intercropping mixtures were higher than 1·0 due to the significantly lower DM yields of amaranth than those of maize or mixtures such that intercropping had an advantage. In Experiments 1 and 2 intercropping decreased components of DM yield of fertilized maize but DM yield of amaranth was little affected, suggesting that amaranth is a better competitor than maize (Manga *et al.*, 2003). In fertilized plots, LER values show that land use efficiency under intercropping was either equal to or slightly higher than land use efficiency of maize or amaranth. However, total DM yields from intercropping were lower or similar to maize but consistently higher than amaranth. This shows that land use efficiency under intercropping increased only in relation to amaranth and not in relation to maize.

Chemical composition of whole plants

Chemical composition of whole plants of maize (treatment M), amaranth (treatment A) and in intercropped maize–amaranth (MA) plots for Experiments 1 and 2 are presented in Table 4. In Experiment 1, the chemical composition of whole plants was determined for fertilized and unfertilized plots. In Experiment 2, chemical composition was determined only for the fertilized plots.

Dry matter content of whole plants varied from 223·0–349·0 to 203·0–305·0 g kg^{-1} in Experiments 1 and 2 respectively. In both experiments, DM content of whole plants declined with increasing proportion of amaranth in the mixture with maize having the highest DM content and amaranth the lowest. Crude protein concentration of whole plants varied from 98·5 to 227·6 g kg^{-1} DM. In Experiment 1, whole plants of amaranth had the highest CP concentration, followed by the maize–amaranth mixture with maize having the lowest values. A similar trend was obtained in Experiment 2 where CP concentrations increased with increasing proportion of amaranth in the mixture. Neutral-detergent fibre (NDF) concentration varied from 348·6 to 525·2 g kg^{-1} DM and acid-detergent fibre (ADF) concentration from 201·5 to 312·3 g kg^{-1} DM. Maize had the highest NDF and ADF concentrations, maize–amaranth mixtures were intermediate and amaranth had the lowest concentrations.

Application of fertilizer increased the CP concentration of all the forages but had little effect on NDF and ADF concentrations.

Digestibility of conserved forages

The chemical composition of the diets used in the digestibility study in Experiment 3 is presented in Table 5. Dry matter content of sun-dried fodders did not vary with values ranging from 874·0 to 888·0 g kg^{-1} while ensiled forages varied from 216·0 to 308·0 g kg^{-1}. This was due to the wide difference observed in the DM content of whole plant of maize and amaranth. Crude protein concentrations of the conserved forage ranged from 92·5 to 224·0 g kg^{-1} DM with sun-dried forages having higher values than ensiled forages. For sun-dried forages, CP concentration increased with inclusion of amaranth in the diet. Ensiled maize, amaranth and maize–amaranth forage had similar CP concentrations. Due to the high moisture content in ensiled amaranth and maize–amaranth mixtures, liquid was observed to collect at the base of the silo. Much of the CP in amaranth may have been leached during the ensiling process, leading to a reduction in CP concentration of ensiled amaranth and maize–amaranth mixtures. Increasing the DM content of amaranth by wilting or mixing with dry feedstuffs prior to ensiling might reduce this occurrence in ensiled amaranth. Maize had higher NDF and ADF concentrations than amaranth while the mixtures were intermediate.

Apparent digestibility values of sun-dried or ensiled maize, amaranth or maize–amaranth mixture are shown in Table 6. There were significant differences ($P < 0{\cdot}05$) between maize and amaranth fodders in DM digestibility. In spite of the higher CP concentration in amaranth, maize had a higher CP digestibility than amaranth or the mixtures. Presence of anti-nutritional factors in amaranth seed-heads might be responsible for the lower CP digestibility values observed in amaranth and maize–amaranth mixtures. Anti-nutritional compounds, such as oxalates, saponins, phenols, trypsin inhibitors and nitrates, have been reported in some species of amaranth (Cheeke and Bronson, 1980; Gupta and Wagle, 1988; Pisarikova *et al.*, 2006). The specific effects of these compounds on the nutritive value of amaranth for ruminants need further investigation. Although heat treatment has been suggested as an effective means of reducing the effects of anti-nutritional factors in plants (Andrasofszky *et al.*, 1998), the high cost of this treatment makes it impractical for processing large quantities of ruminant diets. Digestibility values of CP, NDF and ADF followed the same general trend as DM digestibility showing that the WAD sheep digested conserved maize forages to a greater extent than amaranth or maize–amaranth forages. Dry matter digestibility of ensiled maize forage was slightly higher than that of sun-dried maize. The reverse was the case for ensiled amaranth and ensiled maize–amaranth forages with their sun-dried counterparts having slightly higher digestibility values. Loss of CP in ensiled amaranth during the ensiling process might have contributed to the lower CP digestibility observed for ensiled amaranth and maize–amaranth compared to their sun-dried counterparts. There were no significant differences in NDF and ADF digestibility of sun-dried or ensiled forages.

Conclusions

Results from this study show that the application of fertilizer increased DM yields and CP concentration of maize, amaranth and their intercropping mixtures. Although intercropping of maize and amaranth increased DM yield and land use efficiency when compared with amaranth, it had no yield advantage over maize. The CP concentration of total forage increased when maize was intercropped with amaranth but this did not translate into increased digestibility values for sheep fed mixtures of maize and amaranth forages. Since amaranth increased CP yield ha^{-1} and gave a reasonable yield in unfertilized plots, it offers potential in complementing maize as a dry-season forage for ruminants in the south-west of Nigeria. In spite of the lower DM yield of amaranth, CP and digestible CP yields from amaranth and maize–amaranth mixtures ha^{-1} exceeded those of maize. In view of the relatively high cost of CP-rich concentrates, this benefit may outweigh the lower digestibility of amaranth and maize–amaranth mixtures compared to maize. In order to derive maximum benefits from amaranth as a ruminant feed, there is need to further investigate the presence of anti-nutritional factors in the plant and to provide practical methods for reducing their potential effects on nutritive value.

References

ANDRASOFSZKY E., SZOCZ Z., FEKETE S. and JELENITS K. (1998) Evaluation of the nutritional value of the amaranth plant. I. Raw and heat-treated grain tested in experiments on growing rats. Acta Veterinaria Hungarica, 46, 47–59.

ANON (2006) Nigeria fertilizer strategy report. Proceedings of Africa Fertilizer Summit, International Conference Centre, Abuja, Nigeria 9–13 June 2006, 44pp. Abuja, Nigeria: Federal Ministry of Agriculture.

AOAC (1995) Official methods of analysis, 16th edn. Washington, DC, USA: Association of Official Analytical Chemists.

BALASUBRAMANIAN V. and SEKAYANGE L. (1991) Area harvests equivalency ratio for measuring efficiency in multi-season intercropping. IITA Research, 1, 16–19.

CARRUTHERS K., PRITHIVIRAJ B., FE Q., CLOUTIER D., MARTIN R.C. and MAIZEITH D.L. (2000) Intercropping of corn with soybean\lupin forages: silage yield and quality. Journal of Agronomy and Crop Science, 185, 177–185.

CHEEKE P.R. and BRONSON J. (1980) Feeding trials with Amaranthus grain, forage and leaf protein concentrations. In: Proceedings of 2nd Amaranth Conference, Rodale Research Center, Kutztown, PA, USA 13-14 September 1979, pp. 5–11. Emmaus, PA, USA: Rodale Press.

DARBY H.M. and LAUER J.G. (2002) Harvest date and hybrid influence on corn forage yield, quality and preservation. Agronomy Journal, 94, 559–566.

FASINA A.S., ARULEBA J.O., OMOLAYO F.O., OMOTOSO S.O., SHITTU O.S. and OKUSAMI T.A. (2005) Properties and classification of five soils formed on granitic parental material in Ado-Ekiti, Southwestern Nigeria. Nigerian Journal of Soil Science, 15, 21–29.

GUPTA K. and WAGLE D.S. (1988) Nutritional and antinutritional factors of green leafy vegetables. Journal of Agriculture and Food Chemistry, 36, 474.

KADOSHNIKOV S.I., MARTIROSIAN D.M., KADOSHNIKOVA I.G. and CHERNOV I.A. (2001) A study on the silage use of plain and combined amaranth in ontogenesis. The Official Newsletter of the Amaranth Institute No 14. Columbia, MO, USA: Amaranth Institute.

MANGA A.A., BALA M.G. and ASHAFA L.W. (2003) Evaluation of maize (Zea mays) and grain amaranth (Amaranthus cruentus) intercrops. Nigerian Journal of Horticultural Science, 8, 7–10.

NJOKA E.M., MURAYA M.M. and OKUMU M. (2005) Plant density and thinning regime effect on maize (Zea mays) grain and fodder yield. Australian Journal of Experimental Agriculture, 44, 1215–1219.

PHIPPS R.H. (1996) A crop from over there that's doing rather well over here: forage maize in the diet of the lactating dairy cow. Journal of the Royal Agricultural Society of England, 157, 103–115.

PISARIKOVA B., ZRALY Z., KRACMAR S., TRCKOVA M. and HERZIG I. (2006) The use of amaranth (Genus Amaranthus L.) in the diets for broiler chickens. Veterinarni Medicina, 51, 399–407.

POND W.G. and LEHMANN J.W. (1989) Nutritive value of a vegetable amaranth cultivar for growing lambs. Journal of Animal Science, 67, 3036.

SAS (1995) SAS/STAT User's Guide. Version 6, 4th edn, Volumes 1 and 2. Cary, NC, USA: SAS Institute Inc.

SLEUGH B.B., MOORE K.J., BRUMMER E.C., KNAPP A.D., RUSSELL J. and GIBSON L. (2001) Forage nutritive value of various amaranth species at different harvest dates. Crop Science, 41, 466–472.

SSSA (1996) Methods of soil analysis, Part 3 - chemical methods. Madison, WI, USA: Soil Science Society of America.

SVIRSKIS A. (2003) Investigation of amaranth cultivation and utilization in Lithuania. Agronomy Research, 1, 253–264.