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Abstract A two year field investigation was carried out during 2003-2004 to determine the effectiveness of intercropping single and double rows of sorghum, soybean and sesame in a cotton crop on the suppression of purple nutsedge (Cyperus rotundus L.). Results revealed that all three intercropped crops were effective in inhibiting purple nutsedge density (70-96%) and dry matter production (71-97%) during both years of experimentation. Control in the second year was more effective than in the first year. The seed cotton yield was also depressed by the intercrops but its suppression (8-23%) was far less severe than that of purple nutsedge and its loss was compensated by greater total economic returns. Intercropping of sorghum and sesame produced greater than 20% net benefits (up to 60%) in comparison with the control (cotton alone). Soybean intercropping produced comparable net benefits (95-103%). Sesame two rows intercrop treatment appeared the most profitable with net benefit of 51-59% with good purple nutsedge control (73-92 density suppression, 77-95% dry weight suppression) during both years of experimentation.

Intercropping of field crops in cotton for the management of purple nutsedge (*Cyperus rotundus* L.)

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Abstract. A two year field investigation was carried out during 2003-2004 to determine the effectiveness of intercropping single and double rows of sorghum, soybean and sesame in a cotton crop on the suppression of purple nutsedge (*Cyperus rotundus* L.). Results revealed that all three intercropped crops were effective in inhibiting purple nutsedge density (70-96%) and dry matter production (71-97%) during both years of experimentation. Control in the second year was more effective than in the first year. The seed cotton yield was also depressed by the intercrops but its suppression (8-23%) was far less severe than that of purple nutsedge and its loss was compensated by greater total economic returns. Intercropping of sorghum and sesame produced greater than 20% net benefits (up to 60%) in comparison with the control (cotton alone). Soybean intercropping produced comparable net benefits (95-103%). Sesame two rows intercrop treatment appeared the most profitable with net benefit of 51-59% with good purple nutsedge control (73-92 density suppression, 77-95% dry weight suppression) during both years of experimentation.

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Introduction

Purple nutsedge (*Cyperus rotundus* L.) has been described as the world's worst weed (Rao 2000) It is highly competitive especially under high soil nitrogen conditions (Morales-Payan et al. 1998; Santos et al. 1998). In Pakistan, it is among the most common weeds found throughout the Indus valley during the summer season in major field crops such as cotton, sugarcane and maize. Bryson et al. (2003) reported that purple nutsedge causes seed cotton yield reductions of 62-85%. It is difficult to control purple nutsedge effectively through usual weed control methods because of its specific biological characteristics, ie. having different means of propagation (seeds rhizomes, tubers) with varying degree of dormancy (Charles, 1997). Weed control methods such as manual or mechanical means only kill the top growth of purple nutsedge plants with little effect on tubers. Glyphosate is the most widely used herbicide for the control of purple nutsedge although, under certain conditions, glyphosate application in cotton may lead to fruit shedding and yield reduction (Viator et al., 2004). There is no selective post emergence herbicide available in Pakistan to control purple nutsedge in cotton crops. Moreover, the cost of using herbicides to control weeds is increasing and is rapidly becoming beyond farmers' affordability. The use of chemicals for weed control is under community challenge due to concerns with human and environmental health (Duke et al., 2001). Therefore, alternatives for safe, cheap and effective control of purple nutsedge in cotton crops are urgently required in Pakistan.

Individual crops have been shown to inhibit certain weeds through allelopathic mechanisms. These include sorghum (Weston and Duke 2003), rice (Seal et al., 2004), and wheat

(Huang et al., 2003). Recently Iqbal and Cheema (2007) reported effective control of purple nutsedge through the utilization of natural plant extracts from various allelopathic crops (sorghum, sunflower and brassica) in the field. Their results showed that 12 and 15Lha^{-1} crop water extracts, mixed with reduced rate of glyphosate, decreased purple nutsedge density by 59 to 99% and dry weight by 66 to 99%. Glyphosate application rate was reduced by up to 67%. Singh et al. (2003) suggested that utilizing companion plants, that are selectively allelopathic to weeds but do not appreciably interfere with crop growth, may provide a cost effective alternative to the use of synthetic chemicals for the management of weeds, thereby contributing to a more sustainable agriculture. Such companion plants can be effectively incorporated into an intercropping system.

Intercropping is a common practice among farmers of the developing countries for maximizing land resources and reducing risks of a single crop failure. Its advantages of improved crop yields and better soil conservation have been well demonstrated over thousand of years. Yield advantages from intercropping are often attributed to better weed control (Narwal 2004), mutual complementary effects of component crops and better utilization of farm resources (Legard and Steel 1992). The weed control advantage of intercrops over sole crops have attributed to strong competitiveness in usurping resources from weeds or suppressing weed growth through allelopathy (Liebman and Dyck 1993). Recent studies have suggested intercropping as an option for integrated weed management (Rana and Pal 1999; Schoofs and Entz 2000).

In Pakistan different cotton based intercropping systems have been reported to increase farm income by 30-40% (Saeed et al. 1999), but the magnitude of such agro-economic advantages heavily depends upon the type of intercrops chosen (Rao 1991). Choice of intercrops plays a vital role in the successful implementation of a cotton intercropping system and in increasing productivity, leading ultimately to improved economic returns. Therefore, for those purposes, the present studies were designed to determine the economic viability and purple nutsedge suppressing effectiveness of intercropping field crops of sorghum, soybean, and sesame in irrigated cotton in the semiarid central region of Pakistan.

Materials and methods

General procedures

Field experiments for suppression of purple nutsedge (*Gossypium hirsutum* L.) were conducted during 2003 and 2004 under intercropping systems involving sorghum (*Sorghum bicolor* L.), soybean (*Glycine max* L.) and sesame (*Sesamum indicum* L.) in cotton (*Gossypium hirsutum* L.) at the Agronomic Research Area, University of Agriculture, Faisalabad, Punjab, Pakistan, (31.25°N, 73.09°E, 184.8m altitude). The soil belongs to the Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in the FAO classification scheme). The experiment was laid out as a randomized complete block design with four replications in plots measuring 7m×3m. Field history showed heavy infestation of purple nutsedge. Cotton (*Gossypium hirsutum* L., cv FH901) was sown by single row hand drill in 75 cm spaced rows on a moist seedbed. Between the cotton rows, single and double rows of sorghum, soybean and sesame were planted in May of each year. Two hand hoeings were given at 20 and 50 DAS to the standard treatment and a weedy check (control), ie. cotton alone without any other treatments, was maintained for comparisons. Fertilizer was applied at 115kg N and 57kg P_2O_5 ha^{-1} in the form of urea and triple super phosphate, respectively. One third nitrogen and all phosphorus were applied at sowing while the remaining nitrogen was applied in two splits, at first irrigation and at boll formation stage. In addition to soaking irrigation, five (2003) and seven (2004) irrigations were given with 15-21 days interval and there was also 52.6mm (2003) and 23.9mm (2004) rainfall recorded during the growth period. Cotton insect pests were controlled by spraying appropriate insecticides.

Data on purple nutsedge density and biomass were measured and recorded 15, 45 and 75 days after sowing (DAS) from two randomly selected quadrats (50cm×50 cm) of each experimental plot. Purple nutsedge dry weight was recorded after drying in an oven at 80°C for 48 h. Data on cotton plant height (cm), sympodial branches per plant, number of bolls per plant, boll weight (g), seed index, seed cotton yield (kg ha^{-1}), and yields of intercrops were recorded for each plot using standard sampling procedures. Statistical software package" MSTAT C" was used to analyze all data (Anon. 1986). Least significance difference (LSD) test was applied at 5% level of significance to compare treatment means.

Economic Analysis

Analysis of economic returns was accomplished by following the procedure of Byerlee (1988). Variable costs (ha^{-1}) of purchased inputs, labor, and machinery were determined by the market prices. Net benefits were calculated by subtracting the total variable cost from the gross benefits for each treatment.

Results

Effect of intercropping on the growth of Purple nutsedge (Cyperus rotundus L.)

All intercropping systems and treatments significantly and effectively inhibited purple nutsedge population and dry matter production relative to the control treatment, which was comparable to hand hoeing (Table 1). Suppression ranged for weed density from 70 to 96% and for dry weight from 65 to 97%. As the growth of purple nutsedge plants progressed, the degree of inhibition increased. At 15 DAS the inhibition was between 31 and 46% with the exception of double row soybean. By 75 DAS the inhibition had increased to 70%-86% (2003) and 90-96% (2004). A similar trend but with less difference was evident for dry matter production. There was no significant difference in suppression of purple nutsedge between the three intercropped species, nor between single or two row treatments.

Continuous practice of intercropping resulted in more effective control of purple nutsedge. In the second year of the field experiments, ie. 2004, the suppression on purple nutsedge, measured both in density and dry weight, was greater than in the first year in all treatments of the three intercrops, the range of difference being 8% to 30%. In 2003, the suppression of purple nutsedge density was greater than 70% across all treatments and up to 86% with double row treatments of sorghum and soybean. For drymatter production, suppression was 65% and up to 88% with double row sorghum. In 2004 the suppression on purple nutsedge density was increased, being greater than 90% across all treatments. Greater than 94% suppression was achieved on dry matter production. In contrast the suppression achieved by hand hoeing was reduced by up to 10% in the second year although it was still significant and effective.

There was a significant difference, particularly in the second year, in the suppression of purple nutsedge between the intercropping systems and the hand hoeing treatments. All intercropping systems achieved similar suppression on purple nutsedge as hand hoeing but such suppression by the intercropping treatments significantly surpassed that by hand hoeing control in the second year, being 9% to 15% more effective on density control, and 8% to 12% more effective on dry matter production.

Effect of intercropping on seed cotton yield and components

All intercropping systems had a negative impact on seed cotton yield and its components (Table 2). Seed cotton yield was significantly reduced, ranging from 8% to 23%. Double row sesame caused the biggest reduction of 23%, while single row soybean the least of 8%. However, there was no significant difference in yield reduction and its components between years. Negative impacts differed among cotton yield components. The most significant reduction was on the number of bolls, between 15 to 30%. The negative effects on plant height and sympodial branches were below 20%. For seed index there was no effect. There were no significant differences among single or two row treatments on negative impacts. However, single row sorghum and single row soybean treatments showed consistently less negative impact across all parameters measured. The reduction in yield and its components by single row sesame was equivalent to that by double row soybean. Double row sesame produced the biggest reduction across all the parameters measured and single row soybean the least. In contrast, the hand weeding treatment had positive impacts on yield components and significantly increased the seed cotton yield.

Economic analysis

All intercropping systems produced significantly higher or comparable net returns (Tables 3 & 4). Sorghum and sesame systems (single or double rows) yielded the highest returns, particularly with the two row treatments up nearly 60% in comparison with the weedy control. Due to its low production and market variability, soybean treatments produced lower but still quite comparable net returns relative to the weedy control, ie. 88-104% of the weedy control, particularly with the single row treatment (101-104% of the weedy control). There was a year to year variation in net returns. The sorghum system produced the highest net return in the first year, ranging from 39 to 56% for single and two row treatments over the weedy control. Such high returns were halved in the second year but were still more than 20%. The high net returns produced by the sesame system were stable across two years, ranging from 19 to 59% (single or double rows) over the weedy control, being slightly higher in the second year with the two row treatment and lower with the single row treatment. The two row soybean in the second year was the only treatment that returned a significant negative return. The hand weed control produced consistent returns of 26% higher than the weedy control across two years.

Discussion

All three chosen intercrops effectively controlled purple nutsedge (*Cyperus rotundus* L.) population and dry matter production in the cotton crops. The suppression was greater than 70% of control, and in some cases largely eradicated purple nutsedge (up to 97% of control), which was comparable with that achieved by non-selective synthesised herbicides and hand weeding. The suppression in the second year was more effective than the hand weeding.

Such effective suppression of purple nutsedge may be attributed to several reasons. Crop allelopathy may play an important role in intercropping systems as it could affect the germination and growth of neighboring plants. Roots are the site of greatest activity within the soil matrix during crop growth (Bertin et al. 2003) and crop plants have the capability to produce and exude allelochemicals into their surroundings to suppress the growth of weeds in their vicinity (Huang 2003). The allelopathic potential of sorghum, soybean, and sesame has been well documented (Weston and Duke 2003, Chon 2003; Limei et al. 2000; Neeser and Varshney 2001). Comprehensive work by Weston has strongly established allelopathy of sorghum in the field, glasshouse, and controlled laboratory experiments and has identified allelochemicals responsible for observed sorghum allelopathy, detailed allelochemical-secreting mechanisms and identified the genes controlling allelochemical (ie. sorgoleone) secretion (Weston et al. 1989, Weston et al. 2002, Weston and Duke 2003, Czarnota et al. 2003, Weston 2005). In soybean, rhizospheric soil compounds, mainly organic acids, acetone, aldehyde, naphthalene phenyl and furan hydrocarbon have been identified and many of these have been reported as allelochemicals (Limei et al. 2000) affecting the germination of different weed seeds (Rose et al. 1983; Chon 2003). Allelopathic effects of sesame (*Sesamum indicum*) on purple nutsedge have also been reported (Neeser and Varshney 2001). It is possible that allelopathy of these three chosen intercrops might have contributed to the greater suppression of purple nutsedge in cotton crops. This may also partially explain why comparatively less purple nutsedge density was observed during 2004 than 2003 in all the intercropping treatments, probably due to the residual allelopathy from those crops carried over from the previous year, ie. 2003 (Narwal 2004).

Although the field was fertilized adequately the resource depletion effect can not be ruled out. In addition to their allelopathic effects, these three intercrops might have stronger competitiveness, when intercropped with cotton crops, against purple nutsedge. Liebman and Dyck (1993) indicated that intercrops may demonstrate a weed control advantage over sole crops as intercrops may be more effective in usurping resources from weeds. Many researchers (Moody 1978; Zuofa et al. 1992; Olasantan et al. 1994) also have indicated that mixtures could serve as a complementary biological method to suppress weeds by better utilizing resources. It might also be possible that both competition and allelopathy are contributing to the suppression of purple nutsedge through intercrops. It has been reported that increasing density of crop plants can increase crop competitiveness and effectively control growth of weeds by reducing their biomass and seed production (Lemerle et al., 2004). Recently An et al. (2007) proposed the concept of 'allelochemically-enhanced competition' as a mechanism for such observed suppression of weed growth. They postulated that allelopathy and competition may not be two independant processes as commonly perceived. Thus increased competitiveness of crop plants may be a result of the effects of allelochemicals released from those plants. The suppression of purple nutsedge by intercropping systems might also have been due to such a mechanism.

While purple nutsedge growth was effectively controlled by all intercropping systems, cotton crops benefited from less competition due to purple nutsedge but also encountered the decline of seed cotton yield due to competition from the intercrop. However, the negative impact on seed cotton yield was far less, only 8-23%, while suppression of weeds growth was greater, 70- 97%. Less negative impact could be attributed to some compatibility of cotton with the intercrops, eg.

addition of nitrogen through fixation, in the case of soybean, and perhaps to allelopathy on the weed.

Relative density of crop and weed may also be a factor. In the field, the density of cotton plants was generally higher than that of purple nutsedge. Weidenhamer et al. (1989) found that the nature of phytotoxic interactions was density-dependent, phytotoxicity on the target plant decreasing as the density of the target plant increased. They termed this phenomenon the 'diluting effect'. Thereby, the possible allelopathic impacts on the cotton crop by intercrops might have been diluted by a higher density of cotton plants leading to a less negative impact on cotton yield decline. To maximise the benefits of weed suppression by intercropping systems it is important to implement other means such as choosing high competitive cotton cultivars, more compatible and selective intercrop species or cultivars and perhaps increasing plant density of cotton plants,

Intercropping of field crops in cotton was not only an effective option for integrated weed management, but also produced greater immediate short-term economic returns for farmers. Slight cotton yield decline under intercropping systems was largely compensated for by immediate higher economic net returns. In Pakistan different cotton based intercropping systems have been reported to increase farm income by 30-40% (Saeed et al. 1999). In our study the net return increase in the first year was greater than 50% with sorghum and sesame intercropping systems (double row), far higher than that of the hand weeding option. The intercropping system with two row sesame consistently produced greater than 50% increased net returns during two year study. Such immediate greater economic returns resulted from the combined benefits of reduced weed control cost and additional intercrop returns.

Intercropping brings other benefits such as reduced risks of single crop failure, diversified farm incomes, increased soil organic carbon content and reduced herbicides input This study showed that intercropping of field crops in cotton could be implemented as an effective option for an integrated management of purple nutsedge.

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References

Abdel Malik K K I, Abdel Quader A E M and El- Razaz M M 1991 Studies on the effect of intercropping maize in cotton fields. *Assiut. J. Agric. Sci.,* 22:337- 349.

An, M., Liu, Y.H. and Pratley, J. 2007. Allelochemically-Enhanced-Competition: concept, modelling and ecological significance. EcoSummit2007-Ecological Complexity and Sustainablity:Challenges and Opportunities for 21st-Century's Ecology, May 22-27, 2007, Beijing, China, pp. 15.

Anonymous 1986 MSTATC. Microcomputer Statistical Programme. Michigan State University, Michigan, Lansing, USA.

Bertin C, Yang X and Weston L A 2003 The role of root exudates and allelochemicals in the rhizosphere. *Plant Soil.* 256: 67-83.

Bryson C T, Reddy K N and Molin W T 2003 Purple nutsedge (*Cyperus rotundus*) population dynamics in narrow row transgenic cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) rotation. *Weed Technol.* 17: 805-810.

Byerlee D 1988 From agronomic data to farmers recommendations. Academic Training Manual CIMMYT. Mexico, D. F. p. 31-33.

Charles, G 1997 Controlling nutsedge in cotton. *CRS-News letter for the Research,Extension, Education Program* **3**.

Chon S 2003 An assessment of allelopathic potential of Korean black soybean plant parts. *Korean J. Crop Sci.* 48: 345-350.

Czarnota MA, Paul RN, Weston LA, Duke SO 2003 Anatomy of sorgoleone-secreting root hairs of Sorghum species. *International Journal of Plant Sciences* 164: 861-866.

Duke, S.O., Scheffler, B.E., Dayan, F.E., Weston, L.A. and Ota, E 2001 Strategies for using transgenes to produce allelopathic crops. *Weed Technology* 15: 826-834.

Gomaa M A 1991 Inter and intraspecific competition among cotton and soybean plants. *Ann. Agric. Sci.*, Moshtohor, 29:757-768.

Gomaa M A and Randwan 1991 The effect of intercropping cotton plant with soybean on yield and yield components of soybean plant. *Ann. Agric. Sci.* Moshtohor, 29:745-756.

Huang, Z., Haig, T, Wu, H., An, M, and Pratley, J 2003 Correlation between phytotoxicity on annual ryegrass (*Lolium rigidum*) and production dynamics of allelochemicals within root exudates of an allelopathic wheat. *Journal of Chemical Ecology*, 29, 2263-2279.

Iqbal, J and Cheema, Z A 2007 Effect of allelopathic crops water extracts on glyphosate dose for weed control in cotton (*Gossypium hirsutum*). *Allelopathy Journal,* 19: 403-410.

Khan M B 2000 Bio-economic efficiency of different cotton-based inter/relay cropping systems. Ph.D Dissertation, Deptt. Of Agronomy University of Agriculture, Faisalabad, Pakistan.

Kobayashi K 2004 Factors affecting phytotoxic activity of allelochemicals in soil. *Weed Biol. Manag.* 4: 1-7.

Liebman M and Dyck E 1993 Crop rotation and intercropping strategies for weed management. *Ecolog. Applic.* 3: 92-122.

Legard S F and Steel K W 1992 Nitrogen fixation in legumes/ grasses pastures. Biological N fixation for sustainable agriculture, pp: 137-53. Kluwer Academic publishers,The Netherlands.

Limei H, Fei Y, Shuqi W, Huiyan J, Zhenming Y and Jichang Y 2000 Primary identification of organic compounds in soybean rhizopheric soil on continuous and alternate cropping and their allelopathy on soybean seed germination. *Yingyong-Shengtai-Xuebao.* 11: 582-586.

Mahmood A 2003 Utilization of allelopathic properties of sorghum for controlling purple nutsedge (*Cyperus rotundus* L.) in maize. Ph.D. Dissertation, University of Agriculture, Faisalabad, Pakistan.

Mohammad M K, El-din G M S, Hosny A A 1991 Evaluating three patterns of intercropping cotton and forage cowpeas. *Ann. Agric. Sci. Mashtohor*, 9:1269-84.

Moody K 1978 Weed control in intercropping in tropical asia. Paper presented at the international weed science conference, 3-7 July 1978, IRRI, Los Banos, Philippines.

Morales-Payan J P, Santos B M, Stall W M and Bewick T A 1998 Interference of purple nutsedge (*Cyperus rotundus*) population densities on bell pepper (*Capsicum annuum*) yield as influenced by nitrogen. *Weed Technol.* 12, 230-234.

Narwal S S 2004 Allelopathy in crop production. Scientific publishers. Jodhpur, India.

Narwal S S and Sarmah M K 1996 Effect of wheat residues and forage crops on the germination and growth of weeds. *Allelopathy J.,* 3:229-240.

Neeser C and Varshney J G 2001 Purple nutsedge: biology and principles for management with out herbicides. *Ind. J. Pulses Res.* 14: 10-19.

Olasantan F O, Lucas E O and Ezumah H C 1994 Effects of intercropping and fertilizer application on weed control and performance of cassava and maize. *Field Crop Res.* 39:63-69.

Rana K S and Pal M 1999 Effect of intercropping systems and weed control on crop weed competition and grain yield of pigeonpea. *Crop Res.* 17:179-182.

Rao V P 1991 A study on intercropping of cotton with grain legumes under rainfed conditions. *J. Res. APAU.* 19: 73-4.

Rao V S 2000 Principles of weed science. 2nd . ed. Pp. 72.

Rice E L 1984 Allelopathy. Academic press, Orlando, FL.

Rose S J, Burnside O C, Specht J E, Williams J H and Swisher B A 1983 Competition and allelopathy of soybean (*Glycine max* L. Merr.) cultivars to weeds. (Bibliographic citation) Absts. Meeting of the weed Sci. Soc. Am. 7.

Saeed M, Shahid M R M, Jabbar A, Ullah E and Khan M B 1999 Agro-economic measurement of different cotton based inter-relay cropping system in two geometrical patterns. *Int. J. Agric. Biol.* 4:234-7.

Santos B M, Morales-Payan J P, Stall W M and Bewick T A 1998 Influence of purple nutsedge (*Cyperus rotundus*) density and nitrogen rate on radish (Raphanus sativus) yield. *Weed Sci.* 46, 661-664.

Seal, A. N., Pratley, J. E., Haig, T. and An, M. 2004 Identification and quantitation of compounds in a series of allelopathic and non-allelopathic rice root exudates. *Journal of Chemical Ecology*, 30: 1629-1644.

Schoofs A, Entz M H 2000 Influence of annual forages on weed dynamics in a cropping system. *Can. J. Plant Sci.* 80: 187-198.

Singh H P, Batish D R and Kohli R K 2003 Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. *Crit. Rev. Plant Sci.* 22:239-311.

Viator, R.P., Jost, P.H., Senseman, S.A. and Cothren, J.T 2004 Effect of glyphosate application timings and methods on glyphosate-resistant cotton. *Weed Science* **52**: 147-151.

Weidenhamer JD, Hartnett DC, Romeo JT 1989 Density-dependent phytotoxicity: Distinguishing resource competition and allelopathic interference in plants. *J Appl Ecol* 26: 613-624.

Weston L A, Harmon R and Mueller S 1989 Allelopathic potential of sorghum-sudangrass hybrid (sudex). *Journal of Chemical Ecology* 15: 1855-1865.

Weston L A 2001 Allelochemicals: Managing plant competition. 98th Ann. Int. Conf. of American Society for Hort. Sci., Sacramento, California, USA, July 21-25.

Weston L A, Yang X and Scheffler B E 2002 Gene regulation by bioactive root exudates produced by *Sorghum* spp. *Third World Congress Allelopathy Abstracts* 76.

Weston L A and Duke S O 2003 Weed and crop allelopathy. *Crit. Rev. Plant Sci.* 22: 367-389.

Weston L A 2005 History and current trends in the use of allelopathy for weed management. *Horttechnology* 15: 529-534

Zuofa K, Tariah N M and Isirimah M O 1992 Effects of groundnut, cowpea and melon on weed control and yields of intercropped cassava and maize. *Field Crop Res.* 28:309-314.