ProNIVA II

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Effect of Variety Mixtures on Cowpea Vegetable Leaf and Seed Yields in a Traditional Cowpea/Maize Intercropping System in the Semi-Arid Tropics of Uganda

Promotion of Neglected Indigenous Leafy and Legume Vegetable Crops for Nutritional Health in Eastern and Southern Africa
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Effect of variety mixtures on cowpea vegetable leaf and seed yields in a traditional cowpea/maize intercropping system in the semi-arid tropics of Uganda

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Dedication

To Joyce Nankumbi and Timothy Kisakye Okonya

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List of Abbreviations

Abbreviation	Description
%	Percent
°C	degree Celsius
°E	degree East
°N	degree North
µg	Microgram
ANOVA	Analysis of Variance
asl.	above sea level
AVRDC-RCA	The World Vegetable Center's Regional Center for Africa, Tanzania
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung, Germany
cm	Centimeter
DAP	Days After Planting
DM	Dry Matter
g	Gram
GLM	General Linear Model
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit, Germany
ha	Hectare
IBPGR	International Board for Plant Genetic Resources (now Bioversity International, Italy)
IITA	International Institute of Tropical Agriculture, Nigeria
ILRI	International Livestock Research Institute, Kenya and Ethiopia
kg	Kilogram
km	Kilometer
l	Liter
m	Meter
mg	Milligram
ml	Milliliter
mm	Millimeter
M.Sc.	Master of Science
NaSARRI	National Semi-Arid Resources Research Institute, Uganda
NIRS	Near Infrared Reflectance Spectroscopy
PLABSTAT	PLAnned Block experiments and their STATistical analysis
ppm	parts per million
ProNIVA	Promotion of Neglected Indigenous Leafy and Legume Vegetable Crops for Nutritional Health in Eastern and Southern Africa
R	correlation coefficient
SARI	Selian Agricultural Research Institute, Tanzania
t	Tonne
USA	United States of America
USDA	United States Development Agency, USA
WHO	World Health Organisation, Switzerland

Abstract

Cowpea is considered to be one of the top four leafy vegetables in Uganda grown for both its seed and leaves. Vegetable leaves are more popular than seed in the Eastern and Northern parts of the country and are a source of protein and micronutrients for the resource-poor subsistence farmers. Cowpea is usually grown in intercrop with maize, sorghum, cassava or mung bean but sole cropping is also practiced by several farmers. Most farmers in Soroti and Kumi districts continue to grow landraces ('Ecirikukwai' and 'Ebelat') because no improved varieties have been successfully bred/promoted. Erratic rainfall, low soil fertility and insect pests are among the most important constraints to cowpea production in Uganda leading to low seed yields (200-400 kg/ha) while leaf yield levels had never been assessed. Agronomic strategies to optimise both leaf and seed yields like through the use of variety mixtures are long over due.

Variety mixtures containing up to four cowpea varieties were grown in intercrop with maize during the first cropping season of 2008 at NaSARRI, Serere, Kikota village and Kogili village in Eastern Uganda. The results of these three experiments indicated that: accumulated dry matter leaf yield from 3-4 harvests and seed yield ranged from 34.7 to 70.9 kg/ha and 33.4 to 551.2 kg/ha, respectively. There was no significant difference between accumulated leaf yield of mixtures and the means of their respective component varieties. Though not significant, mixtures had both positive (4.3 to 111.4%) and negative (3 to 72.5%) effects on seed yield. Seed and leaf yield did not always increase with increasing number of component varieties in a mixture. The leaf-harvesting strategy employed by farmers enhanced seed yield in some but not all the treatments. Seed yield components like pod number, seeds/pod and 100-seed weight were not significantly affected by leaf-harvesting. On average, leaf yield was more stable in plots with mixtures than those with single cowpea varieties. Levels of leaf protein and iron ranged from 27.9 to 34.8% and 164.1 to 796.3 µg/g, respectively. Cowpea leaves were ranked first by farmers from the region among the top four leafy vegetables of spider-flower, amaranth and white cabbage.

Key words: *Vigna unguiculata*, African leafy vegetables, agrobiodiversity, defoliation, nutritional quality, Soroti and Kumi districts.

1. Background

1.1 State of micronutrient deficiency (hidden hunger) in Uganda

Hidden hunger is a lack of essential vitamins and minerals in the diet, which are vital to boost immunity and healthy development. Vitamin A, zinc, iron and iodine deficiencies are primary public health concerns in Uganda. Lack of sufficient iron and vitamins in the diets of women hinders growth and cognitive development of infants and children, leads to low birth weights and, usually, increases the probability of disability and death among women of childbearing age (WHO, 2009). On top of having 37% of the children below the age of five being stunted (short for their age), and 12% of the women being undernourished/thin, a large part of the population suffers from micronutrient deficiency (hidden hunger). About 73% of the children, 49% of women and 28% of the men are anaemic. Nineteen percent of the women tested during this demographic and health survey were found to be vitamin A deficient (UBOS and Macro International Inc., 2007).

1.2 Role of traditional leafy vegetables in reducing hidden hunger

Although there are many causes of anaemia and vitamin A deficiency, adequate consumption of traditional green leafy vegetables like cowpea (*Vigna unguiculata* (L.) Walp.) leaves, which are rich not only in protein but also mineral elements, offers a chance to reduce this prevalence. The incidence of anaemia and vitamin A deficiency is also higher both in children and women in rural areas as compared to their counterparts in urban areas (52% and 35%, respectively) (UBOS and Macro International Inc., 2007). Starchy staples constitute the main part of human diet of cereals like sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L. ssp. *mays*), rice *(Oryza sativa* L.), millet (*Eleusine coracana* (L.) Gaertn.), and tubers like cassava (*Manihot esculenta* Crantz), potato (*Solanum tuberosum* L.), and sweet potato (*Ipomoea batatas* (L.) Lam.) crops. The tradition of eating indigenous leafy vegetables daily as an accompaniment (side dish) or as sauce (main dish) underscores the need for research on traditional leafy vegetable crops if maximum benefits are to be realized (Bittenbender et al., 1984). The consumption of leafy vegetables like cowpea, African spider-flower (*Cleome gynandra* (L.) Briq.), Amaranth (*Amaranthus* spp.) or okra (*Abelmoschus esculentus* (L.) Moench), by both low-income and high-

income groups as health foods points to the possibility of exploiting this dietary diversification approach to reduce the prevalence of malnutrition (Keding et al., 2007).

In an effort to conserve, promote utilization and improve the use of traditional leafy vegetables in East and Southern Africa, The World Vegetable Center's Regional Center for Africa (AVRDC-RCA) together with Georg-August University Goettingen started the project "Promotion of Neglected Indigenous Leafy and Legume Vegetable Crops for Nutritional Health in Eastern and Southern Africa-ProNIVA" in 2003 that has led to a selection of promising cowpea and lablab (*Lablab pupureus* (L.) Sweet) accessions based on yield, nutritional quality and farmer and consumer acceptance, evaluated in different agro-ecological zones of Tanzania (Angessa, 2006).

1.3 Importance of traditional leafy vegetables

The most important traditional vegetables in Uganda include cowpea, Amaranth, common bean (*Phaseolus vulgaris* L.) (Bittenbender et al., 1984; Isubikalu et al., 1999), African egg plant (*Solanum ethiopicum*), pumpkin (*Curcubita* spp.) and okra (*Corchorus* spp.) among others (Rubaihayo, 1997). Traditional leafy vegetables have a high nutritional value because they are rich in proteins, vitamins A, B and C, as well as minerals like iron and calcium, making them an indispensable tool when it comes to reducing the prevalence of malnutrition, especially among resource-constrained rural and urban households. In addition, cowpea leaves are also appreciated by both rural and urban dwellers and could increase cash incomes of especially women who grow them both for home consumption and for sale in local markets (Isubikalu et al., 1999; Weinberger and Msuya, 2004). A shade-tolerant crop like cowpea allows for efficient use of the limited land resource for cultivation of food crops like cassava or maize, hence, spreading the risk in case one crop fails. Despite their contribution to household food security and poverty eradication, traditional vegetables have been left out (neglected) in many research and development programs of both international and national research institutions (Rubaihayo, 1997; Weinberger and Msuya, 2004; Angessa, 2006), something which is rather unfortunate.

1.4 Utilization of cowpea leaves in Uganda

Unlike in the United States and West Africa where cowpea is grown exclusively for its seeds, young leaves are a staple in more than 18 countries in Africa and seven countries in Asia and the Pacific (Nielsen et al., 1997). Among the top leafy vegetables consumed in many parts of Sub-Saharan Africa, cowpea leaves rank third or fourth in terms of quantity consumed (Bittenbender et al., 1984). In Uganda, cowpea leaves are more popular than seeds especially in the Eastern and Northern regions and to less extent in the central region where they are traditionally part of a daily meal (Bittenbender et al., 1984). Young and tender trifoliate leaves of cowpea are eaten as a vegetable when boiled with sesame (*Sesamum indicum* L.) or peanut (*Arachis hypogaea* L.) pastes, often mixed with other leafy vegetables like okra, to give a thick sauce. They are also eaten when boiled alone, fried alone or with other vegetables like tomatoes (*Solanum lycopersicum* L.) and onions (*Allium cepa* L.). The average daily consumption of leafy vegetables per person in Uganda during the rainy season ranges from about 12 g in urban areas to 160 g in rural areas indicating that, though widely consumed in most parts of Uganda, not enough quantity is eaten to meet the nutritional requirements of the body (Rubaihayo, 1997). Besides quantity, preparation and processing methods like sun-drying prior to cooking, addition of crude sodium carbonate salt in the cooking water and long cooking time reduce the amount of available nutrients like vitamin C in these leafy vegetables (Imungi and Potter, 1983; Keding et al., 2007).

1.5 Nutritional quality of cowpea leaves

Protein content of leaves from five IITA cowpea cultivars grown in a green house was found to vary depending on the cultivar and the stage of harvest (Nielsen et al., 1994). Nielsen et al. (1997) reported that leaves contained higher amounts of protein than seeds and that leaf protein was superior to seed protein in terms of amino acid composition. Solar drying was noted to increase the content of glutamic acid, valine and aspartatic acid, however, it decreased the amount of histidine and lysine. If compared to seeds, cooked cowpea leaves have been reported to contain at least several hundred times the β-carotene and ascorbic acid, seven times the calcium, three times the iron, two thirds the protein and half the phosphorus of the cooked seed

(Bittenbender et al., 1984; Barrett, 1990; Bubenheim et al., 1990). Minerals like calcium and iron in cowpea leaves are not bound to phytic acid (the storage form of phosphorous) and are more bioavailable as compared to those in seeds (Bittenbender et al., 1984). Since leaves are produced earlier and in bigger quantities than the seeds, the protein output from the leaves is said to be 15 times that of cowpea seeds.

Weinberger and Msuya (2004) recorded contents of up to 18.7 mg of iron, 0.547 mg of zinc, and 4.45 mg of beta carotene per 100 g of edible portion of freeze-dried raw cowpea leaves in the three districts of Kongwa, Singida and Arumeru, Tanzania. In a number of on-farm and on-station experiments conducted in Malawi and Tanzania, Malidadi (2006), Angessa (2006) and Kabululu (2008) recognized that protein content of both cowpea seed and leaves varied from one harvest to another, was dependent on the environment in which the crops were grown and the cultivar of cowpea in question. Of the 13 varieties evaluated in Malawi, leaf protein content (dry weight basis) varied from 35.0 to 43.1%, while seed protein content varied from 21.9 to 26.3% (Malidadi, 2006). Angessa (2006) realized between 29.4 and 33.1% in leaf and 25.0 and 26.3% in seed for the 23 accessions he evaluated in Tanzania, while Kabululu (2008) reported 25.0 to 34.4% in leaf samples of the five varieties evaluated in Dodoma, Tanzania. When Towett (2008) analysed 561 samples of young cowpea leaves collected from different regions of Tanzania and Uganda for nutritional quality, he recorded values ranging from 21.5 – 40.3% for crude protein content, 140.5 – 3994.7 μg/g for iron concentration and 4.1 – 30.5 mg/100 g for β-carotene content. The 561 cowpea leaf samples that were analysed belonged to 10 accessions and about 10 landraces.

1.6 Leaf and seed yield levels of cowpea in East Africa

Crop yield in a given environment can be explained in terms of the resources available in that environment to support growth and yield together with the biotic and abiotic stresses that affect the attainment of the potential contained in the resources (Bidinger et al., 1996). Cowpea leaf production has received little attention in programs of most research institutions in Uganda and no literature on leaf yield could be found, as previously mentioned. However, factors like frequency of leaf harvesting, amount of leaf harvested, number of leaf harvests made, timing of leaf

removal, cultivar under investigation and the environment are bound to influence leaf yield levels even among plants of the same growth type (Barrett, 1990). Total leaf dry matter yields after four harvests ranging from 16.8 to 29.2 g/plant have been realized in Tanzania under sole cropping (Angessa, 2006), while under a 1:1 cowpea/maize relay intercropping system in Tanzania, Kabululu (2008) reported 5.1 to 5.6 g/plant after five harvests. Using soilless culture in a green house experiment, Bubenheim et al. (1990) attained leaf yields of 33.8 g/plant from two harvests in a combined vegetable leaf and seed harvest strategy where two or four recently formed trifoliate leaves were removed at 25 and 40 days after germination.

Similarly, seed yield is also determined by a number of factors, which include cultivar, plant spacing, growth period, growth habits, cropping system, fertilizer application or insecticide application (Ntare et al., 1993; Singh et al., 2003; Ajeigbe et al., 2006). Seed yield of sole cropped cowpea was found to vary across three environments in Tanzania from 12 g/plant in accession TZA2322 to 58 g/plant in cultivars TumainiR and VuliR (Angessa, 2006). About 90% of cowpea production in Uganda is in the Northern and Eastern districts where it is an important food and cash crop especially in Soroti, Kumi and Pallisa districts (Sabiti et al., 1994). Seed yield in these districts averages between 150 and 400 kg/ha and pests, drought, inadequate labor and low yielding potential of the landraces are some of the major constraints to cowpea seed production. Adipala (2003) attained yields ranging from 324 to 828 kg/ha for the landrace 'Ebelat' and 402 to 750 kg/ha for the landrace 'Icirikukwai' on farmers' fields in different sub-counties of Kumi and Pallisa districts. The majority of farmers in eastern Uganda grow landraces, namely 'Ebelat' and 'Icirikukwai' usually in intercrop with maize, cassava, mung bean (*Vigna radiata* (L.) R. Wilczek) or sorghum. Although quite adapted to the environment, these landraces are low-yielding with regard to seeds, have long maturity periods, and are susceptible to pests and diseases. Farmers, however, continue to grow these two landraces because of their adaptability to leaf-harvesting and tasty leaves on the one hand, but also no improved varieties are available (Isubikaru et al., 1999; Karungi et al., 2000; Nampala et al., 2002).

1.7 Effect of defoliation on seed yield of cowpea

Seed yield cannot be adversely affected if leaf harvest is done within limits but, this depends on a number of factors like cultivar differences (spreading, semi-spreading, erect or semi-erect), growth period (early-maturing, medium-maturing or long-duration), leaf-harvesting initiation time, magnitude and frequency of leaf harvest (Nielsen et al., 1997). After four leaf harvests, seed yield of sole cropped cowpea was on average reduced by 60% at Mwanga and 78% at Arusha, Tanzania. Seed yield of leaf-harvested plants varied from 4.5 to 10.2 g/plant while that of non leaf-harvested plants was between 20.7 and 25.6 g/plant (Angessa, 2006). In a green house experiment carried out using two dual-purpose cowpea landraces from Kenya, Saidi et al. (2007) reported that cultivars responded differently to leaf harvesting, that is, one cultivar (Kathoka) yielded more vegetable leaves than seed, while another cultivar (Ex-Luanda) that gave higher seed yields, produced fewer consumable leaves. This difference in leaf and seed yields was attributed to higher number of leaves on the plants, which offered a higher photosynthetic surface leading to higher seed yields as a result of better carbon reserve accumulation at low leaf harvest frequencies. Nielsen et al. (1994) observed a decrease of 2 g/plant in seed weights of plants whose leaves had been harvested once, while Stewart et al. (1978) found no effect on seed weight but rather seed yields, which were reduced by 60% when 50% of the young leaves had been removed.

Pandey (1983) and Bubenheim et al. (1990) observed that partial defoliation of cowpea during early reproductive stages (post flowering) severely reduced pod and seed yields but not seed weight or size. This reduction in seed yield may have been due to reduced nitrogen from leaves for seed formation, reduced symbiotic nitrogen fixation due to low amounts of photosynthetic material reaching nodules or little assimilate production for pod development. Bubenheim et al. (1990) further noted that leaf production in two cowpea cultivars (Bainkey-21 and IT 84E-124) was stimulated by periodic partial defoliation to a tune of 68%. Seed yields of leafy indeterminate types were less affected by defoliation than those of determinate types (Bittenbender et al., 1984).

Karikari and Molatakgosi (1999) defoliated four cowpea varieties in Botswana and they observed that low to moderate rates of leaf-harvesting increased pod length, number of pods, number of seeds per pod, thousand-seed-weight and seed yield in the two indeterminate varieties, but high rates of defoliation decreased seed yield for determinate (d) and indeterminate (i) varieties alike. At high rates of defoliation (75%), seed yield was reduced by 32%, 36%, 60% and 21% for Tswana (i), Black-eye (i), ER7 (d) and TVX3236 (d) respectively. Similarly, Rahman et al. (2008) showed that cowpea seed yield was highly dependent on the intensity and stage of defoliation. Defoliation during the vegetative stage reduced seed yields of variety IAR 48 in the two years when the field trial was conducted. However, seed yields increased with 50% defoliation at flowering stage.

Consequently, the level by which seed yield is affected by defoliation cannot be deduced by taking in consideration a single factor but rather a complex interaction of factors like genotype, age of leaves harvested, intensity and frequency of leaf-harvest, cropping system among others.

1.8 Genotype-by-environment interaction and/ or stability

The yield of crop varieties is under the control of many genes. The contribution of these genes is complicated by the interaction between the varieties under consideration and the environment in which they are grown. Yield stability is, therefore, a measure of consistency or reliability of performance of crop varieties across environments (Ceccarelli, 1994; Padi, 2004). Ceccarelli (1994) argues that for subsistence farmers to be able to benefit from the advances of plant breeding when genotype-by-environment interaction is large, selection/testing of breeding line/cultivars needs to be done under environmental conditions and agronomic practices usually practiced by farmers. This will help to identify genotypes with specific adaptation to unfavourable environments where crop yields are commonly low due to abiotic and biotic stresses. This will help to adapt the cultivars to their environment rather than modifying the environment to fit new cultivars, which can only express their superiority at high levels of inputs.

Many models have been used to assess stability and/or genotype-by-environment interaction and they include the following: (i) Composite, which considers the interaction as a single, composite source with its (G - 1)(E - 1) df and is most often used if the analysis stops with the additive ANOVA model; (ii) Regression of yields of each genotype on the environment means by partitioning the interaction into (G - 1) df for genotype regressions and the residual (G - 1)(E - 2) df for deviations from regression (Finlay and Wilkinson, 1963, cited by Gauch, 1988); (iii) Biplot or AMMI (additive main effects and multiplicative interaction) model, which applies principal component analysis (PCA) to the interaction (Bradu and Gabriel, 1978; Gauch, 1985, cited by Gauch, 1988), and (iv) Single-df contrasts for cases where one or several genotypes and environments behave differently from others. And data of either the genotypes, environments or both may be grouped for simplicity (Byth et al., 1976, cited by Gauch, 1988).

When Blade et al. (1992) evaluated seed yield stability of nine breeding cowpea lincs in 13 experiments under sole and intercrop management schemes in Nigeria using Finlay and Wilkinson (1963) regression analysis, it was observed that breeding lines greatly differed in their response to environments. Line 1 was the most stable with a regression coefficient of 0.59, although its performance was below average in both low- and high-yielding environments. Line 5 on the other hand, had a regression coefficient of 1.64 and, therefore, least stable but it out-yielded other lines in all except in the poorest environment. The management regime, that is, insecticide application, rainfall and cropping system significantly influenced cowpea seed yields. For instance, the traditional system of planting cereals prior to legumes limited the ability of cowpea lines to express their seed yield potential. Seed yields of 200 kg/ha were achieved in a maize-cowpea intercrop, but the lines yielded significantly more under sole-cropping, and seed yields were also strongly depressed in plots where no insecticides were applied. Cowpea seed yield variation was greater when no insecticides were applied. Yield of cowpea and millet intercrop was more stable than sole crops under rain-fed conditions in Ghana, although seed yield was higher in sole crops (Dapaah et al., 2003).

Using MSTAT-C statistical program STABIL (Michigan State University, version 1.41) to calculate phenotypic stability (b-value) for the 28 cowpea genotypes, based

on regression analysis as described by Finlay and Wilkinson (1963), Padi (2004) observed that traits which predict cowpea seed yield varied among environments depending on the nature and intensity of stress factors. Tolerance to pests or effective pest control improved the ability of 28 cowpea genotypes to express their yield potential as compared to susceptible genotypes. Genotypes with high yielding potential always had a lower b-value and, hence, phenotypically unstable. For instance, the most stable genotype (SARC-104) had a b-value of 0.33 and yielded 771 kg/ha of seeds, while the least stable genotype (1T87D-885) had a b-value of 1.79 and yielded 1629 kg/ha of seed.

Angessa (2006) used the ecovalence value according to Wricke (1926, cited by Hill et al., 1998) to measure stability of both vegetable leaf and seed yields of 23 cowpea accessions grown in three different environments in Tanzania. He reported that the most stable (ecovalence value of 79.2) accession (ILRI11114) always had the lowest fresh leaf yields (122.7 g/plant) while ILRI19334 had the most unstable (ecovalence value of 2469.7) yields. The ecovalence value of the total dry matter leaf yields per plant, however, ranged from 0.6 (yield of 19.9 g/plant) in accession TZA2463 to 71.0 (yield of 25.5 g/plant) in accession ILRI19334. For seed yield, the ecovalence value ranged from 2.1 (yield of 23.1 g/plant) in accession Vuli2 to 539.1 (yield of 35.1 g/plant) in accession Vuli1.

1.9 Advantages of crop mixtures (intercropping)

Dependence on a few plant genotypes in modern agriculture often leads to vulnerability to both biotic and abiotic stresses. Monoculture can be looked at from various levels like, species, variety or disease resistance (Wolfe, 1985). Intercropping is the growing of two or more crop species in such a way that they interact agronomically/biologically. The four most common types of intercropping are: (i) row-intercropping where one or more crops are planted in rows; (ii) strip-intercropping where crops are planted in strips wide enough for independent cultivation but narrow enough for interaction; (iii) mixed-intercropping where there is no distinct row arrangement; and (iv) relay-cropping where two or more crops are simultaneously planted but harvested at different times.

Edema et al. (1997) investigated the influence of season and cropping system on the occurrence of cowpea diseases in Uganda. They observed that the disease incidence and severity was lower when cowpea was grown in mixed stands with other crops like mung bean, sorghum, maize, cassava and pigeon pea (*Cajanus cajan* (L.) Millsp.), than as a sole crop. This highlights the importance of increased diversity for sustainable cowpea production. In crop mixtures with cereals like sorghum, sesame or maize, the legume cowpea has been noted to increase cereal seed yields, possibly due to increased soil fertility through nitrogen fixation, shade tolerance, and reduced soil erosion and/or pressure from pests and diseases (Edema et al., 1997; Nampala et al., 2002). In species mixtures, one host species may provide refuge for the predators of the pest, which usually occurs on the second host species, and this usually results in the reduction of a pest population (Wolfe, 1985).When the performance of sole cowpea was compared to that in intercrop with early-maturing maize in three trials in western Kenya, Ehlers (1994) observed that seed yield losses of intercropped cowpea were significantly less (47%) than those of sole-cropped cowpea (62%) in the presence of pest pressure from flower thrips and pod-sucking bugs. This highlighted the possibility of pest population reduction by intercropping.

1.10 What is a variety mixture?

A variety mixture is a composite population made up of a mixture of different varieties; it may exhibit considerable phenotypic variation in one or more characters like disease resistance, and growth habits, but have sufficient similarity to be grown together (Browning and Frey, 1981; Wolfe, 1985). The term 'variety mixture' is often used interchangeably with 'variety blends' to mean mixtures of seeds of two or more individual varieties (Bowden et al., 2001). A 'multiline mixture,' however, is a combination of seeds of several resistant lines that differ only in the resistance genes they carry (Browning and Frey, 1981; Wolfe, 1985). Depending on the intended use and agronomic characteristics, mixtures need to have similar traits like seed type, height and maturity. This, however, is not always the case as phenotypically dissimilar mixtures exist in Africa for example, in red and white-seeded sorghum (Castro, 2001). The term variety mixture will be used in this thesis.

1.11 Mechanisms by which variety mixtures suppress disease, stabilize and increase yield

1.11.1 Complementation

Since the yield of varieties depends a great deal on the presence or absence of biotic or abiotic stress in a given environment, combining varieties with complementary strengths like drought tolerance or disease resistance can reduce the yield fluctuations of any particular variety (Bowden et al., 2001). Mixtures with morphologically heterogeneous growth habits or canopy cover can better exploit their niches like light interception, which will increase the overall yield (Newton et al., 1997)

1.11.2 Compensation effect

Unlike when varieties are grown singly, compensation for a weak or damaged component by a high-yielding variety in a mixture through the production of heavier seeds, more tillers or bigger heads in case of wheat (*Triticum aestivum* L.), for instance, is possible. The whole can be attained even if various components vary in their contribution in different environments. Compensation is more likely among varieties with different genetic backgrounds than closely related genotypes (Wolfe, 1985).

1.11.3 Disease restriction

The spread of a disease may be controlled in mixtures for specialized pathogens provided the components differ in their susceptibility. Secondly, if component varieties are susceptible to different races of the same pathogen, each race will be restricted by its non-host, hence, controlling the disease. Wolfe (1985) further highlighted that mixtures control the spread of a pathogen in three ways: (i) by decreasing the spatial density of susceptible plants to avoid fast growth of inoculum; (ii) by providing a barrier of resistant plants around susceptible plants; and (iii) by developing induced resistance caused by non-pathogenic spores.

1.12 Yield advantage, yield stability and disease control of variety mixtures: Experimental evidence

In a number of investigations, mixtures have yielded no less than the mean of their components or the worst component. Wolfe (1985) pointed out that, due to the improbability of farmers to predict the best-yielding variety prior to planting, they choose to take advantage of the stability that comes with using variety mixtures. This is particularly the case, if farmers lack the means to minimize environmental variation through management practices like irrigation, pesticide and fertilizer use. Because of the high heterogeneity of environments in which crops are grown, getting a steady yielding variety across environments remains a challenge to breeders. The term 'environment' in this case refers to both locations and/or year-to-year variation.

Variety mixtures have been used in crop production to increase and, especially, stabilize yields in highly unstable environments. In a trial involving all possible 3-way variety mixtures of five early-maturing oat (*Avena sativa* L.) cultivars at four locations in Iowa, Helland and Holland (2001) found that mean variety mixture yields and volume weights were, on average, higher in variety mixtures than in individual varieties. In addition, these variety mixtures had a smaller genotype-by-environment interaction implying that they were more stable and, according to Lin and Binn's (1988, cited by Helland and Holland, 2001) adaptability parameter, they were more adapted for consistent and higher yields across environments than individual varieties.

Seven cultivars of winter barley (*Hordeum vulgare* L.) expressing a range of resistance levels to scald (*Rhynchosporium secalis* (Oudem.) Davis) were grown in all possible 2-way, 3-way, 4-way, 5-way and 6-way component combinations at several locations in Poland. Newton et al. (1997) reported from these trials that *R. secalis* infection reduced with increasing number of components in the mixture. Yield response showed a similar trend in infected plots when mixtures alone increased yield by 7% during 1995/6. In mixtures involving two susceptible and two moderately resistant barley varieties, the development of scald and net blotch (*Pyrenophora teres* Drechs.) infections was reduced by 12% compared to pure stands. Yield in mixed

plots, however, was not any better than that of pure stands over three field seasons (Mundt et al., 1994).

When Bowden et al. (2001) tested 3-way hard red winter wheat variety mixtures in four location-year experiments with 100 comparisons, the variability in yields expressed as the standard deviation, was less for mixtures than for individual varieties, and mixtures had a yield advantage of 57 kg/ha. Variety mixtures that had high-yielding components out-yielded those with mediocre yields and, in environments where stress occurred late or did not affect the plant size, compensation was of little effect. In a review of variety mixtures, Lenné and Smithson (1994) pointed out that the yield advantage of mixtures over their components reached 49.7% in wheat. Using combining ability analysis, the mixing ability of five club wheat cultivars for disease (rust) severity and for yield was investigated by Knott and Mundt (1990). Five wheat cultivars were grown in all possible 2-way, 3-way, 4-way and 5-way mixtures. It was observed that certain mixtures did better than predicted based on their average performance. In two field experiments in North Carolina, USA, involving 13 mixtures each consisting of two or three cultivars of eight soft red wheat at moderate disease pressure, Cowger and Weisz (2008) recognized that mixtures significantly out-yielded the means of their components across the two environments with a mean overall mixture advantage of 130 kg/ha. The yield stability of the mixtures was also higher than that of the pure cultivars as assessed by principal component analysis and the stability variance.

After careful review of literature, the study by Kabululu (2008) was the only one found to have investigated the effect of variety mixtures on cowpea leaf yield in Tanzania. The findings from that study indicated that cowpea variety mixtures enhanced total leaf dry matter yield by up to 99.7% and seed yield by up to 193.3%. In another study involving three cowpea pure lines and four mixtures (one 3-way and three 2-way) in six different environments of lowland Papua Guinea, mixtures yielded significantly more seeds than component lines on two occasions. When the performance of the entries was assessed for stability using Baker's (1969) stability parameter, yields of only two (one 2-way and one 3-way) of the four mixtures were more stable than their pure lines (Erskine, 1977).

1.13 Reported use of (variety) mixtures in traditional and modern agriculture

Based on their reviews of multiline cultivars and variety mixtures, Wolfe (1985) and Lenné and Smithson (1994) pointed out that varicty mixtures are cultivated to a greater extent than is usually imagined. Examples of variety mixture use in traditional agriculture include; rice mixtures in the Philippines, Indonesia and Sierra Leon with two to five components matched to the same maturity periods and yield. In their review, Lenné and Smithson (1994) however, reported that up to 44-90 rice varieties were grown together in the same garden by farmers in these regions. Twenty five to 35 potato varieties are usually grown by subsistence farmers in the Andes, while 20 sweet potato varieties may be grown in the same garden in the highlands of Papua New Guinea. In Africa, south Asia and the Pacific, as many as 38 different varieties of yam (*Dioscorea* spp.) may be planted together. *Phaselus* beans in East Africa and in the great lakes region are usually grown in mixtures of two to 30 varieties, which may differ even in color, size and shape (Wortman et al., 1996). East African Highland cooking bananas (*Musa* spp., AAA group) in Uganda (Okonya, personal observation), cassava in Peru and barley in Syria are often grown as mixtures (Lenné and Smithson, 1994).

In industrial agricultural systems, successful utilization of mixtures by farmers has been reported for winter wheat (Bezostaja 1) in Russia, wheat and barley in the UK (Wolfe, 1985), spring barley (Triumph) in East Germany (Wolfe, 1985), spring barley in Denmark (Finckh, 2000), wheat (KSLM3, a mixture of six components) in India (Gill et al., 1979). Oats and barley in Ontario, Canada (Wolfe, 1985). In Scotland, mixtures of three wheat varieties (Virtue, Mardler and Husler) set the world record wheat yield of 13.99 t/ha in 1981 (Newton and Swanston, 1999). Current successful use of intra-crop diversification can be seen for instance in Washington state, USA where 688 ha were planted to a soft white club winter wheat multiline 'Rely' in 2007 (USDA, 2008). Winter hardy wheat varieties are grown by farmers in Oregon together with drought-resistant varieties to reduce losses due to cold or drought (Finckh et al., 2000).

Despite the use of mixtures in both subsistence and commercial agriculture, certain challenges still limit their use in modern agriculture. These include: (i) Matching:

components need to have similar maturity periods if a crop is to be harvested at the same time. For instance, combining short with tall wheat varieties may force much straw into the combine at harvesting. (ii) Large-scale production of correctly mixed seed is not yet available due to lack of seed handling equipments to do the mixing. Branding/selling seed mixtures by seed companies or plant breeders is a little complicated due to legal variety protection involved (Newton and Swanston, 1999). (iii) Since proportions of a mixture are likely to shift during each growing season due to the reduction of seed of the poorer competitor, mixtures need to be reconstituted at every planting because yield stability is strongly influenced by the relative proportion of the components, adding to the time and cost involved in mixing. (iv) Because the yield of a mixture depends on the yield of the component varieties, appropriate components with advantageous traits like drought tolerance, disease resistance or higher yielding need to be identified for every crop and included into the mixture (Bowden et al., 2001). (v) Insect pests, unlike fungal or bacterial pathogens are able to search for susceptible components within a mixed plant stand. (vi) In a market where consumers expect a uniform product, acceptance of variety mixtures would take some time (Wolfe, 1985).

1.15 Problem statement and justification of study

1. Although variety mixtures have shown to give higher and stable yields across environments in cereals (Finckh et al., 2000), the performance of mixtures in crops like cowpea in subsistence agriculture is little or not known (Lenné and Smithson, 1994).
2. Improvement of cowpea for higher leaf yields has not received much attention from researchers despite the nutritious value and popularity of cowpea leaf dishes in East Africa (Angessa, 2006; Okonya, personal observation). In spite of this, the contribution of cowpea as a leafy vegetable to reducing malnutrition among the smallholder farmers and urban poor households, who cannot afford other nutrient-rich (protein, vitamin A, calcium and iron) foods like meat or fish, cannot be ignored if maximum impact of the crop is to be realized.
3. Most studies on the effect of leaf-harvesting on seed yield have been done in either green houses or in environments different from those prevailing in

Uganda and with different cowpea varieties. Field trials in a semi-arid tropical environment with varieties particular to Uganda are still needed since genotypes respond differently to various environmental conditions.

1.16 Objectives of study

The main aim of this study was to determine the effect of cowpea variety mixtures on leaf and seed yields in a traditional intercropping production system with maize. Specific objectives were;

1. To determine whether leaf and seed yields of mixtures are higher than those of individual varieties;
2. To compare both leaf and seed yield stability of mixtures and individual varieties at three locations in Eastern Uganda;
3. To investigate the extent to which frequent leaf harvest affects seed yield;
4. To compare the leaf nutritional quality (crude protein and iron) of the six cowpea varieties and their corresponding mixtures.

1.17 Hypotheses

1. Mixtures interact less with their environment than individual cowpea varieties and this will stabilize their yields in all the three environments;
2. The leaf and seed yields of mixtures increases with increasing numbers of components;
3. Frequent leaf-harvest reduces the final seed yield;
4. The crude protein content and iron concentration of cowpea leaves is cultivar-dependant.

2. Materials and Methods

2.1 Cowpea varieties

Seven dual purpose cowpea varieties differing in morphology and phenology were used. The choice of varieties was partly based on (but not limited to) recommendations from a previous study by Angessa (2006). Growth habits, days to maturity, seed colour, leaf and seed yields were some of the factors considered for selection. UG-CP-9 (KOL 42) is a collection from Soroti, Uganda; Dakawa is a cultivar from Dakawa Research Institute, Morogoro, Tanzania; Ex-Iseke is a cultivar originating from Iseke village, Singida district, Tanzania; IT 93K-2045-29 was developed at the International Institute of Tropical Agriculture (IITA), Nigeria; while ILRI 15742 was provided by the International Livestock Research Institute (ILRI), Ethiopia. These different materials will be all called 'variety' throughout this thesis. The status and current seed source of the varieties is shown in Table 1 with ID standing for the identification of the variety in this experiment, and AVRDC-RCA (The World Vegetable Center's Regional Center for Africa) was the current seed source.

Table 1: Cowpea varieties used in the study of variety mixtures in Soroti and Kumi districts of Uganda during the first cropping season of 2008.

ID	Variety	Status	Current seed source
A	UG-CP-9 (KOL 42)	Experimental line	AVRDC-RCA, Tanzania
B	Dakawa	Cultivar	AVRDC-RCA, Tanzania
C	Ex-Iseke	Cultivar	AVRDC-RCA, Tanzania
D	IT 93K-2045-29	Experimental line	AVRDC-RCA, Tanzania
D*	ILRI 15742	Research material	AVRDC-RCA, Tanzania
E	Icirikukwai	Landrace	Serere market, Uganda
F	Ebelat	Landrace	Serere market, Uganda

D* was used in place of D in the trial at Kikota village due to insufficient seed of D.

The cowpea varieties used in this study differed not only in seed colour but also in growth habits and seed sizes. Varieties A and F had kidney-shaped seeds, were white in colour and both had an indeterminate growth habit. Variety D* had rhomboid-shaped brown seeds and an indeterminate growth habit. The remaining varieties (B, C, D and F) had ovoid to globose-shaped seeds with a smooth texture and a determinate

growth habit. The physical appearance of the seeds used in this study can be observed in Figure 1.

Figure 1: Appearance of the seeds of cowpea varieties used in the study of variety mixtures in Soroti and Kumi districts of Uganda during the first cropping season of 2008.

2.2 Maize variety

In this study, cowpea was intercropped with maize as is the case in most traditional cropping systems of subsistence farmers in the districts of Soroti and Kumi. Situka 1 is a drought-tolerant and low-nitrogen requiring, open-pollinated synthetic variety released in 2001 by the Selian Agricultural Research Institute (SARI), Tanzania. It has been released in the countries of Tanzania, Malawi, Zimbabwe and South Africa, and yields 25 to 50% more under drought stress than popular maize varieties in the region. It has flint seeds, matures early (110 to 120 days), and has good roasting and processing quality, which are important selection criteria of farmers. It is also resistant to cob rots, Mosaic streak virus and Grey leaf spot, which are important diseases in the region.

2.3 Experimental sites

Yield evaluations were conducted at three locations in Soroti and Kumi districts, Uganda from April to August 2008 (Figure 2). Trial 1 was conducted at the National Semi Arid Resources Research Institute (NaSARRI), Serere in an experimental field that had finger millet for the previous season. NaSARRI is located 28 km southwest of Soroti town at latitude 01°32'22.6''N and longitude 033°26'48.0''E in Serere county, Soroti district, Uganda. Elevation is about 1140 m asl. The 2nd trial was carried out at a farmer's field in Kikota village located about 3 km East of NaSARRI at latitude 01°32'09.6''N, longitude 033°28'22.9''E, and an elevation of 1077 m asl. The field was cropped with cassava in the previous season of 2007. The 3rd trial was conducted on farm at Kogili village, Kumi County, Kumi district located about 20 km South of Kumi town at latitude 01°32'22.7''N and longitude 033°27'01.1''E. Elevation was 1119 m asl. and the farmer's field was cropped with maize in the previous growing season of 2007.

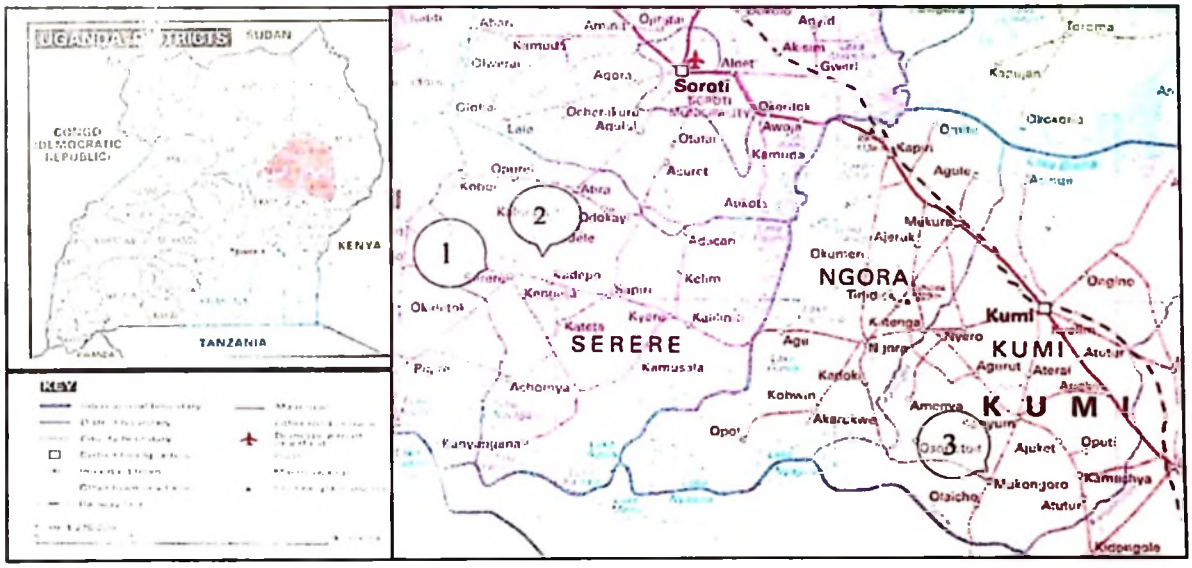


Figure 2: Location of trial sites at NaSARRI, Serere (1), Kikota village (2) and Kogili village (3), in Soroti and Kumi districts, Uganda.

2.4 Weather

The Teso sub-region (Soroti and Kumi districts) is a semi-arid agro-ecological zone with two rainy seasons. The first season occurs between March and July and the 2nd

season is between September and November. The average annual rainfall in this region varies from 800 to 1200 mm. During the period when the experiments were conducted, the precipitation at Serere and Soroti was 81% and 59% above the long-term means for the month of March 2008. Kikota village is presumed to have experienced weather conditions similar to those at NaSARRI, although, it occasionally missed rain showers that were reported at the research station probably because it is on the leeward side of a small mountain (rain shadow effect). This low precipitation at Kikota caused the maize to wilt. The weather station in Soroti district (about 30 km from Serere and 60 km from Kogili village) is taken to be representative of the weather conditions at Kogili village as it is the only nearest weather station serving the whole Teso sub-region. Details of rainfall and temperature at Serere and Soroti districts during the cropping season are shown in Figure 3.

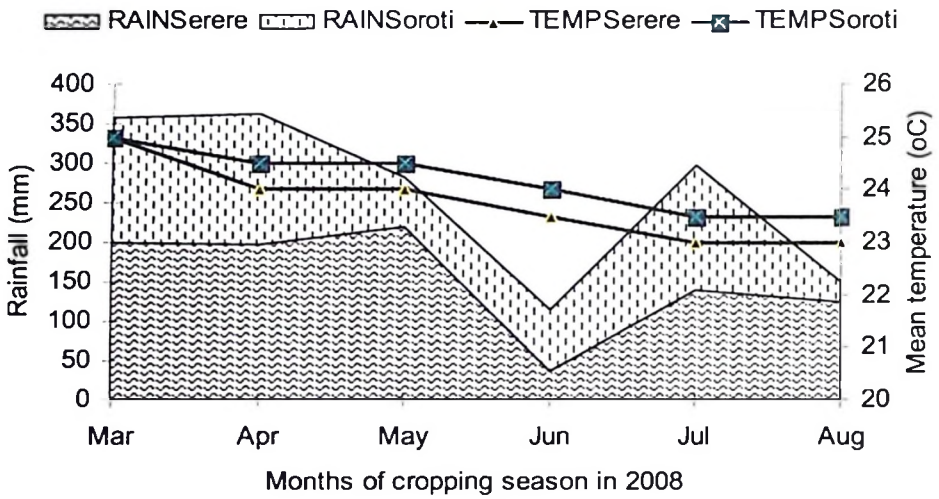


Figure 3: Rainfall and temperature distributions at the weather stations nearest to the trials sites in Uganda.

Source: Meteological departments at NaSARRI, Serere and Soroti Flying School, Soroti district, Uganda.

2.5 Soil type

The soils at Serere and Kumi are classified as ferrallitic (sandy loams to sandy clay loams) with a yellowish to red colour (Selvaradjou et al., 2005). The trial site at Kikota village had the highest content of organic matter, available phosphorous,

calcium, magnesium, potassium, sodium and copper, while the trial site at Kogili had the lowest content of organic matter, nitrogen, calcium and copper (Table 2). The soils are slightly to moderately acidic with low to deficient soil fertility indicating that most farmers would benefit from application of fertilizers through increased crop yields. Analyses were carried out in the soil, water and plant analytical laboratory at the Department of Soil Science, Makerere University, Kampala on well-mixed representative soil samples taken from 0-30 cm depth.

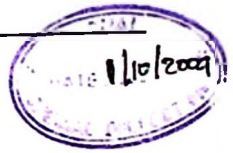
Table 2: Soil characteristics at the three trial sites in Soroti and Kumi districts, Uganda.

Soil Parameter	Units	Trial site		
		NaSARRI, Serere	Kikota Village	Kogili village
pH		5.8	6.0	5.9
Sand	%	47	60	68
Clay	%	20	18	25
Silt	%	33	22	7
Organic matter	%	2.38	3.26	1.59
Nitrogen	%	0.18	0.11	0.09
Phosphorous (Bray 1)	mg/kg	2.45	5.72	2.85
Calcium	me/100 g (cmoles/kg)	5.4	5.7	3.0
Magnesium	me/100 g (cmoles/kg)	1.19	1.84	1.33
Potassium	me/100 g (cmoles/kg)	0.29	0.37	0.34
Sodium	me/100 g (cmoles/kg)	0.07	0.08	0.07
Copper	mg/kg (ppm)	2.84	5.04	2.10
Iron	mg/kg (ppm)	211.7	221.1	264.3
Zinc	mg/kg (ppm)	1.20	1.74	1.74
Manganese	mg/kg (ppm)	37.2	35.9	52.7

Source: Soil, water and plant analytical laboratory, Department of Soil Science, Makerere University, Kampala, Uganda.

2.6 Experimental design and treatments

All experiments were conducted during the 2008 crop growing season (April to August). The trials were laid out in a complete randomized block design with three replications for each treatment. Four cowpea varieties were subjected to all possible 2-way, 3-way and 4-way combinations. The mixture level of the two landraces was unknown as seeds were purchased from the local market at Serere. Seeds of each variety were planted as pure lines and as blends in an alternating manner.



Three trials were conducted, which involved evaluating leaf and seed yields and yield stability of four varieties (UG-CP-9, Ex-Iseke, Dakawa and IT 93K-2045-29 or ILRI 15742) together with two landraces ('Ebelat' and 'Icirikukwai') in a maize-intercropping system. Due to insufficient planting material of variety IT 93K-2045-29, variety ILRI 15742 was used instead at Kikota village. The component varieties served as controls for mixture treatments and details of each treatment are shown in Table 3.

Table 3: Treatments of cowpea variety mixtures investigated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

Treatment ID	Variety	Mixture level
A	UG-CP-9 (KOL 42)	pure variety
B	Dakawa	pure variety
C	Ex-Iseke	pure variety
D/D*	IT 93K-2045-29/ ILRI 15742	pure variety
E	Icirikukwai	Unknown
F	Ebelat	unknown
A+B	UG-CP-9 (KOL 42) + Dakawa	2-way mixture
A+C	UG-CP-9 (KOL 42) + Ex-Iseke	2-way mixture
A+D	UG-CP-9 (KOL 42) + IT 93K-2045-29/ ILRI 15742	2-way mixture
B+C	Dakawa + Ex-Iseke	2-way mixture
B+D	Dakawa + IT 93K-2045-29/ ILRI 15742	2-way mixture
C+D	Ex-Iseke + IT 93K-2045-29/ ILRI 15742	2-way mixture
A+B+C	UG-CP-9 (KOL 42) + Dakawa + Ex-Iseke	3-way mixture
A+B+D	UG-CP-9 (KOL 42) + Dakawa + IT 93K-2045-29/ ILRI 15742	3-way mixture
A+C+D	UG-CP-9 (KOL 42) + Ex-Iseke + IT 93K-2045-29/ ILRI 15742	3-way mixture
B+C+D	Dakawa + Ex-Iseke + IT 93K-2045-29/ ILRI 15742	3-way mixture
A+B+C+D	UG-CP-9 (KOL 42) + Dakawa + Ex-Iseke + IT 93K-2045-29/ ILRI 15742	4-way mixture

2.7 Crop husbandry

The trial site at NaSARRI, Serere was ploughed and disked using a tractor, while the trial sites at Kikota and Kogili villages were ploughed using oxen. Cowpea was intercropped with maize, which is a common practice in subsistence agriculture. Spacing for maize was 75 x 60 cm, while that of cowpea was 75 x 20 cm. Five rows of maize and four rows of cowpea were inter-planted. Each plot measured 3 x 6 m spaced 1 m between treatments and 1.5 m between replicates in the trial at NaSARRI, Serere and Kogili, but the spacing between replicates was reduced to 1 m in the trial at Kikota village. Distance between plots of the same treatment was 1 m. Three seeds of

both cowpea and maize were planted per hill. After two weeks, maize was thinned to two plants per hill, while cowpea was thinned to one plant per hill. The state of the plants in a plot can be seen from the photographs in Figure 4. Cowpea was sprayed with Dimethioate at a rate of 2500 ml/ha at 2-3 week intervals to control insect pests. Weeds were manually removed using a hand hoe whenever it was necessary. Neither irrigation nor fertilizers were applied in any of the three trials. Dates for the field activities are indicated in Table 4.

Table 4: Dates of field activities for each site in Soroti and Kumi districts of Uganda where cowpea variety mixtures were tested.

Activity	Trial 1 at NaSARRI, Serere	Trial 2 at Kikota village	Trial 3 at Kogili village
1st ploughing	11 April 2008	20 April 2008	November 2007
2nd ploughing	Not applicable	28 April 2008	25 April 2008
Planting maize	29 April 2008	01 May 2008	02 May 2008
Planting cowpea	13 May 2008	15 May 2008	20 May 2008
1st weeding	10 May 2008	12 May 2008	10 May 2008
2nd weeding	05 June 2008	04 June 2008	04 June 2008
1st spraying	05 June 2008	10 June 2008	05 June 2008 *
1st leaf harvest	13 June 2008	16 June 2008	19 June 2008
2nd spraying	20 June 2008	27 June 2008	18 June 2008*
2nd leaf harvest	27 June 2008	30 June 2008	03 July 2008
3rd weeding	01 July 2008	04 July 2008	08 July 2008
3rd spraying	05 July 2008	05 July 2008	17 July 2008*
3rd leaf harvest	16 July 2008	19 July 2008	22 July 2008
4th spraying	19 July 2008	19 July 2008	28 July 2008*
4th leaf harvest	Not applicable	Not applicable	31 July 2008
1st pod harvest	24 July 2008	26 July 2008	31 July 2008
2nd pod harvest	01 August 2008	02 August 2008	14 August 2008
3rd pod harvest	Not applicable	16 August 2008	28 August 2008
Maize cob harvest	18 August 2008	27 August 2008	28 August 2008

* Its doubtful that the farmer was applying the pesticide in right amounts due to high pest infestation observed at this site.

Trial 1 at NaSARRI, Serere County, Soroti district

Trial 2 at Kikota village, Serere County, Soroti district

Trial 3 at Kogili village, Kumi County, Kumi district

Figure 4: Experimental fields of cowpea intercropped with maize at 8 and 10 weeks after planting cowpea and maize, respectively, in Soroti and Kumi districts, Uganda.

2.8 Data collection

Data was collected using interviews, direct observation and field trials. For all the three trials, data was collected from the three inner rows of maize and from the two inner rows of cowpea; one row of cowpea was for leaf-harvesting, while the other row was left unharvested as a control. Plots with only one component variety served as controls for mixed plots.

2.8.1 Cowpea leaf yield

The leaf-harvest was carried out whenever enough leaves were available, with the first harvest taking place at four weeks after planting cowpea. Leaf-harvest continued every two weeks until flowering. Three leaf-harvests were made at NaSARRI, Serere and Kikota village, while four leaf-harvests were possible at Kogili village (Table 4). Only fully opened trifoliolate, tender leaves suitable for human consumption were hand-picked, and the number of plants from which leaves were picked was counted after each leaf-harvest. The total fresh weight was taken using an electronic balance (Mettler PM3000 model, Mettler-Toledo Inc.) and recorded. After harvest, leaf samples were open sun-dried in net bags (320 x 440 mm) for 1-2 weeks, and the dry weights were taken using the same balance mentioned above. The dry matter leaf yield per plant and per square meter was then calculated.

2.8.2 Determination of cowpea leaf protein using NIRS and wet chemistry

Dried leaf samples from the second leaf-harvest of each trial were taken to the University of Goettingen where they were milled through a 1 mm sieve to get a fine powder using a Culatti micro hammer mill (Type DFH 48). The leaf powder was put into cuvettes and scanned using a FOSS 6500 Near Infra Red Spectrophotometer (NIRS) machine to get a spectrum from which the nitrogen content was estimated using a calibration equation developed by Angessa (2006) and further improved by Towett (2008). To check the accuracy of prediction, the spectra was characterized with NIRS software (WinISI) and, by the help of Principal Component Analysis, a set of 20 out of 151 samples was chosen. This chosen validation set of leaf samples (13.1% of all the samples) together with another 22 samples chosen across treatments and locations, were submitted to wet chemistry in the laboratory for nitrogen content

analysis using an elemental analyser (Type Vario III). The nitrogen content was then multiplied by a factor of 6.25 to get the crude protein content of the leaf samples. The predictions from NIRS were then checked on how well they corresponded to the laboratory values (Figure 5, Table 5). After satisfactory correspondence of all the predicted values by an R^2 value of 0.87 using the calibration equation developed by Angessa (2006) and further improved by Towett (2008), no further wet chemistry analysis was carried out and the NIRS equation was applied to the remaining samples.

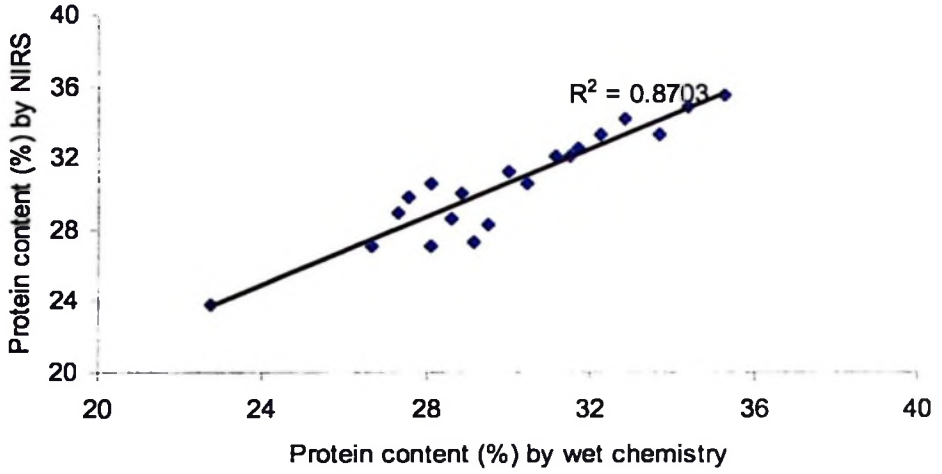


Figure 5: Crude protein values of selected cowpea leaf samples from Uganda comparing the relationship between NIRS and wet chemistry analytical methods.

Table 5: Prediction statistics when applying a NIRS equation developed by Angessa (2006) and improved by Towett (2008) for crude protein content in young cowpea leaves to different batches of cowpea leaf samples originating from Uganda independent from the calibration sets (Equation applied = teferich.eqa).

Sample/batch selected for	N	Global-H	R^2	Slope	SEP	Bias	SEP(C)
Spectral variability only	20	0.732	0.870	0.922	1.22	-0.590	1.099
Spectral variability + diversity of experimental settings	42	0.692	0.876	0.964	1.26	-0.625	1.111
Diversity of experimental settings only	22	0.656	0.883	0.998	1.30	-0.657	1.146

Key: N = number of spectra in the calibration set; R^2 = determination coefficient of prediction; SEP = standard error of prediction; SEP(C) standard error of cross-validation.

2.8.3 Determination of cowpea leaf iron content using NIRS and wet chemistry

About 200-250 mg of 34 out of 153 representatively-selected milled leaf samples were weighed into Tephlon beakers using a Sartorius analytical balance (Gebr. Rettberg GmbH, Germany). 2 ml of concentrated nitric acid were added to the sample and this was then heated at about 165 °C for six hours in a modified microwave oven. After cooling, the resulting digest was then diluted with distilled water up to 50 ml in a volumetric flask. The dissolved digest was then filtered through a filter paper. 2 ml buffer solution (2% cesium chloride) was added to 10 ml of the filtrate before the sample was analysed using the atomic absorption spectrophotometer (novAA 315, Analytikjena AG, Germany) for iron content. The concentration of iron (µg/g) in the sample was then calculated as follows:

$$\frac{\text{Sample reading - blank reading (mg/L) x dilution factor 50 (ml)}}{\text{Sample weight (mg)}}$$

Because NIRS has shown to reliably predict crude protein content of cowpea leaf samples to a tune of nearly 90% precision, its usefullness was extended to predict iron concentration as well. When the prediction equation developed by Towett (2008) (Equation 1) was applied to the 34 leaf samples from the current study, the coefficient of prediction got was not statistically satisfactory ($R^2 = 0.603$). However, when the 34 leaf samples from the current study were included in the calibration set in order to improve equation 1, the R^2 value improved slightly to 0.626 (Table 6 and 7). When three out-layer values were removed, the R^2 value of prediction increased to 0.677 (Figure 6). This fit of regression of the NIRS statistics is still low and equation 2 cannot be used to precisely predict the iron concentration of cowpea leaves but could, nonetheless, help in classifying samples.

Table 6: NIRS modified partial least squares (PLS) statistics of calibration and cross-validation for first calibration equations developed for iron contents (%) in young cowpea leaves from Africa. Equation 1 included samples from Kenya, Tanzania and Uganda, while Equation 2 added 34 more samples from Uganda.

Eqa. No.	Cal.ID	N	Mean	SD	Est.Min	Est.Max	SEC	R^2_{cal}	SECV	R^2_{cval}	#	RPD
1Fe	Erick2i.eqa	406	434.2	325.8	0.0	1411.5	106.1	0.894	121.3	0.861	173	3.070
2Fe	EriJosh.eqa	440	424.7	310.1	0.0	1355.0	106.7	0.882	122.2	0.845	173	2.906

Key: Eqa No. = equation number; Cal. ID = calibration equation; N = number of spectra in the calibration set; Mean = estimated by NIRS (expressed as %); SD = standard deviation; Est. Min = lowest value of reliably estimating samples; Est. Max = maximum value of reliably estimating samples; SEC = standard error of calibration; R^2_{cal} = determination coefficient of calibration; SECV = standard error of cross-validation; R^2_{cval} = determination coefficient of cross-validation; # = number of variables per spectrum; RPD = ratio performance deviation.

Table 7: Prediction statistics when applying a NIRS equation developed by Towett (2008) for iron content in young cowpea leaves to cowpea leaf samples originating from Uganda. While equation 1 was independent, equation 2 included the calibration set.

Eqa. No.	Equation applied	N	Global-H	R^2	Slope	SEP	Bias	SEP(C)
1Fe	Erick_2i.eqa	33	1.193	0.603	0.644	238.0	202.9	126.4
2Fe	EriJosh.eqa	33	1.193	0.626	0.686	123.0	40.7	117.8

Key: N = number of spectra in the prediction set; SEP = standard error of prediction; SEP(C) = standard error of cross-validation.

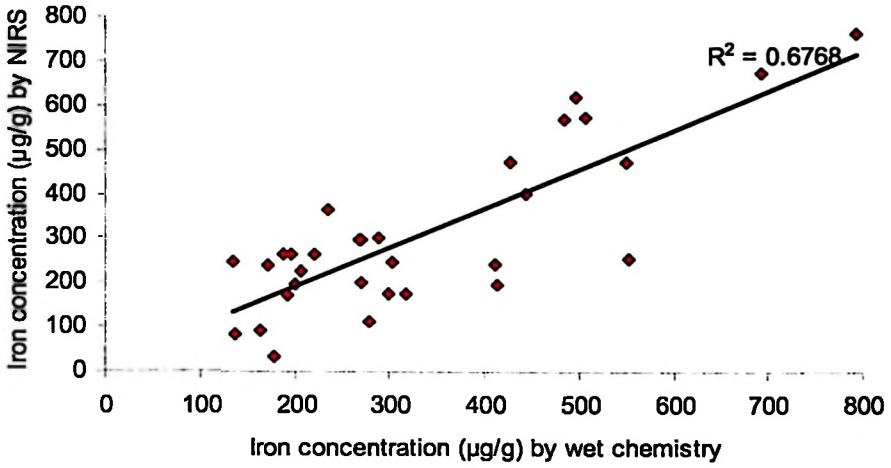


Figure 6: Iron concentration values of 31 selected cowpea leaf samples from Uganda comparing the relationship between NIRS and wet chemistry analytical methods. Three outlier values were omitted.

2.8.4 Cowpea pod and seed yields

At maturity (when pods had turned from yellow to brown), pods were harvested by hand from each plot, counted, and the number of plants from which pods were picked was recorded. Pods were harvested twice at NaSARRI, Serere and thrice at Kikota and Kogili villages (Table 4). Afterwards, pods were open sun-dried in net bags (430 x 550 mm) for about one week, hand-shelled and the seeds weighed to get the dry weight. The total dry weight was then used to calculate the seed yield per plant and per square meter.

2.8.5 Dry matter shoot yield

In order to determine the amount of shoot dry matter in cowpea at the time when leaf-harvesting was done, one plant from one of the two border rows was randomly selected at the first and second leaf harvests. The whole plant was cut at ground level and its fresh weight determined. The plant was then open-sun dried in a net bag (430 x 550 mm) for 1-2 weeks until constant weight and the dry weight was taken. Dry matter shoot yield per plant was then determined.

2.8.6 Variety-specific characteristics

The seven cowpea varieties used in the study were also morphologically characterized according to the descriptors of cowpea (IBPGR, 1983) for their growth habits, growth pattern, twining tendency, growth vigour and days to 50% maturity. All the descriptors applied are detailed in the following:

i. Growth habit (acute erect, erect, intermediate, semi-prostrate, prostrate or climbing) evaluated in the 6th week after sowing;
ii. Growth pattern (determinate or indeterminate);
iii. Twining tendency (none, slight, intermediate or pronounced);
iv. Terminal leaflet shape (globose, sub-globose, sub-hastate or hastate) recorded in the 6th week after sowing;
v. Days to flowering (from sowing to when 50% of the plants started to flower);
vi. Days to first mature pods (from sowing to when 50% of plants had mature pods);
vii. Pod length (mean of the 10 longest mature pods from 10 randomly selected mature plants, in cm);
viii. Pod width (mean width of 10 pods measured for length in (vii), in cm);
ix. Seed weight (weight of 100 seeds with moisture content of about 12%, in g);
x. Plant vigor (non-vigorous, intermediate, vigorous or very vigorous) based on plant width and length at 3-4 weeks after sowing;
xi. Number of pods per plant (mean number of mature pods from 10 randomly selected plants);

2.8.7 Maize yield

Maize cobs were hand-harvested at 111, 118 and 118 days after planting at NaSARRI, Serere, Kikota village and Kogili village, respectively. The number of cobs per plot was counted, and cobs were then open sun-dried for seven days. The weight of the dry maize cobs per plot was then taken to determine cob yield per plant. The dry cobs were then hand-threshed and the seeds were weighed to determine seed yield per plant. A hanging spring balance (E-211T-228 BD model, EKATA weighing machine and tools) was used to weigh both maize cobs and seeds.

2.8.8 Perception of farmers about cowpea production in Serere and Kumi Counties, Uganda

Thirteen farmers (10 women and three men) at Serere County, and eight female farmers at Kumi County, who had cropped cowpea in the first growing season of 2008, were interviewed about their knowledge of cowpea as a leafy vegetable, cowpea production systems, constraints and the variety mixture concept. Figure 7 shows how the interviews were conducted by the researcher with the help of a translator at a farmer's home in Kogili village, Kumi County. The questionnaire used in this study of cowpea variety mixtures in Soroti and Kumi districts of Uganda is shown in Appendix 1. Farmers' fields of cowpea were visited by the researcher together with the farmer prior to the interview and the appearance of one of the farmers's fields visited at Kikota village is shown in Figure 8.

Figure 7: Administering a questionnaire at a farmer's home in Kogili village, Kumi County, Kumi district, Uganda.

Figure 8: A farmer's field of cowpea intercropped with maize at Kikota village, Serere County, Soroti district, Uganda.

2.9 Data analysis

In order to detect the differences between treatments, yield data for leaf, seed, pod and shoot from three replicated plots of cowpea in each environment was subjected to analysis of variance using the SYSTAT procedure general linear models (GLM; SYSTAT version 5.0, 1990 -1994 SYSTAT, Inc.).

The effect of mixtures on cowpea yield variables from three replications in each environment was calculated as follows:

Mixture effect = mixture yield – pure line component mean.

And in percentage as;

$$\text{Mixture effect (\%)} = \frac{\text{(Mixture yield – Pure line component mean)}}{\text{Pure line component mean}} \times 100.$$

Statistical differences in mean yields for every mixture were calculated from a matrix (Appendix 2) using a contrast test of the SYSTAT procedure at 5% level.

The effect of leaf-harvesting on pod and seed yield parameters from each of the treatments was calculated as follows:

Harvesting effect = NH – H.

And in percentage as;

$$\text{Harvesting effect (\%)} = \frac{(NH - H)}{NH} \times 100.$$

Where NH = yield parameter from non leaf-harvested plants and H = yield parameter from leaf-harvested plants.

The same basic model used for analysis of genotype-by-environment interaction was applied in this study to analyse for stability of traits. Regression (linear or joint) analysis was used to determine whether each genotype exhibits a characteristic linear response to environmental change. The observed performance (Y_{ij}) of the i^{th} genotype ($i = 1,\ldots,g$) in the j^{th} environment ($j = 1,\ldots,e$) was expressed as:

$$Y_{ij} = \mu + g_i + e_j + ge_{ij} + \varepsilon_{ij}$$

Where μ is the grand mean of over all genotypes and environments, g_i is the additive contribution of the i^{th} genotype, e_j is the additive environment contribution of the j^{th} environment, ge_{ij} is the genotype-environment interaction of the i^{th} genotype in the j^{th} environment, and ε_{ij} is the experimental error of i^{th} the genotype in the j^{th} environment (Hill et al., 1998). The use of the term genotype in the present study means variety.

To be able to measure the contribution of the i^{th} genotype to the genotype-by-environment interaction, Wricke (1962; in Hill et al., 1998) proposed a parameter he term ecovalence (W) expressed as:

$$W_i = \sum_j (Y_{ij} - Y_{i.} - Y_{.j} + Y_{..})^2$$

Where $Y_{..}$ is the overall mean, $Y_{i.}$ the mean of genotype i and $Y_{.j}$ the mean of environment j.

In this study, PLABSTAT (Version 3A-pre of 2005-08-16) (Utz, 1997) was used to generate the ecovalence values as a measure of stability with low ecovalence values indicating stability. A model that analyzes a series of experiments over places in a complete randomized block design with one factor was used in PLABSTAT when analyzing for the ecovalence values.

Model P + R: P + T + TP + RTP

Where T = treatments, R = replications and P = places

Ecovalence values for accumulated dry matter leaf yield, number of pods, seed yield, dry matter shoot yield and leaf protein content across the three environments of NaSARRI, Serere, Kikota village and Kogili village were determined.

The relationship between yield traits was also assessed using Spearman's correlation coefficient in PLABSTAT.

3. Results

3.1 Cowpea variety-specific characteristics

The six cowpea varieties that were planted at NaSARRI, Serere differed in their days to flowering, days to maturity, growth patterns, twining tendencies and terminal leaflet shapes (Table 8). However, all the varieties had a non-vigorous plant vigor (height less than 37 cm and width less than 75 cm), under the traditional 1:1 cowpea/maize intercropping system across the three sites. Varieties A, B and E flowered slightly earlier than varieties D, F and C. Pod maturity was more distinct, with variety E maturing first and variety F maturing about a week later. An indeterminate growth pattern was observed for varieties A and E, while the other four varieties were determinate and this was maintained across the three environments. The twining tendency of varieties B, C, D and F was slight, however, that of variety A was intermediate, and it was pronounced for variety E. The terminal leaflet shape was either sub-globose or sub-hastate and did not vary with the environment. The agro-morphological characteristics of the individual cowpea varieties observed at NaSARRI, Serere varied slightly from those noticed at Kikota and Kogili villages (Appendix 3a and 3b). On average, flowering was earliest at NaSARRI, Serere at 54 days after planting and latest at Kikota village at 58 days after planting. For maturity, plants at NaSARRI, Serere had on average 50% of their pods maturing first at 69 days after planting, while pods at Kogili village took 74 days.

Table 8: Mean of agro-morphological characteristics of the cowpea varieties used in the study of variety mixtures at NaSARRI, Serere, Uganda during the first cropping season of 2008.

Variety ID	Days to flowering	Days to 1st mature pods	Growth pattern	Twining tendency	Terminal leaflet shape
A	53 ± 0.58	67 ± 0.73	indeterminate	intermediate	sub-globose
B	53 ± 0.58	66 ± 0.73	determinate	slight	sub-hastate
C	56 ± 0.58	71 ± 0.73	determinate	slight	sub-hastate
D	54 ± 0.58	71 ± 0.73	determinate	slight	sub-hastate
E	53 ± 0.58	65 ± 0.73	indeterminate	pronounced	sub-globose
F	54 ± 0.58	73 ± 0.73	determinate	slight	sub-hastate

Values are the mean ± s.e. of three replicate plots of each variety.
Values for days to flowering and 1st mature pods were significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.2 Maize yield

The maize that was intercropped with cowpea was stunted at Kikota village due to the low precipitation observed during the flowering stage, and this led to poor seed filling of the cobs. The maize at NaSARRI, Serere and Kogili village, however, grew vigorously. The highest mean maize seed yield of 128.1 g/plant (1,311.5 g/m^2) was realized in the trial conducted at NaSARRI, Serere, whereas only 63.3 g/plant (537.0 g/m^2) was recorded from the trial site at Kikota village (Table 9). Like maize seed yield, cob yield followed a similar trend and for comparison purposes the mean seed and cob yields have also been expressed in grams per square meter (Appendix 4).

Table 9: Mean seed and cob yields of the maize that was intercropped with cowpea at the three trial sites of NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008.

	Maize seed and cob yield (g/plant)					
	Serere		Kikota		Kogili	
Treatment plot	seed	cob	seed	cob	seed	cob
A	146.7	176.7	71.4	84.0	91.4	107.5
B	132.1	164.3	60.2	67.7	100.0	120.0
C	111.9	138.1	43.5	56.5	112.7	154.9
D	116.5	150.4	63.7	86.0	92.3	107.7
E	144.4	183.1	70.3	78.1	99.0	109.4
F	123.1	156.7	75.8	87.1	101.3	121.2
A+B	130.4	166.7	66.9	70.4	113.6	118.1
A+C	115.9	142.4	65.8	79.0	104.2	136.4
A+D	130.4	166.7	76.5	106.0	96.6	110.5
B+C	129.5	161.9	52.4	60.5	75.6	142.9
B+D	113.5	144.2	48.9	52.6	114.3	107.1
C+D	135.6	178.0	70.0	80.0	95.3	114.5
A+B+C	137.0	174.1	64.1	68.4	84.3	131.3
A+B+D	124.0	160.0	68.6	83.3	93.4	150.7
A+C+D	132.4	169.1	63.6	72.7	137.0	120.9
B+C+D	120.9	153.6	57.9	63.2	93.4	123.4
A+B+C+D	133.8	165.6	56.5	60.9	103.9	139.2
mean	**128.1**	**161.1**	**63.3**	**73.9**	**100.5**	**124.4**

Values are the mean maize weights from three replicate plots where the cowpea varieties were planted. Refer to table 1 for cowpea variety names corresponding to ID A, B, C, D, E and F.

The average maize seed and cob weights across the three trial sites for each treatment plot was compared, plots planted to mixtures A+C+D and A+B+D gave the highest maize seed (111.0 g/plant) and cob (131.3 g/plant) yields, respectively (Figure 9). The lowest maize seed (85.8 g/plant) and cob (101.3 g/plant) yields came from those plots that had been planted with cowpea variety mixtures B+C and B+D, respectively.

However, no significant differences could be seen among the mean maize cob and seed yields in the various treatment plots at the three trial sites.

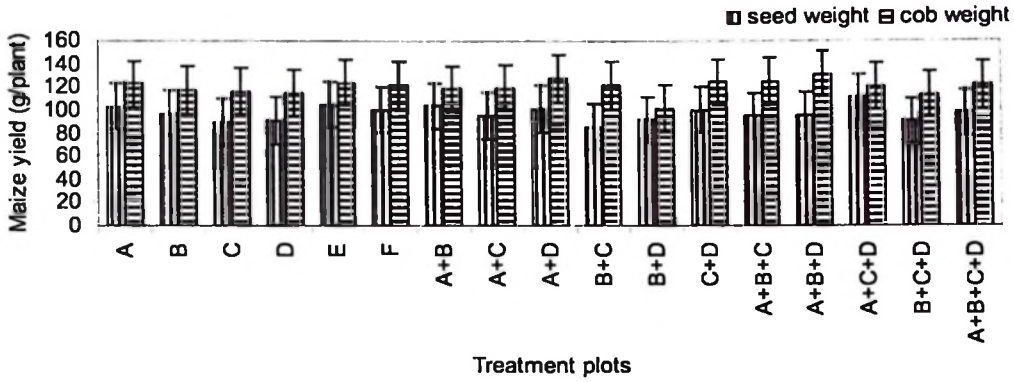


Figure 9: Overall mean seed and cob yields of the maize that was intercropped with cowpea at the three trial sites of NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008. Standard error bars estimate the distance of treatment means from the grand mean. Refer to Table 1 for variety names corresponding to ID A, B, C, D, E and F.

Comparing the seed and cob yield per plant among the individual plots, which had been planted to individual cowpea varieties, landraces, 2-way, 3-way or 4-way mixtures, both cob and seed yields were highest in the plots planted to the landraces at NaSARRI, Serere and Kikota village, but not at Kogili village (Figure 10). Nevertheless, no significant differences were detected between plots planted to different cowpea treatments.

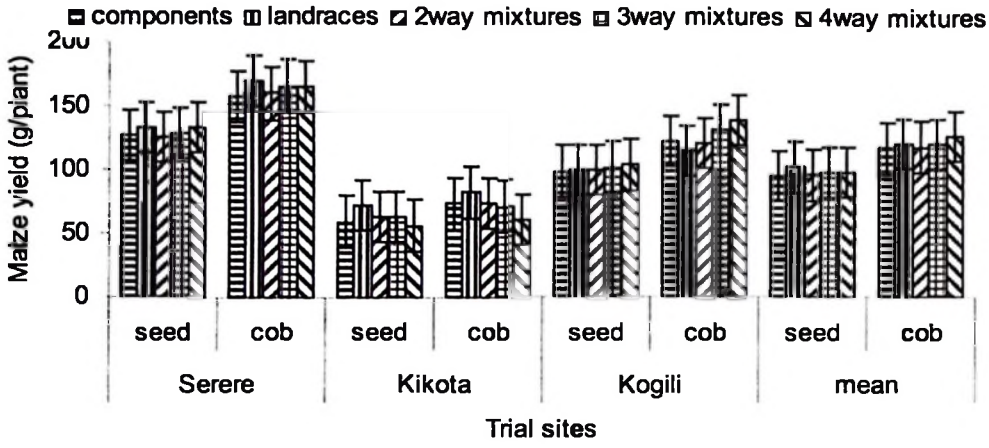


Figure 10: Mean seed and cob yields of the maize that was intercropped with cowpea at the three trial sites of NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008. Standard error bars estimate the distance of treatment means from the grand mean.

When comparing the performance of maize in plots where cowpea varieties were grown in a mixture or as individual varieties, the yield from plots with 3-way and 4-way mixtures increased by 0.8% and 2.5% respectively across the sites (Table 10). At Kikota village, a negative effect was seen in all the plots that were planted to cowpea variety mixtures, while at Kogili village, a positive effect on maize yield was observed in all the plots planted to cowpea variety mixtures. The overall mixture effect was, however, positive.

Table 10: Effect of cowpea mixtures on maize seed yield that was intercropped with cowpea at the three trial sites of NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008.

Effect of mixtures on maize yield (g/m^2)								
Trial site	**Serere**		**Kikota**		**Kogili**		**mean**	
mixture plot	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**
2-way mixtures	-6.17	0.11	-46.30	-6.32	12.35	3.10	-13.37	-1.04
3-way mixtures	-9.26	-0.21	-83.33	-13.75	87.96	16.39	-1.54	0.81
4-way mixture	240.74	18.31	-101.85	-17.46	37.04	6.67	58.64	2.51
mean	**75.10**	**6.07**	**-77.16**	**-12.51**	**45.78**	**8.72**	**14.57**	**0.76**

Mixture effect expressed as deviations from the average of the component pure lines.
Mixture effect (%) = (mixture yield-pure line component average)/ pure line component average × 100.

When the mean yields of maize seeds, total cowpea leaves, and cowpea seeds were compared, no obvious relationship could be observed (Figure 11). This indicates that, the performance of maize was independent of the treatment subjected to cowpea varieties (individual components, 2-way, 3-way, 4-way mixtures or landraces) and vice versa.

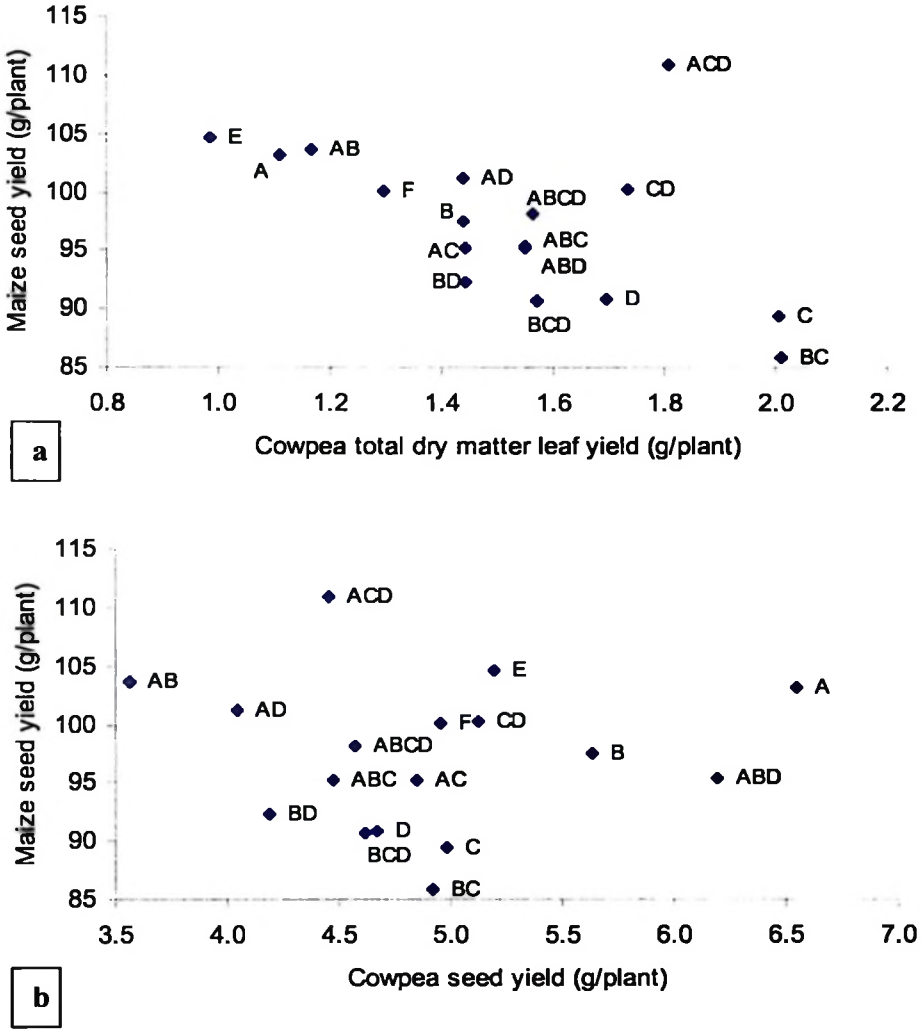


Figure 11: Relationship between overall mean (a) maize seed yield and total cowpea leaf yields and (b) maize seed yield and cowpea seed yield at NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008. Refer to Table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.3 Cowpea leaf yield

Cowpea dry matter leaf yields from three or four harvests at each location (Appendix 5) were added to get the total/accumulated dry matter leaf yield per plant at each site. The proportion of the dry matter content to the fresh leaf yield per plant ranged from 13.5% for mixture A+B at Kogili village to 18.7% for mixture A+D at Kikota village (Appendix 6). The lowest mean total dry matter leaf yield of 1.30 ± 0.17 g/plant (3.47 ± 0.45 g/m^2) was attained from the on farm trial at Kogili village, whereas the highest mean total dry matter leaf yield of 1.80 ± 0.39 g/plant (7.09 ± 1.23 g/m^2) was realized at NaSARRI, Serere (Table 11 and Appendix 7a). Whereas, the mean total dry matter leaf yield attained at NaSARRI, Serere was not significantly different from that obtained at the on farm trial at Kikota village when the yield was expressed in g/plant, it was significantly different when the yield was expressed in g/m^2. The yields of the different treatments at the two on-farm field trials at Kikota and Kogili villages were, however, not significantly different from each other (Appendix 7b). Varieties F and E gave the lowest total leaf yields at Kogili village of 0.64 ± 0.17 g/plant and 1.17 ± 0.45 g/m^2, respectively, while the highest total leaf yields of 2.37 g/plant and 9.97 ± 1.23 g/m^2 were from mixture C+D and B+C at NaSARRI, Serere, respectively.

Table 11: Mean total dry matter leaf yield of pure cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Dry matter leaf yield (g/plant)			
Treatment	**Serere**	**Kikota**	**Kogili**	**mean**
A	1.31	1.19	0.83	1.11
B	1.86	1.29	1.17	1.44
C	2.19	1.92	1.92	2.01
D	1.82	1.22	2.05	1.70
mean of components	**1.79**	**1.40**	**1.49**	**1.56**
E	1.24	0.93	0.79	0.98
F	1.55	1.69	0.64	1.30
mean of landraces	**1.39**	**1.31**	**0.72**	**1.14**
A+B	1.36	1.02	1.13	1.17
A+C	1.87	1.23	1.23	1.44
A+D	1.51	1.56	1.24	1.44
B+C	2.18	2.25	1.60	2.01
B+D	1.86	1.02	1.45	1.44
C+D	2.37	1.43	1.40	1.74
mean of 2-way mixtures	**1.86**	**1.42**	**1.34**	**1.54**
A+B+C	1.98	1.38	1.29	1.55
A+B+D	1.89	1.67	1.10	1.55
A+C+D	2.22	1.61	1.61	1.81
B+C+D	1.22	1.98	1.51	1.57
mean of 3-way mixtures	**1.83**	**1.66**	**1.38**	**1.62**
A+B+C+D	2.06	1.21	1.43	1.56
overall mean	1.80	1.45	1.30	1.51
standard error	**± 0.39** [a]	**± 0.32** [ab]	**± 0.17** [b]	

Values are the mean ± s.e. weights of three or four leaf harvests from three replicate cowpea plots.
Values with the same letter are not significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.4 Effect of mixing on cowpea dry matter leaf yield

Mixing of cowpea varieties had both positive and negative effects on leaf yield. Percentage mixture effects ranged from -23.4% in B+C+D to 33.7% in C+D at NaSARRI, Serere, -17.7% in A+C+D to 32.1% in B+C+D at Kikota village and -24.4% in A+B+D to 12.1% in B+C at Kogili village (Table 12). On average, positive effects were observed for seven out of the eleven mixtures. Whereas B+C was the only mixture that maintained positive effects across the three sites, the highest mean positive effects came from mixture C+D. On the other hand, mixture A+B+C+D had negative effects across all the three sites, but the lowest mean mixture effects were observed for mixture A+C+D. Although mixture effects were more pronounced when

expressed in weight per area (g/m^2) than in weight per plant (g/plant), they were nonetheless not significantly different at P≤ 0.05.

Table 12: Effect of mixing cowpea varieties on dry matter leaf yield per square meter for the study conducted at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

Mixture effects of cowpea leaf yield (g/m^2)								
Trial site	**Serere**		**Kikota**		**Kogili**		**mean**	
mixture level	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**	**mixture effect**	**mixture effect (%)**
A+B	-1.20	-16.27	-0.58	-11.98	0.31	10.67	-0.49	-5.86
A+C	1.26	17.27	-0.33	-6.52	0.01	0.31	0.31	3.69
A+D	-0.86	-17.11	0.89	24.86	-0.77	-19.62	-0.24	-3.95
B+C	0.13	1.35	0.02	0.37	0.47	12.11	0.21	4.61
B+D	0.49	6.45	0.94	21.53	-0.10	-2.16	0.44	8.61
C+D	2.51	33.74	1.20	26.48	-0.90	-18.11	0.94	14.04
mean	**0.39**	**4.24**	**0.36**	**9.13**	**-0.16**	**-2.80**	**0.19**	**3.52**
A+B+C	-0.38	-4.69	0.43	8.11	-0.02	-0.66	0.01	0.92
A+B+D	0.60	9.04	1.10	25.84	-0.91	-24.36	0.26	3.51
A+C+D	0.65	9.87	-0.77	-17.65	-0.82	-20.13	-0.32	-9.30
B+C+D	-1.94	-23.37	1.57	32.09	-0.23	-5.16	-0.20	1.19
mean	**-0.27**	**-2.29**	**0.58**	**12.10**	**-0.50**	**-12.58**	**-0.06**	**-0.92**
A+B+C+D	-0.09	-1.27	-0.35	-7.49	-0.21	-5.34	-0.22	-4.70
overall mean	**0.01**	**0.23**	**0.20**	**4.58**	**-0.29**	**-6.91**	**-0.03**	**-0.70**

Mixture effect expressed as deviations from the average of the component varieties.
Mixture effect (%) = (mixture yield–pure line component average)/pure line component average × 100.
None of the mixture effects is significantly different at P≤ 0.05.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.5 Interactive effects of genotype-by-environment on the total dry matter leaf yield of cowpea

Variety mixture B+D had the lowest ecovalence value and, therefore, the most stable leaf yields, while variety D had the highest ecovalence value making it the most unstable variety for leaf yield across the three field sites (Figure 12). On average, the ecovalence value decreased with increasing number of component varieties in a mixture, with individual varieties having the highest mean ecovalence values and the 4-way mixture having the lowest mean ecovalence value. Landraces, similarly, had a lower ecovalence value compared to the individual component varieties and, therefore, were more stable across the three environments. Some individual varieties

like A and C, however, had a comparably lower ecovalence value compared to other individual varieties and some mixtures.

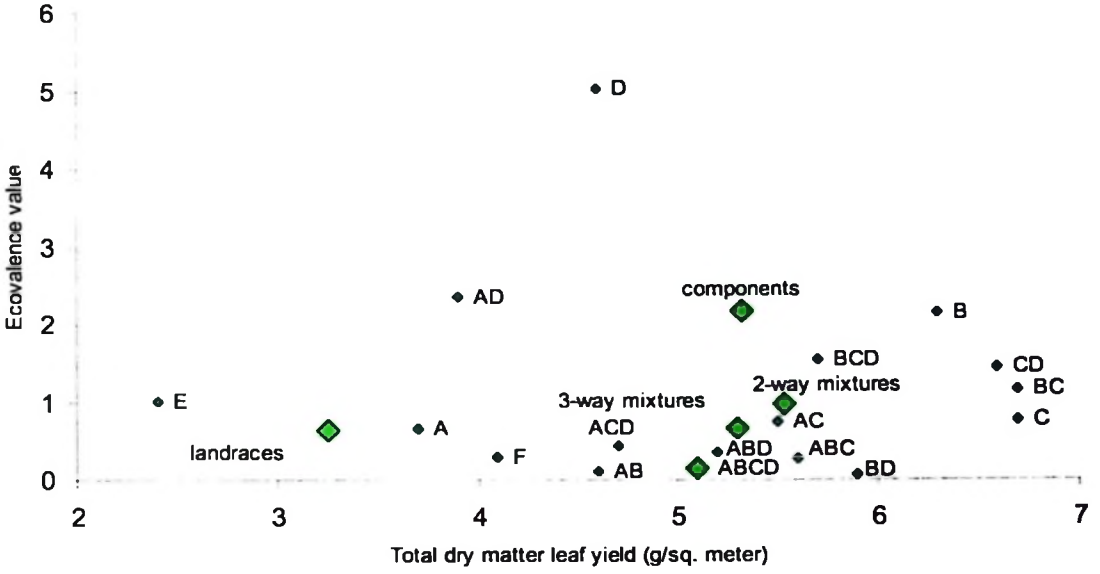


Figure 12: Stability (expressed by ecovalence) of the total dry matter leaf yield of individual cowpea varieties and variety mixtures grown at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008. Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.6 Nutritional quality of cowpea leaves

The mean iron concentration of the 34 cowpea leaf samples analysed using wet digestion method in the laboratory varied from 232.5 µg/g in variety B to 444.4 µg/g in variety E at NaSARRI, Serere; from 135.5 µg/g in landrace F to 363.0 µg/g in variety B at Kikota village and from 384.8 µg/g in landrace E to 796.3 µg/g in mixture A+B+D at Kogili village (Table 13). Between treatments, the concentration of iron was, however, not significantly different. The iron concentration was on average highest at Kogili village and lowest at Kikota village.

Table 13: Iron concentration (wet chemistry) of 34 sun-dried cowpea leaf samples from field trials conducted at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Serere			Kikota			Kogili		
Treatment	Iron (µg/g)	SE	N	Iron (µg/g)	SE	N	Iron (µg/g)	SE	N
A	na	na	na	198.2	97.8	2	na	na	na
B	232.5	46.4	2	363.0	97.8	2	695.0	99.2	1
C	254.7	46.4	2	138.4	138.3	1	385.7	70.2	2
D	235.3	46.4	2	178.9	138.3	1	449.1	70.2	2
E	444.4	65.7	1	301.5	97.8	2	384.8	70.2	2
F	290.1	65.7	1	135.5	138.3	1	450.4	70.2	2
A+B	na	na	na	164.1	138.3	1	na	na	na
A+D	na	na	na	193.3	97.8	2	na	na	na
B+C	na	na	na	na	na	na	551.7	99.2	1
B+D	na	na	na	279.3	138.3	1	413.9	99.2	1
A+B+D	na	na	na	na	na	na	796.3	99.2	1
mean	**291.4**	**54.1**	**1.6**	**216.9**	**120.3**	**1.4**	**515.9**	**84.7**	**1.5**

Values are the mean ± s.e. iron concentration of cowpea leaves from the second leaf harvest.
All values are not significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.
na=not available.

When the improved NIRS equation (Equation 2) was used to predict the iron concentration of sun-dried cowpea leaf samples from the second leaf-harvest, values ranged from 67.7 µg/g for variety D at Kikota village to 628.2 µg/g for landrace F at Kogili village (Table 14). At all the three trial sites, the two landraces (E and F) had, highest mean iron concentration (332.8 µg/g for E and 379.4 µg/g for F), while mixture A+B+C+D had the lowest iron concentration (196.9 µg/g). Nonetheless, the difference between the mean values for the iron concentration was not statistically significant. Across sites, leaf samples from Kogili village had the highest mean iron concentration (387.0 µg/g), while samples from Kikota village had the lowest mean iron concentration (176.3 µg/g). Nevertheless, care must be taken with NIRS-estimated iron concentration values (Table 4), as only about 67% of the variation could be explained through of spectral analysis

Table 14: Iron concentration (NIRS prediction) of sun-dried cowpea leaves from field trials conducted at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Iron concentration (µg/g)			
Treatment	**Serere**	**Kikota**	**Kogili**	**mean**
A	212.5	244.3	321.8	259.5
B	257.3	190.7	599.3	349.1
C	205.8	141.2	318.9	221.9
D	193.9	67.7	371.6	211.1
Mean of components	**217.4**	**161.0**	**402.9**	**260.4**
E	300.8	222.7	475.0	332.8
F	306.8	203.1	628.2	379.4
Mean of landraces	**303.8**	**212.9**	**551.6**	**356.1**
A+B	244.6	81.2	280.6	202.1
A+C	220.6	119.1	486.4	275.4
A+D	233.9	272.9	222.3	243.1
B+C	268.2	192.6	503.3	321.4
B+D	260.3	220.0	218.4	232.9
C+D	186.9	183.7	362.6	244.4
Mean of 2-way mixtures	**235.8**	**178.3**	**345.6**	**253.2**
A+B+C	198.3	140.9	366.2	235.1
A+B+D	296.4	192.3	543.5	344.0
A+C+D	202.9	238.9	242.6	228.1
B+C+D	204.7	161.2	371.3	245.7
Mean of 3-way mixtures	**225.6**	**183.3**	**380.9**	**263.3**
A+B+C+D	199.0	124.6	267.1	196.9
overall mean	**234.9**	**176.3**	**387.0**	**266.1**
SE	**37.2**	**44.6**	**102.4**	**61.4**

Values are the mean ± s.e. iron concentration of cowpea leaves from the second leaf harvest.
All values are not significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

The protein content of the open-sundried cowpea leaves from the second leaf harvest at the three trial sites varied from 23.7% for variety C at Kikota village to 34.8% for variety A at Kogili village (Table 15). On average, variety C, had the lowest leaf protein content across the three locations, whereas, the highest mean leaf protein content was from mixture A+D. Compared to the mean of components and all the mixture levels, landraces had the highest leaf protein content. Crude protein content was lowest in the leaves collected from the trial at Kikota village.

Table 15: Comparing the crude protein content of cowpea leaves from individual component varieties with that from variety mixtures grown at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Protein content of sundried cowpea leaves (%)			
Treatment	**Serere**	**Kikota**	**Kogili**	**Mean**
A	33.15	27.63	34.75	31.84
B	32.17	28.90	28.83	29.97
C	28.54	23.71	31.82	28.02
D	33.06	26.57	32.38	30.67
mean of components	**31.73**	**26.71**	**31.94**	**30.13**
E	33.94	32.36	32.78	33.03
F	33.02	28.95	31.82	31.26
mean of landraces	**33.48**	**30.65**	**32.30**	**32.15**
A+B	34.10	29.05	31.91	31.69
A+C	31.32	29.14	31.50	30.65
A+D	34.53	32.59	33.87	33.66
B+C	31.72	26.13	30.84	29.57
B+D	31.05	27.05	33.39	30.49
C+D	32.72	25.39	31.55	29.89
mean of 2-way mixtures	**32.57**	**28.22**	**32.18**	**30.99**
A+B+C	30.01	28.21	32.52	30.25
A+B+D	30.55	27.51	31.16	29.74
A+C+D	29.86	28.82	33.75	30.81
B+C+D	31.36	25.02	31.00	29.13
mean of 3-way mixtures	**30.44**	**27.39**	**32.11**	**29.98**
A+B+C+D	30.92	27.20	32.85	30.32
Overall mean	**31.88**	**27.90**	**32.16**	**30.65**
SE	**± 1.107[a]**	**± 1.324[b]**	**± 0.846[a]**	

Values are the mean ± s.e. of the second leaf harvest from three replicate cowpea plots.
Values with the same letter are not significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.7 Stability of leaf protein content of cowpea

The ecovalence value, which is the measure of stability, ranged from 0.23 for mixture A+B+D (most stable) to 5.4 for variety B (least stable). On average, individual cowpea varieties had the highest mean ecovalence values for leaf protein indicating highly unstable protein content. The 4-way mixture was on average the most stable mixture with the lowest ecovalence value among the mixtures (Figure 13). The crude protein content of landrace F was more stable than landrace E.

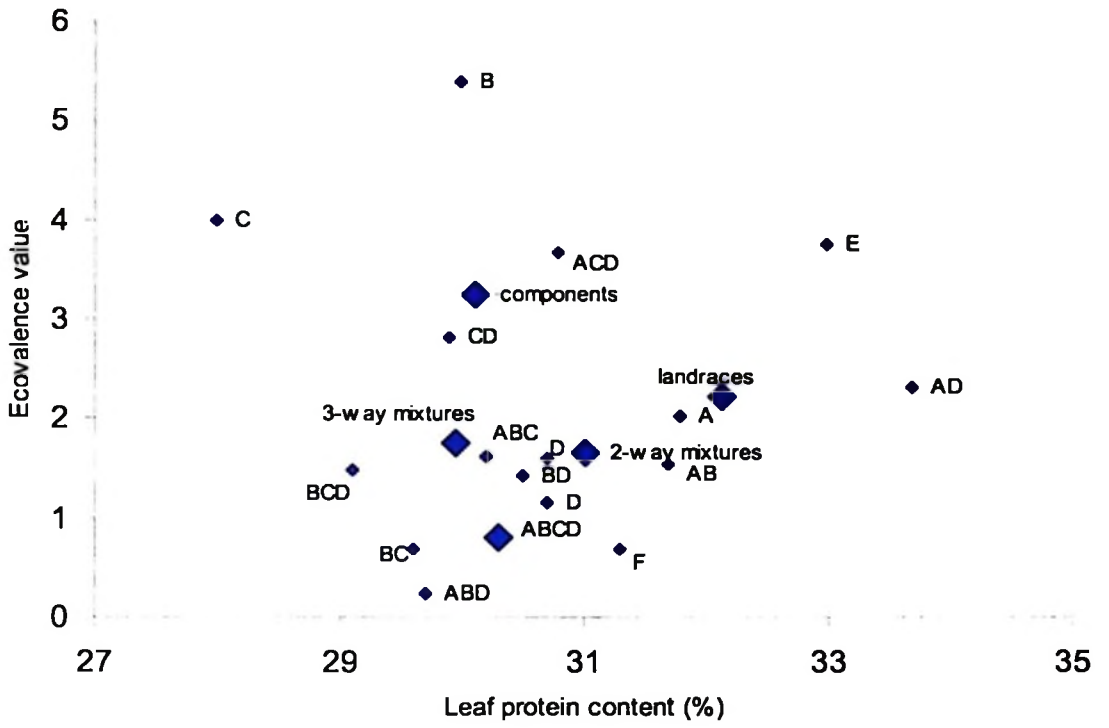


Figure 13: Stability (expressed by ecovalence) of leaf protein content of individual cowpea varieties and their possible mixtures grown at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008. Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.8 Effect of leaf-harvesting on pod number

Leaf-harvesting caused different effects on pod number. The number of pods per non leaf-harvested plant varied from 13.37 (54.3 pods/m^2) in landrace E at Kikota village to 0.68 (3.33 pods/m^2) in C+D at Kogili village (Table 16a and Appendix 8). Among leaf-harvested plants, the number of pods per plant ranged from 11.70 (5.16 pods/m^2) in landrace E at Kikota village to 0.58 (2.63 pods/m^2) in mixture A+C+D at Kogili village. On average, the highest reduction caused by leaf-harvesting reached 40.6% in component varieties, while the least reduction of 19.8% was observed among the 2-way mixtures (Table 16b). Most of the positive effects in pod number coming with leaf-harvesting were noted at Kikota village and ranged from 33.8% in landrace E to 3.6% in mixture C+D at Kogili village. With the exception of mixture B+C+D at NaSARRI, Serere, mixtures B+D and C+D at Kogili village, leaf-harvesting reduced

the number of pods per plant. Leaf harvesting significantly reduced the number of pods per square meter only at Kogili village, but not at NaSARRI, Serere or Kikota village (Appendix 8b).

Table 16: (a) Mean number of pods per plant of individual and mixed cowpea varieties plus landraces from both leaf-harvested (H) and non leaf-harvested (NH) plants grown during 2008 at NaSARRI, Serere, Kikota and Kogili villages.

	NaSARRI, Serere		Kikota village		Kogili village		Mean	
Treatment	**NH**	**H**	**NH**	**H**	**NH**	**H**	**NH**	**H**
A	9.35	4.73	12.96	9.43	4.19	1.64	8.83	5.27
B	6.95	4.57	5.98	5.32	2.90	1.85	5.28	3.92
C	7.81	2.52	3.97	4.20	2.37	0.95	4.72	2.56
D	9.24	3.87	6.25	4.96	1.66	1.02	5.72	3.28
mean of components	**8.34**	**3.92**	**7.29**	**5.97**	**2.78**	**1.37**	**6.14**	**3.76**
E	10.33	4.66	13.37	11.70	2.12	2.04	8.60	6.13
F	6.64	3.48	6.31	8.44	1.26	0.68	4.74	4.20
mean of landraces	**8.48**	**4.07**	**9.84**	**10.07**	**1.69**	**1.36**	**6.67**	**5.17**
A+B	4.70	3.36	6.38	4.59	2.75	2.26	4.61	3.40
A+C	6.80	4.25	7.27	7.61	2.63	1.26	5.56	4.37
A+D	6.75	6.48	7.60	6.65	2.22	1.36	5.52	4.83
B+C	6.06	3.39	4.93	6.11	1.73	1.00	4.24	3.50
B+D	5.33	5.22	5.99	5.34	0.88	1.02	4.06	3.86
C+D	5.76	5.53	5.81	4.26	0.68	0.70	4.08	3.50
mean of 2-way mixtures	**5.90**	**4.71**	**6.33**	**5.76**	**1.81**	**1.27**	**4.68**	**3.91**
A+B+C	8.65	3.19	5.74	6.63	2.56	1.18	5.65	3.66
A+B+D	8.94	8.63	8.93	7.21	2.65	1.18	6.84	5.67
A+C+D	11.05	5.82	5.41	5.22	0.87	0.58	5.78	3.87
B+C+D	3.68	3.92	5.92	4.96	1.70	1.49	3.77	3.46
mean of 3-way mixtures	**8.08**	**5.39**	**6.50**	**6.00**	**1.94**	**1.11**	**5.51**	**4.17**
A+B+C+D	6.97	2.96	6.14	6.58	1.71	0.68	4.94	3.41
Overall mean	**7.35**	**4.51**	**7.00**	**6.42**	**2.05**	**1.23**	**5.47**	**4.05**
SE	**2.25**	**1.88**	**1.09**	**1.19**	**0.58**	**0.33**	**1.31**	**1.13**

Values are the mean ± s.e. of the number of pods per plant from three replicate cowpea plots.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

Table 16: (b) Pod yield (number of pods per plant) difference between leaf-harvested (H) and non leaf-harvested (NH) plants of individual cowpea varieties and variety mixtures varieties plus landraces grown during 2008 at NaSARRI, Serere, Kikota and Kogili villages.

	NaSARRI, Serere		Kikota village		Kogili village		mean	
Treatment	effect	effect (%)	effect	effect (%)	effect	effect (%)	effect	effect (%)
A	4.62	49.40	3.53	27.26	2.55	60.81	3.57	45.82
B	2.37	34.17	0.66	11.10	1.05	36.05	1.36	27.11
C	5.29	67.74	-0.23	-5.79	1.42	59.86	2.16	40.60
D	5.37	58.08	1.30	20.74	0.64	38.55	2.43	39.12
mean of components	**4.41**	**52.93**	**1.32**	**18.05**	**1.41**	**50.83**	**2.38**	**40.60**
E	5.67	54.88	1.67	12.47	0.08	3.87	2.47	23.74
F	3.15	47.51	-2.13	-33.79	0.58	46.15	0.53	19.96
mean of landraces	**4.41**	**51.99**	**-0.23**	**-2.36**	**0.33**	**19.66**	**1.50**	**23.10**
A+B	1.34	28.51	1.79	28.10	0.50	17.98	1.21	24.87
A+C	2.55	37.48	-0.34	-4.73	1.37	52.09	1.19	28.28
A+D	0.27	3.96	0.94	12.44	0.86	38.84	0.69	18.41
B+C	2.67	44.06	-1.19	-24.08	0.73	42.15	0.74	20.71
B+D	0.11	2.14	0.65	10.84	-0.14	-16.44	0.21	-1.15
C+D	0.23	4.01	1.55	26.66	-0.02	-3.56	0.59	9.04
mean of 2-way mixtures	**1.20**	**20.26**	**0.57**	**8.98**	**0.55**	**30.21**	**0.77**	**19.82**
A+B+C	5.47	63.18	-0.88	-15.36	1.38	53.91	1.99	33.91
A+B+D	0.31	3.42	1.73	19.33	1.47	55.49	1.17	26.08
A+C+D	5.23	47.34	0.20	3.62	0.29	33.41	1.91	28.12
B+C+D	-0.24	-6.57	0.96	16.26	0.21	12.46	0.31	7.38
mean of 3-way mixtures	**2.69**	**33.30**	**0.50**	**7.70**	**0.84**	**43.08**	**1.34**	**28.03**
A+B+C+D	4.01	57.50	-0.44	-7.21	1.03	60.08	1.53	36.79
Overall mean	**2.85**	**38.73**	**0.57**	**8.21**	**0.82**	**40.10**	**1.41**	**29.01**

Harvesting effect = NH – H; a negative value implies an increase due to leaf-harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.9 Effect of mixing cowpea varieties on pod number

Increase in the pod number per square meter varied from 9.0% in 2-way mixtures to 25.5% in the 4-way mixture among non-leaf harvested plants at Kikota village (Table 17). At Kogili village, mixing had a negative effect on pod number among leaf-harvested and non leaf-harvested plants alike. However, neither the positive nor the negative mixture effects observed among both non-leaf harvested and leaf-harvested plants at all the three sites of NaSARRI, Serere, Kikota village and Kogili village were statistically significant.

Table 17: Effect of mixing on cowpea pod yield per square meter from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at NaSARRI, Serere, Kikota and Kogili villages during the first cropping season of 2008.

			Effect of mixtures on number of pods/m^2		
Trial site			**2-way mixtures**	**3-way mixtures**	**4-way mixture**
NaSARRI Serere	H	mixture effect	0.98	4.04	-4.24
		mixture effect (%)	9.45	22.09	-20.95
	NH	mixture effect	-9.22	-1.81	-9.19
		mixture effect (%)	-24.05	-5.00	-25.20
Kikota Village	H	mixture effect	-2.18	-0.70	4.13
		mixture effect (%)	-1.76	-2.41	13.72
	NH	mixture effect	3.07	2.28	7.83
		mixture effect (%)	12.46	8.99	25.52
Kogili Village	H	mixture effect	-0.92	-1.72	-2.94
		mixture effect (%)	-14.54	-26.16	-43.80
	NH	mixture effect	-4.16	-3.39	-5.26
		mixture effect (%)	-37.17	-27.31	-42.52

Mixture effect expressed as deviations from the average of the component varieties.
Mixture effect (%) = (mixture yield–pure line component average)/pure line component average × 100.
All the values for the mixture effect are not significantly different at the 0.05 level.

3.10 Effect of leaf-harvesting on cowpea pod width

Variety C had the widest pods (1.13 cm) among non leaf-harvested plants at Kikota village, while the narrowest pods (0.34 cm) came from leaf-harvested plants of variety A at Kogili village. Whereas pod width was slightly increased by 3.1% and 2.0% due to leaf-harvesting in variety D at NaSARRI, Serere and in Landrace E at Kikota village, respectively, the pod width for the rest of the varieties reduced due to leaf-harvesting. At Kogili village, reduction in pod width ranged from 6.6% in landrace E to 44.4% in variety A. Pod width was, however, not affected by leaf harvesting in landrace F at Kikota village and in varieties B and C at Kogili village (Table 18). There was a great variability in pod width of variety A and landrace E. Pest pressure from pod-sucking bugs, aphids (*Aphis craccivora* Koch), flower thrips (*Megalurothrips sjostedti* Trybom), and the legume pod borer (*Maruca vitrata* Fab. Syn. *Maruca testulalis* Geyer) or diseases like scab (*Sphaceloma* sp.), false rust (*Synchytrium dolichi* (Cooke) Gaum), anthracnose (*Colletotrichum lindemuthianum* (Sacc. & Magnus) Bri. & Car.) and powdery mildew (*Erysiphe polygoni* DC.) may have affected pod formation. Pods from leaf-harvested and non leaf-harvested plants at NaSARRI, Serere were significantly different in their pod width unlike those at

Kikota and Kogili villages. On average, pod width from leaf-harvested and non leaf-harvested plants did not differ significantly across the three sites.

Table 18: Mean pod widths of six cowpea varieties from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at the three locations of NaSARRI, Serere, Kikota village and Kogili village in Uganda during 2008.

	Mean pod width (cm)							
Trial site	**Variety ID**	**A**	**B**	**C**	**D**	**E**	**F**	**mean**
NaSARRI	NH	0.59	0.77	1.06	0.81	0.62	0.77	0.77 ± 0.02
Serere	H	0.56	0.70	1.03	0.83	0.51	0.66	0.71 ± 0.02
	harvesting effect	0.03	0.07	0.03	-0.02	0.11	0.12	
	harvesting effect (%)	5.93	9.09	2.84	-3.11	17.07	14.94	
Kikota	NH	0.74	0.79	1.13	0.81	0.59	0.71	0.79 ± 0.03
village	H	0.57	0.75	1.09	0.73	0.74	0.71	0.76 ± 0.10
	harvesting effect	0.18	0.04	0.03	0.09	-0.15	0.00	
	harvesting effect (%)	23.65	4.46	3.11	10.49	-25.64	0.00	
Kogili	NH	0.61	0.72	0.80	na	0.57	na	0.67 ± 0.05
village	H	0.34	0.72	0.80	0.50	0.56	na	0.58 ± 0.06
	harvesting effect	0.27	0.00	0.00	na	0.01	na	
	harvesting effect (%)	44.35	0.00	0.00	na	2.63	na	
means	NH	0.65	0.76	0.99	0.81	0.59	0.74	0.74 ± 0.04
	H	0.49	0.72	0.97	0.69	0.60	0.68	0.69 ± 0.06
	harvesting effect	0.16	0.03	0.02	0.04	-0.01	0.04	
	harvesting effect (%)	24.64	4.42	1.98	3.69	-1.98	7.47	

Values are the mean ± s.e. pod width from three replicate cowpea plots.
Harvesting effect = NH – H; a negative value indicates an increase in pod width due to harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
na = not available.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.11 Effect of leaf-harvesting on pod length

Among leaf-harvested plants, pod length varied from 17.85 cm in variety B at Kikota village to 7.04 cm in landrace E at Kogili village, while among non leaf-harvested plants pod length was between 17.82 in variety B at Kikota village and 9.30 cm in landrace E at Kogili village. Leaf harvesting increased pod length by 0.1-10.6% for variety B and for variety C at NaSARRI, Serere, but, reduced pod length in the rest of varieties (Table 19). Overall, the reduction in pod length was, however, not significant. The high variability in pod length of variety A and landrace E may reflect the genetic diversity they contain but also pest pressure from pod-sucking bugs and/or aphids may have affected pod development.

Table 19: Mean pod lengths of six cowpea varieties from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at the three locations of NaSARRI, Serere, Kikota village and Kogili village in Uganda during 2008.

		Mean pod length (cm)						
Trial site	**Variety ID**	**A**	**B**	**C**	**D**	**E**	**F**	**mean**
NaSARRI	NH	10.57	16.86	12.79	14.08	10.16	11.42	12.65 ± 0.47
Serere	H	9.75	17.35	13.97	12.98	8.65	9.20	11.98 ± 0.51
	harvesting effect	0.82	-0.49	-1.18	1.11	1.52	2.23	
	harvesting effect (%)	7.76	-2.91	-9.19	7.85	14.91	19.48	
Kikota	NH	12.95	17.82	15.15	14.42	10.16	11.54	13.67 ± 0.40
village	H	10.85	17.85	15.23	12.64	9.91	10.82	12.88 ± 0.38
	harvesting effect	2.10	-0.02	-0.07	1.78	0.25	0.72	
	harvesting effect (%)	16.22	-0.14	-0.50	12.33	2.46	6.24	
Kogili	NH	14.89	14.66	15.83	na	9.30	na	13.67 ± 1.02
village	H	8.14	16.22	14.30	9.65	7.04	na	11.07 ± 1.09
	harvesting effect	6.75	-1.56	1.53	na	2.26	na	
	harvesting effect (%)	45.33	-10.62	9.64	na	24.26	na	
mean	NH	12.80	16.45	14.59	14.25	9.87	11.48	13.33 ± 0.63
	H	9.58	17.14	14.50	11.75	8.53	10.01	11.98 ± 0.66
	harvesting effect	3.22	-0.69	0.09	1.44	1.34	1.47	
	harvesting effect (%)	23.10	-4.56	0.06	10.09	13.88	12.86	

Values are the mean ± s.e. pod length from three replicate cowpea plots.
Harvesting effect = NH – H; a negative value indicates an increase in pod length due to harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
na = not available.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.12 Effect of leaf-harvesting on number of seeds per pod

Mean number of seeds per pod ranged from 14.90 in variety B at NaSARRI, Serere to 5.75 in variety C at Kogili village among non-leaf harvested plants. Leaf-harvested plants on the other hand, had the mean number of seeds per pod between 14.15 in variety B at Kikota village and 5.20 in variety A at Kogili village. An increase in number of seeds per pod due to leaf harvesting was recorded for landrace F (2.7%) at Kikota village, variety B (21.9%) and C (73.9%) at Kogili village and variety C (23.2%) at Kogili village. Whereas there was no significant difference in the number of seeds per pod at Kikota village, there were more seeds per pod in the non leaf-harvested plants than in leaf-harvested plants at NaSARRI, Serere. An opposite trend was observed at Kogili where the number of seeds per pod was higher in leaf-harvested plants than in the non leaf-harvested plants (Table 20). Overall, the number of seeds per pod was not significantly influenced by leaf-harvesting.

Table 20: Number of seeds per pod for six cowpea varieties from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at the three locations of NaSARRI, Serere, Kikota village and Kogili village in Uganda during 2008.

		mean number of seeds per pod						
Trial site	**Variety**	**A**	**B**	**C**	**D**	**E**	**F**	**mean**
	NH	11.55	14.90	11.05	11.25	10.80	10.85	11.73 ± 0.57
NaSARRI	H	9.85	11.90	10.60	7.45	8.95	9.10	9.64 ± 0.71
Serere	harvesting effect	1.70	3.00	0.45	3.80	1.85	1.75	
	harvesting effect (%)	14.72	20.13	4.07	33.78	17.13	16.13	
	NH	12.95	14.80	14.05	11.70	11.60	11.30	12.73 ± 0.54
Kikota	H	12.65	14.15	14.00	6.56	11.40	11.60	11.73 ± 0.62
village	harvesting effect	0.30	0.65	0.05	5.14	0.20	-0.30	
	harvesting effect (%)	2.32	4.39	0.36	43.91	1.72	-2.65	
	NH	8.56	8.75	5.75	na	6.43	na	7.37 ± 1.17
Kogili	H	5.20	10.67	10.00	7.00	5.56	na	7.68 ± 0.61
village	effect	3.36	-1.92	-4.25	-7.00	0.87	na	
	% effect	39.22	-21.91	-73.91	na	13.58	na	
	NH	11.02	12.82	10.28	11.48	9.61	11.08	10.61 ± 0.76
mean	H	9.23	12.24	11.53	7.00	8.64	10.35	9.68 ± 4.30
	harvesting effect	1.79	0.58	-1.25	0.65	0.97	0.73	
	harvesting effect (%)	18.75	0.87	-23.16	38.84	10.81	6.74	

Values are the mean ± s.e. number of seeds per pod from three replicate cowpea plots.
Harvesting effect = NH-H; a negative value indicates an increase in seed number due to leaf harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
na = not available.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.13 Cowpea seed yield

The highest mean seed yield per plant of 10.87 g (55.12 g/m^2) was achieved from the non leaf-harvested plants of variety B at NaSARRI, Serere, while the lowest seed yield of 0.40 g/plant (3.34 g/m^2) came from the leaf-harvested plants of mixture A+C+D at Kogili village. The trend was, however, different when seed yield was expressed in g/m^2, with the highest yield of 86.97 g/m^2 (869.7 kg/ha) coming from the non leaf-harvested plants of variety A at NaSARRI, Serere, while the lowest yield of 1.81 g/m^2 (18.1 kg/ha) came from the non leaf-harvested plants of mixture A+C+D at Kogili village (Table 21 and Appendix 9). Seed yield was generally highest among the non-leaf harvested plants at NaSARRI, Serere and lowest among the leaf-harvested plants at Kogili village. Leaf-harvesting was noted to enhance seed yield in nine out of 41 treatments by 4.3 to 111.4% but decreased cowpea seed yield by 3 to 72.5%, in the rest of the treatments. The decrease or increase in seed yield due to leaf-harvesting was, however, not significant.

Table 21: Mean seed yield per plant of individual cowpea varieties and their possible mixtures plus two landraces from the leaf-harvested plants (H) and non leaf-harvested plants (NH) evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

		Mean seed yield (g/plant)					
Trial site		**A**	**B**	**C**	**D**	**E**	**F**
NaSARRI	NH	5.95	8.28	10.87	10.19	6.12	5.81
Serere	H	2.87	5.41	2.98	2.91	2.67	2.64
	harvesting effect	3.09	2.87	7.88	7.28	3.46	3.17
	harvesting effect (%)	51.85	34.67	72.54	71.47	56.47	54.59
Kikota	NH	12.59	8.45	5.45	7.17	9.49	6.31
village	H	14.97	8.12	7.29	5.83	10.88	13.40
	harvesting effect	-2.38	0.33	-1.84	1.34	-1.39	-7.09
	harvesting effect (%)	-18.90	3.89	-33.85	18.68	-14.65	-112.37
Kogili	NH	2.20	2.33	2.42	1.23	1.00	1.04
village	H	0.76	1.21	0.88	0.69	1.04	0.51
	harvesting effect	1.44	1.12	1.54	0.54	-0.04	0.53
	harvesting effect (%)	65.39	48.03	63.56	44.02	-4.30	51.01
		A+B	**A+C**	**A+D**	**B+C**	**B+D**	**C+D**
NaSARRI	NH	5.26	7.17	5.37	7.42	4.68	8.81
Serere	H	2.68	4.31	5.21	3.47	4.31	6.52
	effect	2.58	2.86	0.16	3.95	0.36	2.29
	% effect	49.02	39.87	2.98	53.27	7.78	25.98
Kikota	NH	6.45	5.70	6.43	7.11	7.83	8.03
village	H	3.92	8.82	4.70	9.69	7.38	6.37
	harvesting effect	2.54	-3.12	1.73	-2.58	0.45	1.66
	harvesting effect (%)	39.30	-54.79	26.88	-36.30	5.75	20.66
Kogili	NH	1.74	2.19	1.76	1.14	0.45	0.59
village	H	1.34	0.90	0.83	0.72	0.49	0.45
	harvesting effect	0.39	1.29	0.93	0.42	-0.04	0.14
	harvesting effect (%)	22.68	58.92	52.78	37.14	-9.82	24.37
		A+B+C	**A+B+D**	**A+C+D**	**B+C+D**	**A+B+C+D**	**overall mean**
NaSARRI	NH	9.04	9.15	9.53	3.78	6.73	7.30 ± 2.46
Serere	H	3.07	8.39	5.42	4.53	2.91	4.14 ± 1.99
	harvesting effect	5.97	0.76	4.11	-0.75	3.81	3.17
	harvesting effect (%)	66.04	8.36	43.12	-19.86	56.69	43.38
Kikota	NH	6.40	9.43	5.60	8.31	7.00	7.51 ± 1.78
village	H	5.58	7.82	5.12	9.24	9.03	8.13 ± 2.24
	harvesting effect	0.82	1.61	0.48	-0.93	-2.03	-0.61
	harvesting effect (%)	12.75	17.07	8.52	-11.14	-28.94	-8.15
Kogili	NH	1.89	1.66	0.67	1.01	1.23	1.44 ± 0.47
village	H	0.84	0.74	0.40	0.81	0.53	0.77 ± 0.26
	harvesting effect	1.05	0.92	0.27	0.20	0.71	0.67
	harvesting effect (%)	55.43	55.52	40.60	19.54	57.31	46.46

Values are the mean ± s.e. seed weight per plant from three replicate cowpea plots.
Harvesting effect = NH-H; a negative value indicates an increase in seed yield due to leaf harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.14 Effect of mixing on cowpea seed yield

Mixing cowpea varieties had both positive and negative effects on seed yield (Table 22). An increase in seed yield due to mixing was observed in 22 of the 66 treatments, though not significant, it varied from 0.3% among the non leaf-harvested plants of A+B+D to 112.5% among the leaf-harvested plants of A+C+D at NaSARRI, Serere. Seed yield reduction due to mixing ranged from 1.1% among the leaf-harvested plants of A+C+D at NaSARRI, Serere to 71.5% among the non-leaf harvested plants at Kogili village and was significant in only eight out of 66 treatments. Seed yield was not significantly affected by mixing among (i) both leaf-harvested and non leaf-harvested plants at NaSARRI, Serere; (ii) non-leaf harvested plants at Kikota village, and (iii) leaf harvested plants at Kogili village. Although seed yield was reduced in leaf harvested and non-leaf harvested plants alike, non leaf-harvested plants suffered a relatively higher reduction of seed yield than leaf-harvested plants.

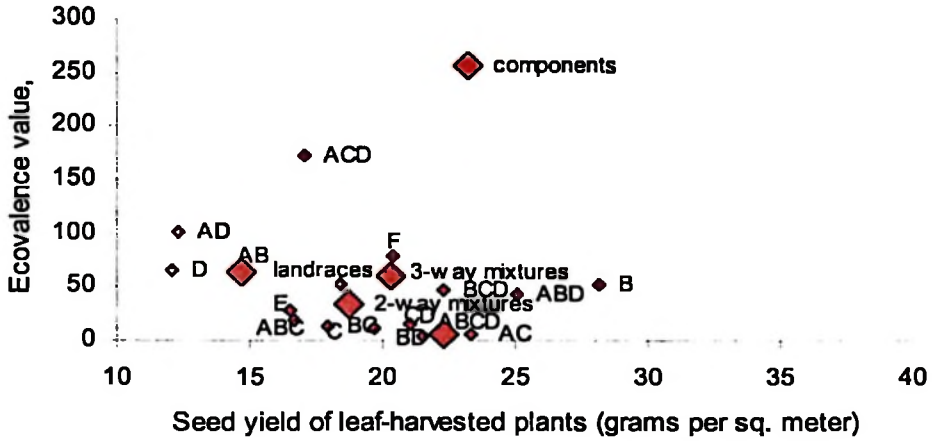
Table 22: Effect of mixing cowpea varieties on seed yield from both leaf-harvested (H) and non leaf-harvested (NH) plants grown during 2008 at NaSARRI, Serere, Kikota and Kogili villages.

	Mixture effect (%)					
Trial sites	**NaSARRI, Serere**		**Kikota village**		**Kogili village**	
Treatment	**NH**	**H**	**NH**	**H**	**NH**	**H**
A+B	-30.00	-41.54	-18.58	-62.64*	-10.59	13.53
A+C	-8.45	71.16	-25.88	-31.42	-6.85	-5.81
A+D	-41.43	13.61	-16.65	-65.13*	5.93	15.32
B+C	-7.41	-13.51	23.91	-11.57	-61.30*	-40.02
B+D	-46.31	-12.45	28.22	28.37	-71.47*	-44.78
C+D	6.09	85.31	35.00	31.76	-64.57*	-51.34
mean of 2-way mixtures	**-21.25**	**17.10**	**4.34**	**-18.44**	**-34.81**	**-18.85**
A+B+C	0.87	-24.24	-12.44	-45.01*	-31.94	-21.06
A+B+D	0.29	55.94	3.33	-19.26	-6.81	-25.83
A+C+D	13.15	112.45	-9.47	-55.55*	-61.37*	-53.93
B+C+D	-56.87	-1.05	42.68	30.37	-41.43	-19.12
mean of 3-way mixtures	**-10.64**	**35.78**	**6.02**	**-22.36**	**-35.39**	**-29.99**
A+B+C+D	-31.08	-14.82	21.25	3.61	-45.10	-36.10
overall mean	**-18.29**	**20.99**	**6.49**	**-17.86**	**-35.95**	**-24.47**

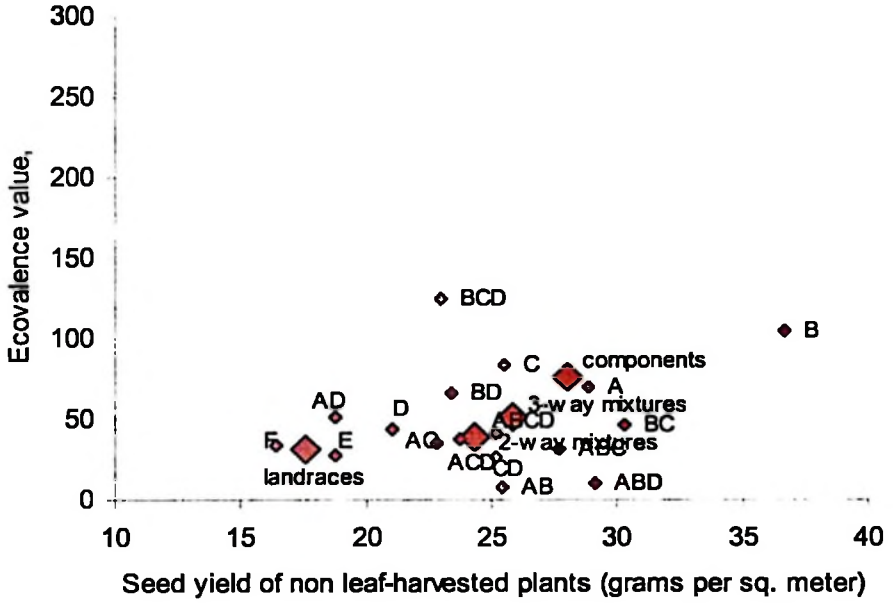
Mixture effect (%) = (mixture yield–pure line component average)/pure line component average × 100.
Values with * are significantly different at the 0.05 level.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.15 Stability of cowpea seed yields

Seed yields of variety A were the most unstable (Ecovalence value of 894.84 and seed yield of 34.7 g/m^2) while those of mixture B+D were the most stable among the leaf-harvested plants (Figure 14). The trend was, however, different among non leaf-harvested plants, where mixture A+B was the most stable and mixture B+C+D was least stable for their seed yield across the three environments. Individual cowpea varieties (particularly variety B) had the highest seed yield for both the leaf-harvested and non leaf-harvested plants, but it also had the highest mean ecovalence values indicating that it was least stable. No clear relationship could be seen between the ecovalence values and the number of components in a mixture or yield. The ecovalence values also varied slightly when the seed yield was expressed in g/plant, with, for instance, 4-way mixtures being more stable in both leaf-harvested and non leaf-harvested plants (Appendix 10). Ecovalence values were also generally lower for the non leaf-harvested plants than for leaf-harvested plants.



(a)



(b)

Figure 14: Stability (expressed by ecovalence) of seed yield of individual cowpea varieties and their possible mixtures grown at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008. (a) Leaf harvested and (b) Non-leaf harvested plants. (Among leaf-harvested plants, variety A had an ecovalence value of 894.84 and seed yield of 34.7 g/m^2 and is not shown in the figure). Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.16 Effect of leaf-harvesting on 100-seed weight of cowpea

Leaf-harvested plants of variety D at NaSARRI, Serere, had the heaviest seeds (18.47 g) while the lightest seeds (6.43 g) came from the leaf-harvested plants of variety A at Kogili village (Table 23). The 100-seed weights of variety A were nearly similar to those of landrace E and they both had the lightest seeds overall. Leaf-harvesting enhanced seed weights of nine out of 36 treatments by 0.4 to 12.2% but also decreased seed weights by 5.1 to10.5%. The mean 100-seed weights from both leaf-harvested and non leaf-harvested plants were not significantly different and were highest at NaSARRI, Serere and lowest at Kogili village.

Table 23: 100-seed weights for six cowpea varieties from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at the three locations of NaSARRI, Serere, Kikota village and Kogili village in Uganda during 2008.

		100-seed weight (g)						
	Variety ID	A	B	C	D	E	F	mean
NaSARRI, Serere	NH	6.70	14.13	16.70	16.47	7.73	11.57	12.22 ± 0.29
	H	7.17	13.33	16.90	18.47	7.13	10.60	12.27 ± 0.44
	harvesting effect	-0.47	0.80	-0.20	-2.00	0.60	0.97	-0.05
	harvesting effect (%)	-6.97	5.66	-1.20	-12.15	7.76	8.36	-0.41
Kikota village	NH	7.47	14.17	16.57	16.13	7.53	11.73	12.27 ± 0.46
	H	7.07	14.47	17.77	14.43	7.70	11.13	12.09 ± 0.58
	harvesting effect	0.40	-0.30	-1.20	1.70	-0.17	0.60	0.18
	harvesting effect (%)	5.36	-2.12	-7.24	10.54	-2.22	5.11	1.47
Kogili village	NH	7.00	12.47	15.60	15.23	6.80	10.70	11.30 ± 0.15
	H	6.43	11.70	15.67	16.10	7.10	9.77	11.13 ± 0.29
	harvesting effect	0.57	0.77	-0.07	-0.87	-0.30	0.93	17.22
	harvesting effect (%)	8.10	6.15	-0.43	-5.69	-4.41	8.72	152.36
Overall mean	NH	7.06	13.59	16.29	15.94	7.36	11.33	11.93 ± 0.30
	H	6.89	13.17	16.78	16.33	7.31	10.50	11.83 ± 0.44
	harvesting effect	0.17	0.42	-0.49	-0.39	0.04	0.83	9.81
	harvesting effect (%)	2.36	3.11	-3.00	-2.44	0.60	7.35	82.24

Values are the mean ± s.e. weight of 100 seeds from three replicate cowpea plots.
Harvesting effect =NH-H; a negative value indicates an increase in seed weight due to leaf-harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.17 Cowpea dry matter shoot yield

At about 31 days after planting (DAP), the percentage of dry matter shoot yield in relation to the fresh matter shoot yield, varied from 12.3% for a plant from mixture B+D at NaSARRI, Serere to 23.2% for a plant from mixture A+D at Kogili village.

As expected, the percentage of dry matter shoot yield was higher at about 45 DAP and it ranged from 14.0% for a plant from landrace F at NaSARRI, Serere to 27.8% for a plant from mixture C+D at Kogili village (Appendix 11). Among component varieties, the smallest percentage of shoot dry weight came from variety A, while plants from variety C had the biggest percentage of dry matter shoot yield. Compared to all the treatments, landraces always had the lowest mean percentage of dry matter shoot yield, while 2-way mixtures had the highest mean percentage of dry matter shoot yield.

The dry matter shoot yield per plant was in the range of 1.20 g for a plant of variety A at Kogili village and 4.77 g for a plant from mixture A+B+C at NaSARRI, Serere at about 31 DAP (Table 24). A plant from landrace E at Kogili village had the lowest dry matter shoot yield of 1.73 g, 45 DAP, while after about the same number of DAP, a plant from mixture A+B gave the highest dry matter shoot yield of 11.37 g at NaSARRI, Serere. On average, plants at NaSARRI, Serere, had the highest dry matter shoot yield while plants at Kogili village had the lowest dry matter shoot yield at both 31 and 45 DAP. The mean dry matter shoot yield across all treatments increased with increasing number of components in a mixture, with the 4-way mixture (A+B+C+D) having the highest mean dry matter shoot yield followed by 3-way mixtures, 2-way mixtures and, lastly, components. Landraces produced the lowest dry matter shoot yield both at 31 and 45 DAP across all the three trial sites.

Table 24: Mean dry matter shoot yield of individual cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Cowpea dry matter shoot yield (g/plant)							
	NaSARRI, Serere		Kikota village		Kogili village		mean	
Treatment	31 DAP	45 DAP	32 DAP	46 DAP	30 DAP	44 DAP	31 DAP	45 DAP
A	1.67	4.53	3.40	3.90	1.20	2.60	2.09	3.68
B	3.80	10.50	3.23	4.17	2.07	3.17	3.03	5.95
C	4.10	8.17	3.40	6.67	3.07	5.80	3.52	6.88
D	3.23	10.63	1.93	4.80	1.70	5.07	2.29	6.83
mean	**3.20**	**8.46**	**2.99**	**4.88**	**2.01**	**4.16**	**2.73**	**5.83**
E	1.53	6.57	2.73	3.13	1.27	1.73	1.84	3.81
F	2.47	5.47	1.90	3.27	1.63	2.50	2.00	3.75
mean	**2.00**	**6.02**	**2.32**	**3.20**	**1.45**	**2.12**	**1.92**	**3.78**
A+B	3.33	11.37	3.17	2.87	2.27	4.10	2.92	6.11
A+C	3.17	5.70	3.63	3.33	2.37	3.43	3.06	4.15
A+D	4.53	4.13	3.03	4.13	1.57	5.00	3.04	4.42
B+C	4.40	10.87	3.63	6.10	2.07	6.00	3.37	7.66
B+D	3.93	6.80	2.70	4.97	1.37	5.47	2.67	5.75
C+D	3.27	10.40	2.93	5.33	1.93	3.47	2.71	6.40
mean	**3.77**	**8.21**	**3.18**	**4.46**	**1.93**	**4.58**	**2.96**	**5.75**
A+B+C	4.77	10.17	1.77	5.83	2.97	3.63	3.17	6.54
A+B+D	4.10	8.00	3.43	7.00	1.77	2.40	3.10	5.80
A+C+D	4.33	9.03	3.47	2.77	1.83	4.37	3.21	5.39
B+C+D	2.93	10.50	4.10	3.20	1.43	5.73	2.82	6.48
mean	**4.03**	**9.43**	**3.19**	**4.70**	**2.00**	**4.03**	**3.07**	**6.05**
A+B+C+D	3.93	10.87	3.50	9.13	1.97	5.77	3.13	8.59
Overall mean	**3.50**	**8.45**	**3.06**	**4.74**	**1.91**	**4.13**	**2.82**	**5.77**
SE	**0.75**	**2.78**	**0.76**	**1.22**	**0.44**	**0.96**	**0.65**	**1.65**

DAP = days after planting.
Values are the mean ± s.e. of the dry matter shoot weights per plant from three replicate cowpea plots.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.18 Effect of mixing cowpea varieties on dry matter shoot yield

Mixing of cowpea varieties increased dry matter shoot yield in 36 out of 66 treatments ranging from 3.0% in variety mixture A+B+C+D at 30 DAP at Kogili village to 92.6% in variety mixture A+B+C+D at 46 DAP at Kikota village. This increase, however, was significant in only two instances, in variety mixture A+D at NaSARRI, Serere at 31 DAP by 85.02% and in variety mixture A+B+C+D at Kikota village at 46 DAP (Table 25). On average, the mixture effect was higher at about 31 DAP than at about 45 DAP. Though not significant, a number of variety mixtures had a trend to

negative effects and they ranged from 0.5% in mixture B+C at Kogili village at 30 DAP to 47.9% in mixture A+C+D at Kikota village at 46 DAP.

Table 25: Effect of mixing varieties on cowpea dry matter shoot yield at different growth stages at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

Mixture effects on cowpea shoot dry matter yield (g/plant)								
	NaSARRI, Serere		Kikota village		Kogili village		mean	
	mixture effect	mixture effect (%)	mixture effect	mixture effect (%)	mixture effect	mixture effect (%)	mixture effect	mixture effect (%)
Treatment	31 DAP		32 DAP		30 DAP			
A+B	0.60	21.93	0.34	12.16	0.38	20.21	0.44	18.10
A+C	0.28	9.83	1.05	40.62	0.28	13.61	0.54	21.35
A+D	2.08*	85.02*	-0.42	-12.09	-0.02	-1.04	-0.22	-6.56
B+C	0.45	11.39	0.65	21.88	-0.01	-0.45	0.36	10.94
B+D	0.42	11.84	-0.63	-19.00	-0.75	-35.43	-0.32	-14.20
C+D	-0.40	-10.90	-0.32	-9.85	-0.06	-3.03	-0.26	-7.92
mean	**0.27**	**8.82**	**0.11**	**5.62**	**-0.03**	**-1.02**	**0.12**	**4.47**
A+B+C	1.58	49.48	-1.11	-38.69	1.01	51.44	0.49	20.75
A+B+D	1.20	41.38	0.52	18.04	-0.13	-6.80	0.53	17.54
A+C+D	1.33	44.43	0.19	5.77	-0.03	-1.51	0.50	16.23
B+C+D	-0.78	-20.96	0.88	27.52	-0.52	-26.80	-0.14	-6.75
mean	**0.83**	**28.58**	**0.12**	**3.16**	**0.08**	**4.08**	**0.35**	**11.94**
A+B+C+D	0.73	22.91	0.44	14.50	0.06	2.99	0.41	13.46
Overall mean	**0.54**	**18.13**	**0.15**	**5.53**	**0.02**	**1.20**	**0.24**	**8.29**
	45 DAP		46 DAP		44 DAP			
A+B	3.85	51.23	-1.25	-30.32	0.53	14.95	1.05	11.95
A+C	-0.65	-10.24	-1.53	-31.51	0.32	10.16	-0.62	-10.53
A+D	-3.45	-45.50	-2.38	-36.58	0.82	19.52	-1.67	-20.85
B+C	1.53	16.43	1.45	31.12	1.56	35.05	1.51	27.53
B+D	-3.77	-35.65	-1.03	-17.22	0.53	10.81	-1.42	-14.02
C+D	1.00	10.64	-0.25	-4.54	-0.91	-20.84	-0.06	-4.92
mean	**-0.25**	**-2.18**	**-0.83**	**-14.84**	**0.47**	**11.61**	**-0.20**	**-1.80**
A+B+C	2.43	31.47	1.33	29.62	-0.36	-9.12	1.13	17.32
A+B+D	-0.56	-6.49	2.26	47.62	-1.44	-37.53	0.09	1.20
A+C+D	1.26	16.14	-2.54	-47.85	0.28	6.95	-0.33	-8.25
B+C+D	0.73	7.51	-1.77	-35.61	1.25	27.74	0.07	-0.12
mean	**0.97**	**12.16**	**-0.18**	**-1.55**	**-0.07**	**-2.99**	**0.24**	**2.54**
A+B+C+D	2.41	28.48	4.39*	92.63*	1.64	39.59	2.02	34.03
Overall mean	**0.46**	**5.96**	**-0.68**	**-11.90**	**0.45**	**10.42**	**0.08**	**1.49**

DAP = days after planting.
Mixture effect expressed as deviations from the average of the component varieties.
Mixture effect (%) = (mixture yield–pure line component average)/pure line component average × 100.
* Significantly different at the 0.05 level.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

3.19 Relationship between cowpea traits

Using Spearman's rank correlation coefficient, a large variation across environments could be seen between the total fresh leaf yield, total dry matter leaf yield, pod yield, seed yield, shoot dry matter yield, seed yield, crude protein content and iron concentration (Table 26). There was a highly significant positive correlation between fresh leaf yield and dry matter leaf yields implying that either trait may be measured. The correlation between dry matter leaf yield and seed yield was however not significant.

Table 26: Spearman's rank correlation coefficient between traits of individual cowpea varieties and variety mixtures assessed across three environments of NaSARRI, Serere, Kikota and Kogili villages in Uganda.

Trait	TFLYd	DMLYd	PdYdH	PdYdN	SdYdH	SdYdN	DMStY1	DMStY2	CP
DMLYd	0.986**								
PdYdH	-0.634**	-0.611**							
PdYdN	-0.532*	-0.506*	0.798**						
SdYdH	-0.265	-0.287	0.585*	0.417					
SdYdN	0.081	0.109	0.247	0.593*	0.317				
DMStY1	0.650**	0.646**	-0.414	-0.405	-0.404	-0.022			
DMStY2	0.630**	0.638**	-0.665**	-0.521*	-0.434	0.014	0.555*		
CP	-0.710**	-0.691**	0.528*	0.357	-0.061	-0.341	-0.492*	-0.515*	
Fe	-0.181	-0.231	0.502*	0.216	0.582*	0.075	-0.159	-0.404	0.58

Key: TFLYd = Total fresh leaf yield, DMLYd = Total dry matter leaf yield, PdYdH = Pod yield from leaf-harvested plants, PdYdN = Pod yield from non leaf-harvested plants, SdYdH = Seed yield from leaf-harvested plants, SdYdN = Seed yield from non leaf-harvested plants, DMStY1 = dry matter shoot yield at 32 DAP, DMStY2 = dry matter shoot yield at 45 DAP, CP = crude protein content, Fe = Iron concentration. +, * and ** stands for significant difference among treatments at $P < 0.01$, 0.05 and 0.10, respectively

3.20 Farmer interviews

Of the 21 farmers that were interviewed about various aspects of vegetable use of cowpea leaves and variety mixtures, 43% had intercropped cowpea with maize. The rest of the farmers cultivated cowpea as a sole crop or in intercrop with cassava, pigeon pea or mung bean. Nearly all the farmers obtained their seeds from local markets and aphids were the main insect pest reported (Figure 15). One kilogram of dry cowpea seeds and fresh cowpea leaves/shoots had nearly the same price ranges, varying from 0.32 to 0.94 USD depending on the season of the year, being highest during the dry season when only farmers near water bodies can grow the crop under irrigation. Farmers used mixtures of the two landraces (E and F) and seeds were

bought from the local markets when mixed. All the farmers interviewed grew cowpea for both its vegetable tender leaves and for the final seed as well. The top four leafy vegetables consumed (in order of their preference) included cowpea (Ebbo), spider plant (Echadoi), amaranth (Boga) and white cabbage, but kale (Sukuma wiki) and pumpkin leaves (Nsujju) were also eaten. The quantity of fresh cowpea leaves consumed per day depended on the size of the household, but ranged from about 0.5 kg for three people to 2 kg for 12 people. Cowpea leaves were usually boiled either alone or with milk, peanut paste, sesame paste, or other vegetables. Sun-drying was the main preservation method used, but blanching and shade-drying were also reported by two farmers. The size of cowpea gardens ranged from very small home gardens (about 0.025 ha), among farmers who grew cowpea solely for home consumption, to large fields of about one hectare. Interesting to note is that four of the farmers interviewed reported that leaf-harvesting prior to flowering enhanced cowpea seed yields. Leaves were reported to be harvested either daily, weekly, twice a week or occasionally but the leaf-harvesting was not always done on the same plants but rather on a plant with sufficient tender leaves.

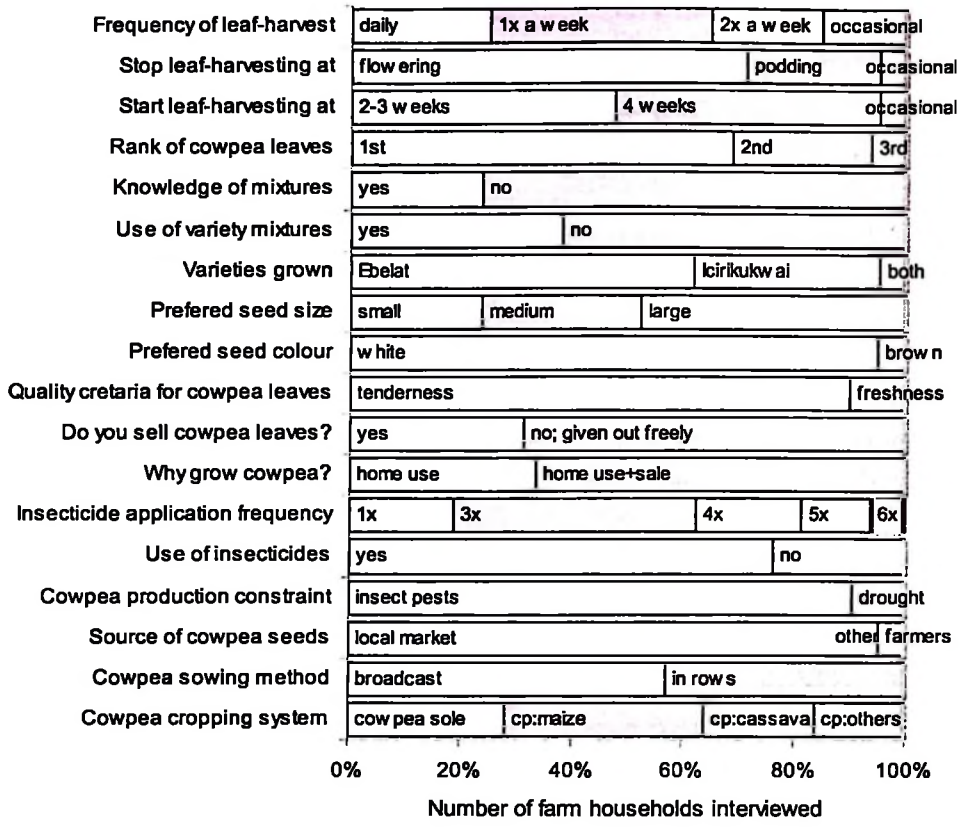


Figure 15: Responses of four farmers at NaSARRI, Serere, eight farmers at Kikota village and nine farmers at Kogili villages, Uganda during 2008. One person was interviewed from each household and they included three men and 18 women. cp=cowpea.

4. Discussion

4.1 Effect of rainfall on morpho-agronomic characteristics of cowpea

The indeterminate growth pattern of variety A and the determinate growth pattern of varieties B, C and D that was observed across the three trial sites in Uganda is similar to that observed for the same varieties in Dodoma, Tanzania (Kabululu, 2008). The cowpea varieties at NaSARRI, Serere and at Kogili village flowered and matured earlier than the cowpea in the trial at Kikota village because of the little rainfall that was received at the latter site. Angessa (2006) and Kabululu (2008) also observed a delayed flowering and maturity of the same cowpea varieties at trial sites in Dodoma and Arusha, Tanzania, respectively, which had received little rainfall. On the other hand, excessive moisture, cool temperatures and photoperiod are said to cause a slight delay in days to flowering of cowpea (Huxley and Summerfield, 1975) but the maximum days to flowering is specific to each genotype (Hadley et al., 1984; Akande, 2007).

4.2 Effect of rainfall on maize yield

The growth and subsequent seed yield of maize was largely influenced by the amount and pattern of rainfall. The low precipitation at Kikota village (<50 mm) during the critical cob-filling stage reduced maize seed yields to 63.30 g/plant compared to 128.13 g/plant that was achieved at NaSARRI, Serere, or 100.5 g/plant at Kogili village where rainfall was not limiting. In similar experiments, low precipitation was observed to cause complete maize crop failure at NaSARRI, Serere during the previous cropping season of 2007 (Polreich, 2008, personal communication) and in Dodoma (Kabululu, 2008). The mean maize seed yield (128.13 g/plant) achieved at NaSARRI, Serere is close to that of 130 g/plant obtained when the same experiment was carried out in Dodoma, Tanzania, probably because annual average rainfall was above 570 mm at both sites and there was adequate soil moisture (Kabululu, 2008). There was no significant difference in maize seed yields from either the plots planted with individual cowpea varieties or mixtures. Similarly, Kamara and Haque (1991) did not find any significant difference in maize seed yield when maize was intercropped with three forage-type cowpea varieties in the Ethiopian highlands. This

implies that this particular maize variety (Situka 1) can be grown with any of the cowpea varieties.

4.3 Is it more beneficial to grow cowpea for both leaf and seed or for seed alone? How did leaf harvesting affect the components of seed yield?

Like it was observed in this study where all the farmers grew cowpea for both leaves and seeds, various authors (Bittenbender et al., 1984; Sabiti et al., 1994; Isubikalu et al., 1999; Adipala, 2003) have noted that most of the subsistence farmers in Uganda grow cowpea for dual purpose use. Whether a mixed (leaf and seed) harvest strategy is more beneficial than seed harvest alone, has been a subject of interest for many scientists. Looking at the total leaf yields (Table 11) and seed yield (Table 21), obtained from the three field trials of this study, one can see that, apart from the trial conducted at NaSARRI, Serere where the proportion of the leaves harvested (1.80 g/plant) could not compensate fully (by 1.36 g) for the decrease in seed yield among the leaf-harvested plants (7.30 – (1.80 + 4.14) = 1.36 g/plant), leaf and seed yield from leaf-harvested plants combined, was more beneficial at the other two trial sites. At Kikota village, leaf yield (1.45 g/plant) and seed yield of leaf-harvested plants (8.13 g/plant) combined exceeded the seed yield of non leaf-harvested plants (7.51 g/plant) by 1.56 g/plant, while at Kogili village, the weight of leaf (1.30 g/plant) and seed (1.44 g/plant) from leaf-harvested plants exceeded the weight of seeds from non leaf-harvested plants by 0.63 g/plant.

The results from the two on farm trials at Kikota and Kogili villages are, however, different from what was reported by Bubenheim et al. (1990) that the leaf and seed harvest strategy is less efficient than either purely leaf or purely seed harvest strategies. This difference in leaf and seed yields could be due to the different management regimes and experimental set up since the experiment of Bubenheim et al. (1990) was conducted in a green house, while in this study, the experiments were carried out in the field (on station and on farm).

However, results from a similar experiment carried out in Dodoma, Tanzania, by Kabululu (2008), also indicated that the seed yield from non leaf-harvested plants (14.94 g/plant at on station and 21.54 g/plant at on farm) was greater than sum of leaf and seed yield of the leaf-harvested plants by 4.27 g/plant at on station (4.18 g/plant

leaf + 6.49 g/plant seed) and by 1.55 g/plant on farm (11.10 g/plant leaf + 8.89 g/plant seed). The difference between the results got in the current study in Uganda and those obtained from the study in Tanzania, may be due to varying environmental conditions prevailing at the locations during the time when the experiments were conducted like soil fertility, pattern and/or amount of rainfall, pest pressure. Factors like frequency of leaf-harvest, age of harvested leaves, degree of defoliation and management practices do strongly influence leaf and seed yields. Akande (2007) also observed that seed yield of a given cowpea genotype is significantly affected by the prevailing environmental conditions. More cowpea leaves had been removed in Kabululu's (2008) study (5.1 to 5.6 g/plant at 75% defoliation) while fewer cowpea leaves have been harvested in the current study (1.30 to 1.80 g/plant at a 25-50% defoliation). The former may have caused a stronger effect on seed production than in this study.

The results of enhanced seed yield due to defoliation observed at Kikota village (8.15%) (Table 21), support the findings of Karikari and Molatakgosi (1999) who observed that partial defoliation (25 to 50%) during the vegetative stages either had no significant effect or even enhanced seed yield of cowpea by increasing pod length, pod number, seed number and seed size. In the current study, the number of pods per plant, the number of seeds per pod and the 100-seed weight were generally not significantly affected by leaf-harvesting, and this is in agreement with the results of several authors (Stewart et al., 1978; Pandey, 1983; Bubenheim et al., 1990). Rahman et al. (2008) also showed that a 50% defoliation at flowering increased cowpea seed yield even more than 0 and 25% defoliation. In presence of sufficient rainfall, Haile et al. (1998) found no effect of between 46 and 66% defoliation on seed yield of soybean, but a decrease of 15 to 75% was observed when the rainfall was low. According to Pandey (1983), if defoliation is stopped before the early reproductive stages, seed yield will not be affected as it largely depends on post-flowering photosynthesis. The non significant correlation coefficient between seed yield and leaf yield indicates that high leaf yield does not necessarily come with low seed yields (Table 26).

Plants are said to compensate for the lost leaves by delayed leaf senescence, expansion of the remaining leaves and through re-growth of auxiliary shoots, which boosts the light interception capacity of the remaining plant canopy (Huxley and

Summerfield, 1976; Bubenheim et al., 1990). After different manipulations of leaf defoliation of cowpea in their study, Huxley and Summerfield (1976) concluded that removal of two-weeks old (or less than two weeks in a stressed environment) cowpea leaves had no effect on the overall growth of the plant and seed yield, and only the loss of the very young leaves near the shoot apex would severely affect growth and yield. The increase in seed yield due to leaf-harvesting indicates that the fraction of assimilates, which would have been used for the maintenance of the harvested leaves was channelled to increase seed yield. Another explanation for the increased seed yield in plants with mild defoliation observed in the present research, could be due to two reasons: the reduced canopy will allow for effective insecticide application (for contact pesticides), which successfully eliminates all pests, and fewer remaining leaves will allow for more sunlight to reach the leaves compared to when leaves would be too many on a plant, thereby shading themselves.

The mean cowpea seed yields of 35–374 kg/ha observed in this cowpea/maize intercropping study are similar to those reported in Nigeria by Blade et al. (1992) of 20-470 kg/ha but lower than 1192 kg/ha achieved in Ethiopia (Kamara and Haque, 1991) and the national on farm average in Uganda of 200-400 kg/ha (Sabiti et al., 1994; Adipala, 2003). The explanation for relatively low cowpea seed yields achieved in this study is possibly because of the traditional relay 1:1 intercropping system of planting cowpea 2-3 weeks after planting maize, which severely limited the ability of cowpea varieties to express their yield potential. Suppression of cowpea seed yields due to shading by cereals was also reported by Blade et al. (1992), when cowpea was planted three weeks after sorghum or millet had been planted. The high infestation of aphids noticed at the on farm trial at Kogili village may largely be responsible for the poor seed yields realized at this site. Aphids, pod-sucking bugs and flower thrips are among the most economically important cowpea pests in Uganda and can cause complete crop failure if no control measure is taken (Isubikalu et al., 1999; Karungi et al., 2000; Nampala et al., 2002). The higher seed yield realized at Kikota village was probably caused by the fact that the maize did not grow vigorously at this site, and this allowed enough sunlight to reach cowpea, hence, increasing the rate of photosynthesis that resulted in a better pod set.

Like it was the case at NaSARRI, Serere and Kogili village (Table 21), where defoliation reduced seed yield by 43.38 and 46.46%, respectively, suppression of seed yield as a result of partial defoliation has been reported elsewhere for cowpea (Stewart et al., 1978; Bittenbender et al., 1984; Bubenheim et al., 1990; Nielsen et al., 1994; Nielsen et al., 1997; Saidi et al., 2007). Muro et al. (2001) also observed that seed yield decreased with increasing level of defoliation in sunflower. The plants whose leaves were not harvested had more leaves at any given time, which offered a higher photosynthetic surface. This may have led to more photosynthates being directed towards seed production (Saidi et al., 2007) and symbiotic nitrogen fixation. The photosynthates of leaf-harvested plants instead go towards growth of fresh leaves or may be translocated to the root system for root and nodule development at the expense of seed production.

Depending on the intensity of defoliation and the age of the leaves removed, cowpea plants subjected to the traditional leaf-harvesting strategy (harvesting tender fully expanded leaves at about two week intervals) practiced by most Ugandan subsistence farmers, not only provides food in form of leaves throughout the whole cowpea growing season but also barely significantly affects the final seed yield. This could explain why all the farmers interviewed in this study harvested leaves from their cowpea for either home consumption or sale in the local market. The observed increase in cowpea seed yield among some of the plants, whose leaf had been periodically harvested, supports the traditional farmers' perception that leaf-harvesting increases seed yield. This also explains why cowpea leaves are culturally not sold but rather given out freely to community members (Figure 15) because such a practice will not only strengthen the relationship between the person growing the cowpea but will also increase the final cowpea seed yield.

4.4 Do plots with mixed cowpea varieties yield better than those with single varieties?

There were no significant differences between the leaf yield of cowpea variety mixtures and the means of their respective component varieties across the three environments. However, positive mixture effects were seen in seven out of the eleven variety mixtures investigated for cowpea leaf yield. The results of this study are

similar to those obtained by Kabululu (2008) in a related research at Dodoma, Tanzania where seven of the fifteen cowpea variety mixtures produced positive leaf yield with only one treatment being significant at one site.

Of the 22 (out of 66) positive variety mixture effects observed for cowpea seed yield in the current study, none was significantly different. Only one out of 11 cowpea mixtures had it's seed yields significantly higher than the mean of component varieties in a related study (Kabululu, 2008). Although no variety mixture exceeded its best pure line component within locations, Erskine (1977) observed higher cowpea seed yields for two out of four mixtures. Some of the positive leaf and seed yields observed may be due to the efficient use of space and resources for increased leaf size or pod number, which a neighboring plant was not able to use. A phenomenon known as compensation effect, as observed among wheat variety mixtures (Bowden et al., 2001). The inconsistent performance of cowpea variety mixtures relative to the mean of individual varieties observed in this study, has also been reported for oat (Shorter and Frey, 1979; Helland and Holland, 2001), barley (Mundt et al., 1994), common bean (Wortmann et al., 1996), ground nut, sorghum, soybean, maize, rye, wheat, rice, cowpea, lima bean, cotton and rape (Lenné and Smithson, 1994).

As Bowden (2001) points out, stress happening late in the season or damage that affects seed yield without influencing plant size may hardly be compensated for by mixtures owing to the short time period of growth until the final harvest. Compensation for pest damage caused to susceptible cowpea plants by variety mixtures was less likely in this study given the fact that none of the individual varieties is known to have been bred for resistance to pests like aphids, flower thrips, legume pod borers and pod sucking bugs or diseases like scab, false rust, anthracnose, powdery mildew, and viral diseases that were encountered at some of the three trial sites. However, Wolfe (1985) points out that, control of pests using variety mixtures remains a challenge since some pests are able to search and locate the susceptible plants among a mixture of varieties unlike pathogenic spores whose spread can be obstructed by resistant plants. Choosing appropriate high-yielding varieties for use in mixture combinations was recommended (Lenné and Smithson, 1994; Helland and Holland, 2001), as key to getting repeatable higher yields when working with variety mixtures.

The negative variety mixture effects observed in this study concur with those observed for soybean, maize (Lenné and Smithson, 1994) and cowpea (Kabululu, 2008). When the competition between varieties for resources like light, soil nutrients or soil water is greater than that within varieties, then negative yields are possible for variety mixtures (Lenné and Smithson, 1994; Helland and Holland, 2001). This was possibly the case in this study since three of the four varieties used in mixtures had an erect growth habit and nearly the same maturity period implying that they required the same space and nutrients at the same time, hence, the competition. Since neither leaf nor seed yield consistently increased with increasing number of component varieties in a mixture in this study, this may point to the fact that increased biodiversity alone may not always confer a yield advantage. Some individual cowpea varieties (C and B) in this study yielded better than some mixtures. In early-maturing oat variety mixtures, Helland and Holland (2001) as well saw that some 2-way or 3-way mixtures did not always yield better than individual components. They also noted that the highest yielding mixture always contained the best-yielding component variety.

4.5 Is the yield of a mixed plot more stable than that planted to an individual variety?

Leaf and seed yield stability across the three trial sites was lowest for the individual cowpea varieties. The results of increased stability with increasing number of components in a mixture obtained in this study concur with those observed for winter wheat variety mixtures (Cowger and Weisz, 2008), hard red winter wheat (Bowden et al., 2001) and early maturing oat varieties (Helland and Holland, 2001). Like it was the case in this study, not all mixtures were more stable than individual cowpea varieties. For example, leaf yields of variety C were more stable than those of mixtures B+C, C+D, B+C+D and A+D. Also seed yields of leaf-harvested plants of variety C were more stable than those of most of the variety mixtures, except A+C, B+D, A+B+C+D and B+C, indicating that increased diversity per se may not induce yield stability. In a similar study, Kabululu (2008) observed leaf yields across different harvests of variety C on station in Dodoma being more stable than 10 (out of the 15) mixtures. Stability of mixtures may be due to the positive effects of

compensation, like production of more pods or heavier seeds by a vigorous plant neighbouring a non-vigorous plant (Wolfe, 1985; Bowden et al., 2001), and/or reduced interaction with the environment (Lenné and Smithson, 1994). Among nine cowpea breeding lines grown in 13 environments in Nigeria under different management regimes, Blade et al. (1992) noted that the stability of a given line was greatly influenced by the predictable effects of the treatments like cropping system and insecticide application than on the unpredictable variation among the environments.

4.6 What is the effect of variety, mixing and environment on protein and iron content of cowpea leaves?

There was a marked variation in the leaf protein content, with the two landraces E and F, having the highest mean protein content followed by varieties A, D, B and C, in a decreasing order. No literature on leaf protein content of the two Ugandan landraces was found and, therefore, no comparison could be made. But for the four component varieties used in the mixtures, the leaf protein values obtained at the second harvest at NaSARRI, Serere (28.5 to 33.2%) and Kogili village (28.8 to 34.8%) compare well with those noticed by Kabululu (2008) for the same varieties (31.4 to 33.9%). Although working with different varieties in sole-cropped cowpea, the protein values found by Angessa (2006) ranged from 29.4 to 33.1%, while the protein values (30.3 and 34.3%) observed by Imungi and Potter (1983) are also within range of the values realized in this study. However, Bubenheim et al. (1990) and Malidadi (2006) reported considerably higher cowpea leaf protein values of 35.0 to 43.1% and 43.0%, respectively. The leaf protein content, though influenced by environmental factors like soil fertility, is highly dependent on the amount of available assimilates and the ability of the individual variety to develop a symbiotic relationship with the nitrogen-fixing bacteria in the root nodules (Ono et al., 1996). The concentration of iron (164.1-796.3 µg/g) obtained in this study is slightly higher than the values between 157.4–575.0 µg/g reported for the same varieties at NaSARRI, Serere (Towett, 2008).

On average, 2-way variety mixtures had higher leaf protein values than individual component cowpea varieties, 3-way and 4-way mixtures. Although the mean of the individual cowpea varieties was least stable across the three environments, no clear

trend could be observed among mixtures. This is possibly because of the different proportions of the cowpea leaves harvested at any given time, some varieties were over-represented than others and the results cannot be compared in a strict sense. In addition to cowpea leaves being available as food (unlike seeds), through out the cropping season, leaf protein content is higher than seed protein content. Angessa (2006) reported protein values in the range of 29.4 – 33.1% for leaves and 24.7 – 25.7% for seeds. The absence of phytic acid (storage form of phosphorous in seeds) in cowpea leaves increases the bioavailablility of nutrients like calcium and iron, which are usually bound to phytic acid. Though not analysed in this study, Towett (2008) found that β-carotene values of young cowpea leaves collected from Tanzania and Uganda ranged from 4.1 to 30.5 mg/100 g dry matter. These nutritional benefits, thereby, make cowpea leaves an indispensible tool, when targeting to improve the nutritional health of the resource-poor subsistence farmers in Uganda.

4.7 What is the farmers' perception about cowpea production in Uganda?

The results of this study show that in Uganda cowpea is grown as a sole crop and/or in intercrop with maize, cassava, green gram or pigeon pea. Various authors (Bittenbender et al., 1984; Sabiti et al., 1994; Edema et al., 1997) found that the same crop plants were being grown together with cowpea in eastern Uganda. Broadcasting was the main method of sowing cowpea that was used where sole-cropping was practiced because it reduced on the cost of labor, however, row-planting was sometimes used in intercrops. Insect pests especially aphids were the most reported constraints to cowpea seed production. Indeed, aphids are among the most important cowpea pests in Soroti and Kumi districts of Uganda (Kyamanywa, 1996; Adipala et al., 2000; Karungi et al., 2000). The importance of cowpea seeds may be one of the driving factors for excessive use of insecticides up to a frequency of six sprays instead of the recommended cost-effective but timely spray regime of three times (Isubikalu et al., 1999).

Though growing landraces, which are believed to be genetically diverse, most farmers were not aware of the use of mixtures and, possibly, the reason for this is that not many varieties are available on the local market apart from the two local varieties used in this study (E and F). The preference for tender young leaves, delay in start of

leaf-picking and stopping leaf-picking before flowering, allows for enough leaves to remain on the plant to carry out photosynthesis, thereby, not significantly affecting seed yields. Pandey (1983) also noted that seed yield is dependent on post flowering photosynthesis.

5. Conclusion and Recommendations

The traditional leaf-harvesting strategy does not only enhance seed yields but also provides leaves, which are an important source of protein among the resource-poor farmers, thereby, improving their nutritional health. The leaf-harvesting strategy also provides leaves as food throughout the cropping season, and this contributes to household food security and fosters community relationships through free-sharing of cowpea leaves among community members. The mentioned advantages help us to understand why subsistence farmers in Uganda continue to practice this mixed leaf and seed harvest strategy and, if any cowpea improvement program is to be successful, then tolerance to leaf-picking, ability to grow in crop or variety mixtures, white seed color, resistance to pests, especially aphids, and high yields need to be taken into account.

In order to get consistent mixture effects, multi-seasonal field trials in various environments will help to identify variety mixtures with repeatable positive effects on yield. Seeds for use in a mixture need to be preferably of the same colour and size to increase acceptance especially in the market where retailers usually mix the seeds of different varieties. To get the best out of complementation in mixtures, equal proportions of each component variety need to be included in a mixture. This will, for instance, avoid any form of competition for resources like space or light especially if the components have contrasting growth habits like determinate and indeterminate.

The vigorous growth of maize in this relay 1:1 cowpea/maize intercropping system, reduced the amount of light reaching cowpea making it impossible to achieve the full yield potential of cowpea. The density of maize, therefore, needs to be reduced in future studies and preferably a 1:2 or 1:4 maize/cowpea intercropping system should be used with both crops being planted at the same time. The performance of cowpea variety mixtures in sole crops needs to be studied as well, if land equivalent ratio is to be calculated but also because a good number of farmers in this region also grow cowpea as a sole crop.

Due to the low fertility of the ferrisols and ferrallitic soils in this region, use of nitrogen and phosphate fertilizers to enhance yields is highly recommendable. Careful

liming and use of compost manure will lower soil pH and increase availability of phosphates. Breeding for crop genotypes with a higher nutrient uptake and utilization efficiencies is a sustainable and environmentally friendly strategy of increasing yields. The unpredictability of rainfall regimes calls for additional irrigation when ever possible, especially during the critical crop growth stages to avoid total crop failure, which may result in family famine.

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7. Appendices

Appendix 1: Questionnaire used in the study of variety mixtures of cowpea in Soroti and Kumi districts, Uganda during the first cropping season of 2008.

District	☐ 1 Soroti		☐ 2 Kumi
Farmer's Name	☐ 1 Serere	☐ 2Kikota	☐ 3 Kogili
Gender	☐ 1 Male	☐ 2 Female	

1. Which cropping system do you practice?
☐ 1 Sole
☐ 2 Intercrop with? 1-maize 2-Cassava 3-greengram 4-beans 5-sorghum 6-eggplant

2. How do you sow cowpea?
☐ 1 Broadcast
☐ 2 In rows

3. What is the source of your planting material?
☐ 1 Seed company
☐ 2 Local market
☐ 3 Own harvest
☐ 4 Other farmers

4. What is the main constraint to cowpea production?
☐ 1 pests and diseases
☐ 2 erratic rainfall
☐ 3 poor yielding varieties
☐ 99 other, please specify_____

5. Do you use insecticides?
☐ 0 no
☐ 1 yes; if yes how frequent? _____

6. What is the main reason of growing cowpea?
☐ **1** home consumption
☐ **2** sale
☐ **0** both

7. What is the price for 1kg of cowpea;
☐ Leaf_____
☐ Seed _____

8. Do you have ready market for cowpea leaves?
☐ 1 yes
☐ 0 no; if no, give reason? _____

9. What quality criteria do you use when buying cowpea leaves in market?
☐ **1** Tenderness
☐ **2** Size and shape
☐ **3** Freshness

10 What cowpea seed color do you prefer?
☐ **1** white
☐ **2** brown
☐ **3** red

11 What size of cowpea seed size do you prefer?
☐ **1** small
☐ **2** medium
☐ **3** large

Appendix 1: Questionnaire used in the study of variety mixtures of cowpea in Soroti and Kumi districts

12 Which cowpea varieties do you grow?
☐ **1** Ebelat
☐ **2** Icirikukwai
☐ **99** other, please specify_____

13 Do you know variety mixtures?
☐ **1** yes
☐ **0** no

14 Do you use cowpea variety mixtures?
☐ **1** yes; if yes, give reason_____
☐ **0** no

15 What do you grow cowpea for?
☐ **1** leaf
☐ **2** seed
☐ **0** both

16 Name the top 4 leafy vegetables you usually eat?
☐ **1** cowpea
☐ **2** amaranth
☐ **3** spider-flower
☐ **4** white cabbage

17 What rank do you give to cowpea leaves among other leafy vegetables?
☐ **1** 1st
☐ **2** 2nd
☐ **3** 3rd
☐ **4** 4th

18 How much leaf do you consume daily? _____

19 How many household members eat that amount of leaf? _____

20 What method do you use for preparing a meal of cowpea leaf dish?
☐ **1** boiling
☐ **2** boiling with milk/peanut/sesame paste
☐ **3** boiling with other vegetables
☐ **4** frying with oil

21 Method of preservation
☐ **1** sun drying
☐ **2** shade drying
☐ **3** boiling with salt

22 At what stage do you starting picking leaves?
☐ **1** at 2-3 weeks (when a plant has 3-4 trifoliate leaves)
☐ **2** at 4-5 weeks (when the plant starts branching, 5-6 trifoliate leaves)
☐ **3** whenever the plant has enough tender leaves

23 At what stage do you stop picking leaves for consumption?
☐ **1** at flowering
☐ **2** at podding
☐ **3** whenever there are no tender leaves on the plant

24 How frequent do you harvest cowpea leaves?
☐ **1** daily
☐ **2** twice a week
☐ **3** weekly
☐ **4** whenever the plant has enough tender leaves

25 What is the size of your cowpea garden? _____

Appendix 2: A set of matrices used in contrast analysis of SYSTAT to calculate the statistical significances of the mixture effect of cowpea yields evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

A set of matrices used in contrast analysis of SYSTAT

	A	AB	ABC	ABCD	ABD	AC	ACD	AD	B	BC	BCD	BD	C	CD	D
AB	-1	2	0	0	0	0	0	0	-1	0	0	0	0	0	0
AC	-1	0	0	0	0	2	0	0	0	0	0	0	-1	0	0
AD	-1	0	0	0	0	0	0	2	0	0	0	0	0	0	-1
BC	0	0	0	0	0	0	0	0	-1	2	0	0	-1	0	0
BD	0	0	0	0	0	0	0	0	-1	0	0	2	0	0	-1
CD	0	0	0	0	0	0	0	0	0	0	0	0	-1	2	-1
ABC	-1	0	3	0	0	0	0	0	-1	0	0	0	-1	0	0
ABD	-1	0	0	0	3	0	0	0	-1	0	0	0	0	0	-1
ACD	-1	0	0	0	0	0	3	0	0	0	0	0	-1	0	-1
BCD	0	0	0	0	0	0	0	0	-1	0	3	0	-1	0	-1
ABCD	-1	0	0	4	0	0	0	0	-1	0	0	0	-1	0	-1

Refer to table 2.1 for the variety names corresponding to variety ID A, B, C, D, E and F.

Appendix 3: Mean agro-morphological characteristics of cowpea varieties used in the study of variety mixtures during the first cropping season of 2008 at;

(a) Kikota village

Variety ID	Days to flowering	Days to 1st pod maturity	Growth pattern	Twining tendency	Terminal leaflet shape
A	57 ± 0.67	72 ± 1.14	indeterminate	intermediate	sub-globose
B	56 ± 0.67	65 ± 1.14	determinate	slight	sub-hastate
C	57 ± 0.67	70 ± 1.14	determinate	none	sub-hastate
D*	58 ± 0.67	72 ± 1.14	determinate	none	sub-hastate
E	61 ± 0.67	67 ± 1.14	indeterminate	intermediate	sub-globose
F	57 ± 0.67	72 ± 1.14	determinate	slight	sub-hastate

b) Kogili village

Variety ID	Days to flowering	Days to 1st mature pods	Growth pattern	Twining tendency	Terminal leaflet shape
A	58 ± 0.92	75 ± 0.67	indeterminate	intermediate	sub-globose
B	53 ± 0.92	72 ± 0.67	determinate	none	sub-hastate
C	55 ± 0.92	74 ± 0.67	determinate	none	sub-hastate
D	57 ± 0.92	75 ± 0.67	determinate	none	sub-hastate
E	56 ± 0.92	74 ± 0.67	indeterminate	intermediate	sub-globose
F	54 ± 0.92	73 ± 0.67	determinate	none	sub-hastate

Values are the mean ± s.e. of three replicate plots of each variety.
Values for days to flowering and 1st mature pods were significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

Appendix 4: Mean cob and seed yields for the maize that was intercropped with cowpea at the three trial sites of NaSARRI, Serere, Kikota village and Kogili village in Uganda during the first cropping season of 2008.

Maize seed and cob yield (g/m^2)								
Treatment	**Serere**		**Kikota**		**Kogili**		**mean**	
plot	**seed**	**cob**	**seed**	**cob**	**seed**	**cob**	**seed**	**cob**
A	1629.63	1962.96	629.63	740.74	629.63	740.74	962.96	1148.15
B	1370.37	1703.70	592.59	666.67	555.56	666.67	839.51	1012.35
C	1111.11	1370.37	370.37	481.48	592.59	814.81	691.36	888.89
D	1148.15	1481.48	740.74	1000.00	444.44	518.52	777.78	1000.00
mean	**1314.81**	**1629.63**	**583.33**	**722.22**	**555.56**	**685.19**	**817.90**	**1012.35**
E	1518.52	1925.93	333.33	370.37	703.70	777.78	851.85	1024.69
F	1222.22	1555.56	740.74	851.85	592.59	814.81	851.85	1074.07
mean	**1370.37**	**1740.74**	**537.04**	**611.11**	**648.15**	**796.30**	**851.85**	**1049.38**
A+B	1333.33	1703.70	703.70	740.74	555.56	592.59	864.20	1012.35
A+C	1296.30	1592.59	555.56	666.67	555.56	629.63	802.47	962.96
A+D	1333.33	1703.70	481.48	666.67	629.63	888.89	814.81	1086.42
B+C	1333.33	1666.67	481.48	555.56	481.48	703.70	765.43	975.31
B+D	1370.37	1740.74	481.48	518.52	592.59	740.74	814.81	1000.00
C+D	1185.19	1555.56	518.52	592.59	592.59	666.67	765.43	938.27
mean	**1308.64**	**1660.49**	**537.04**	**623.46**	**567.90**	**703.70**	**804.53**	**995.88**
A+B+C	1370.37	1740.74	555.56	592.59	518.52	703.70	814.81	1012.35
A+B+D	1148.15	1481.48	518.52	629.63	685.19	962.96	783.95	1024.69
A+C+D	1333.33	1703.70	518.52	592.59	740.74	814.81	864.20	1037.04
B+C+D	1370.37	1740.74	407.41	444.44	629.63	814.81	802.47	1000.00
mean	**1305.56**	**1666.67**	**500.00**	**564.81**	**643.52**	**824.07**	**816.36**	**1018.52**
A+B+C+D	1555.56	1925.93	481.48	518.52	592.59	703.70	876.54	1049.38
overall mean	**1331.15**	**1679.74**	**535.95**	**625.27**	**593.68**	**738.56**	**820.26**	**1014.52**

Values are the mean maize weights from three replicate plots where the cowpea varieties were planted.
Refer to table 1 for cowpea variety names corresponding to ID A, B, C, D, E and F.

Appendix 5: Mean dry matter leaf yield per of harvest of individual cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Mean dry matter leaf yield (LY) per harvest (g/plant)									
	Serere			Kikota village			Kogili village			
Treatment	LY1	LY2	LY3	LY1	LY2	LY3	LY1	LY2	LY3	LY4
A	0.53	0.50	0.42	0.36	0.37	0.47	0.15	0.14	0.32	0.35
B	1.09	0.63	0.40	0.57	0.48	0.70	0.39	0.16	0.43	0.25
C	1.25	0.53	0.41	0.54	0.70	0.67	0.35	0.23	0.87	0.48
D	0.97	0.47	0.39	0.39	0.34	0.49	0.42	0.35	0.72	0.55
mean	**0.96**	**0.53**	**0.40**	**0.47**	**0.47**	**0.58**	**0.33**	**0.22**	**0.59**	**0.41**
E	0.62	0.47	0.23	0.24	0.45	0.70	0.21	0.10	0.26	0.22
F	0.74	0.47	0.51	0.42	0.50	0.78	0.25	0.15	0.21	0.16
mean	**0.68**	**0.47**	**0.37**	**0.33**	**0.47**	**0.74**	**0.23**	**0.12**	**0.24**	**0.19**
A+B	0.91	0.29	0.50	0.48	0.28	0.40	0.33	0.22	0.42	0.17
A+C	1.10	0.44	0.49	0.37	0.48	0.57	0.31	0.17	0.33	0.42
A+D	0.79	0.45	0.42	0.43	0.45	0.68	0.28	0.17	0.45	0.35
B+C	1.11	0.62	0.68	0.62	0.78	0.86	0.41	0.22	0.59	0.39
B+D	1.16	0.55	0.47	0.40	0.62	na	0.32	0.23	0.46	0.45
C+D	1.39	0.60	0.39	0.40	0.58	0.68	0.33	0.24	0.50	0.33
mean	**1.07**	**0.49**	**0.49**	**0.45**	**0.53**	**0.64**	**0.33**	**0.21**	**0.46**	**0.35**
A+B+C	1.21	0.57	0.32	0.43	0.58	0.56	0.34	0.15	0.44	0.36
A+B+D	0.84	0.77	0.42	0.59	0.56	0.52	0.29	0.16	0.40	0.25
A+C+D	0.96	0.55	0.71	0.41	0.37	0.83	0.26	0.14	0.71	0.49
B+C+D	0.89	0.34	na	0.39	0.84	0.75	0.39	0.25	0.51	0.36
mean	**0.97**	**0.55**	**0.48**	**0.46**	**0.59**	**0.66**	**0.32**	**0.18**	**0.51**	**0.37**
A+B+C+D	1.12	0.50	0.44	0.40	0.44	0.37	0.31	0.15	0.56	0.40
mean	**0.98**	**0.51**	**0.45**	**0.44**	**0.52**	**0.63**	**0.31**	**0.19**	**0.48**	**0.35**
SE	**0.20**	**0.13**	**0.27**	**0.10**	**0.17**	**0.22**	**0.05***	**0.03***	**0.11***	**0.08***

Values are the mean ± s.c. of each leaf harvest from three replicate cowpea plots.
Values with * are significantly different at $P \leq 0.05$.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.
LY1, LY2, LY3 and LY4 refer to the 1st, 2nd, 3rd and 4th leaf-harvest, respectively.

Appendix 6: Mean total fresh leaf yield (TFLY) and the dry matter (DM) percentage of individual cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	NaSARRI, Serere		Kikota village		Kogili village	
Treatment	**TFLY (g)**	**DM (%)**	**TFLY (g)**	**DM (%)**	**TFLY (g)**	**DM (%)**
A	8.17	16.04	7.26	16.43	5.71	14.56
B	11.89	15.60	8.11	15.88	7.40	15.87
C	13.71	15.94	10.49	18.28	12.92	14.89
D	10.82	16.85	7.05	17.26	13.06	15.66
E	7.79	15.90	5.05	18.33	5.25	15.05
F	9.94	15.60	11.80	14.35	4.19	15.33
mean	**10.39**	**15.99**	**8.29**	**16.75**	**8.09**	**15.23**
A+B	8.60	15.77	5.82	17.52	8.36	13.50
A+C	11.79	15.88	7.16	17.20	8.35	14.69
A+D	9.32	16.24	8.34	18.66	7.81	15.94
B+C	14.65	14.89	13.22	17.03	10.73	14.90
B+D	11.71	15.89	6.03	16.86	9.58	15.14
C+D	14.18	16.74	8.31	17.25	9.05	15.47
mean	**11.71**	**15.90**	**8.15**	**17.42**	**8.98**	**14.94**
A+B+C	13.78	14.40	7.95	17.40	8.49	15.17
A+B+D	11.58	16.27	10.42	16.00	7.24	15.18
A+C+D	14.00	15.82	9.92	16.21	10.71	15.02
B+C+D	8.38	14.58	11.06	17.89	9.85	15.32
mean	**11.93**	**15.27**	**9.84**	**16.88**	**9.07**	**15.17**
A+B+C+D	12.84	16.02	7.04	17.14	9.31	15.31
overall mean	**11.36**	**15.78**	**8.57**	**17.04**	**8.71**	**15.12**
SE	**± 2.24**		**± 2.00**		**± 1.11**	

Values are the mean ± s.e. weights of three or four leaf harvests from three replicate cowpea plots
Refer to table 1 for cowpea variety names corresponding to ID A, B, C, D, E and F.

Appendix 7: Leaf yield of pure cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

(a) Mean total dry matter;

	Total dry matter leaf yield (g/m^2)			
Treatment	**Serere**	**Kikota**	**Kogili**	**mean**
A	4.83	4.08	2.32	3.74
B	9.96	5.63	3.44	6.34
C	9.71	6.02	4.40	6.71
D	5.18	3.07	5.50	4.58
mean	**7.42**	**4.70**	**3.91**	**5.34**
E	3.30	2.73	1.17	2.40
F	5.59	4.30	2.27	4.06
mean	**4.45**	**3.52**	**1.72**	**3.23**
A+B	6.19	4.27	3.19	4.55
A+C	8.53	4.72	3.37	5.54
A+D	4.15	4.47	3.14	3.92
B+C	9.97	5.84	4.39	6.74
B+D	8.06	5.29	4.37	5.91
C+D	9.96	5.75	4.05	6.59
mean	**7.81**	**5.06**	**3.75**	**5.54**
A+B+C	7.79	5.67	3.36	5.61
A+B+D	7.26	5.36	2.84	5.15
A+C+D	7.22	3.62	3.25	4.70
B+C+D	6.35	6.48	4.22	5.68
mean	**7.15**	**5.28**	**3.42**	**5.28**
A+B+C+D	7.33	4.35	3.70	5.13
overall mean	7.09	4.80	3.47	5.12
SE	± 1.234[a]	± 0.743[b]	± 0.449[c]	

Values are the mean ± s.e. weights of three or four leaf harvests from three replicate cowpea plots.
Values for days to flowering and 1st mature pods were significantly different at $P \leq 0.05$.
Refer to table 2.1 for the variety names corresponding to variety ID A, B, C, D, E and F.

(b) ANOVA.

	Total dry matter leaf yield (g/m^2)								
Trial site	**NaSARRI, Serere**			**Kikota village**			**Kogili village**		
SOURCE	SS	DF	M.S	SS	DF	M.S	SS	DF	M.S
TREATMENT	213.44	17	12.56**	50.54	16	3.16 ns	51.46	17	3.03**
ERROR	164.45	36	4.57	54.62	33	1.66	21.73	36	0.60

**, * significantly different at the 0.01 and 0.05 levels based on the generalized linear model
ns: not significant, ss: sum of squares, df: degrees of freedom and ms: mean square

Appendix 8: Pod number of landraces, individual and mixed cowpea varieties from both leaf-harvested (H) and non leaf-harvested (NH) plants grown at NaSARRI, Serere, Kikota and Kogili villages during 2008.

(a) Mean number of pods per square meter;

	number of pods/m^2							
	Serere		**Kikota**		**Kogili**		**mean**	
Treatment	**H**	**NH**	**H**	**NH**	**H**	**NH**	**H**	**NH**
A	23.04	43.33	54.30	50.37	7.41	17.48	28.25	37.06
B	30.07	45.48	28.15	30.67	9.56	14.15	22.59	30.10
C	12.44	26.82	19.41	19.64	5.41	12.07	12.42	19.51
D	15.41	30.15	18.52	22.07	4.52	5.78	12.82	19.33
mean	**20.24**	**36.44**	**30.09**	**30.69**	**6.72**	**12.37**	**19.02**	**26.50**
E	16.30	32.00	25.41	28.30	5.19	7.33	15.63	22.54
F	14.74	21.85	30.15	24.89	4.07	5.78	16.32	17.51
mean	**15.52**	**26.93**	**27.78**	**26.59**	**4.63**	**6.56**	**15.98**	**20.02**
A+B	18.07	26.07	28.44	37.56	9.19	14.37	18.57	26.00
A+C	24.30	27.63	35.78	38.82	5.85	12.15	21.98	26.20
A+D	19.19	22.89	27.19	36.96	6.37	8.44	17.58	22.77
B+C	21.33	34.82	22.00	30.44	4.74	6.67	16.02	23.98
B+D	24.30	26.22	29.33	33.48	5.33	4.30	19.65	21.33
C+D	20.15	25.70	24.74	25.26	3.33	3.33	16.07	18.10
mean	**21.22**	**27.22**	**27.91**	**33.75**	**5.80**	**8.21**	**18.31**	**23.06**
A+B+C	16.82	39.11	35.33	30.89	5.33	10.22	19.16	26.74
A+B+D	32.74	37.78	37.78	39.56	4.96	12.22	25.16	29.85
A+C+D	30.37	44.15	21.56	28.96	2.67	4.30	18.20	25.80
B+C+D	17.19	17.48	22.89	32.44	7.04	9.19	15.70	19.70
mean	**24.28**	**34.63**	**29.39**	**32.96**	**5.00**	**8.98**	**19.56**	**25.52**
A+B+C+D	16.00	27.26	34.22	38.52	3.78	7.11	18.00	24.30
overall mean	**20.73**	**31.10**	**29.13**	**32.28**	**5.57**	**9.11**	**18.48**	**24.17**
SE	**8.63**	**10.67**	**6.36**	**6.27**	**1.69**	**2.43**	**5.56**	**6.46**

Values are the mean ± s.e. weights of three or four leaf harvests from three replicate cowpea plots
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

(b) ANOVA.

Trial site		Source	Treatment	Error
NaSARRI, Serere	Leaf-harvested plants	SS	1704.57	8040.96
		DF	17	36
		M.S	100.27 ns	223.36
	Non leaf-harvested plants	SS	3596.54	122303.60
		DF	17	36
		M.S	211.56 ns	341.77
Kikota village	Leaf-harvested plants	SS	3631.33	4130.34
		DF	16	34
		M.S	226.96 ns	121.48
	Non leaf-harvested plants	SS	2747.26	4011.64
		DF	16	34
		M.S	171.7 ns	117.99
Kogili village	Leaf-harvested plants	SS	170.65	306.93
		DF	17	36
		M.S	10.4 ns	8.53
	Non leaf-harvested plants	SS	826.35	639.08
		DF	17	36
		M.S	48.61**	17.75

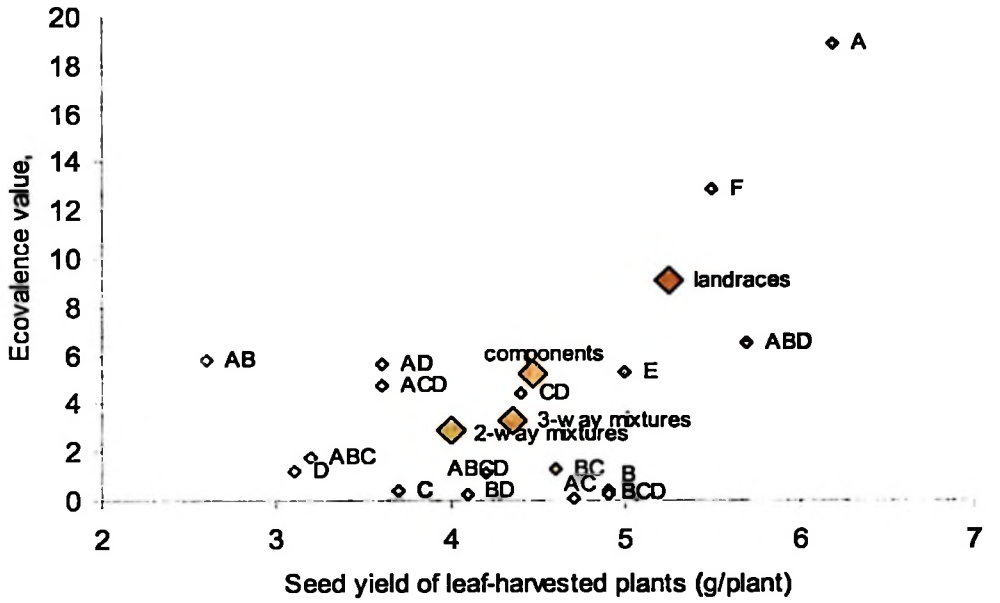
**, * significantly different at the 0.01 and 0.05 levels based on the generalized linear model.
ns: not significant, ss: sum of squares, df: degrees of freedom and ms: mean square.

Appendix 9: Mean total seed yield per square meter of cowpea from the leaf-harvested plants (H) and non leaf-harvested plants (NH) evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during 2008.

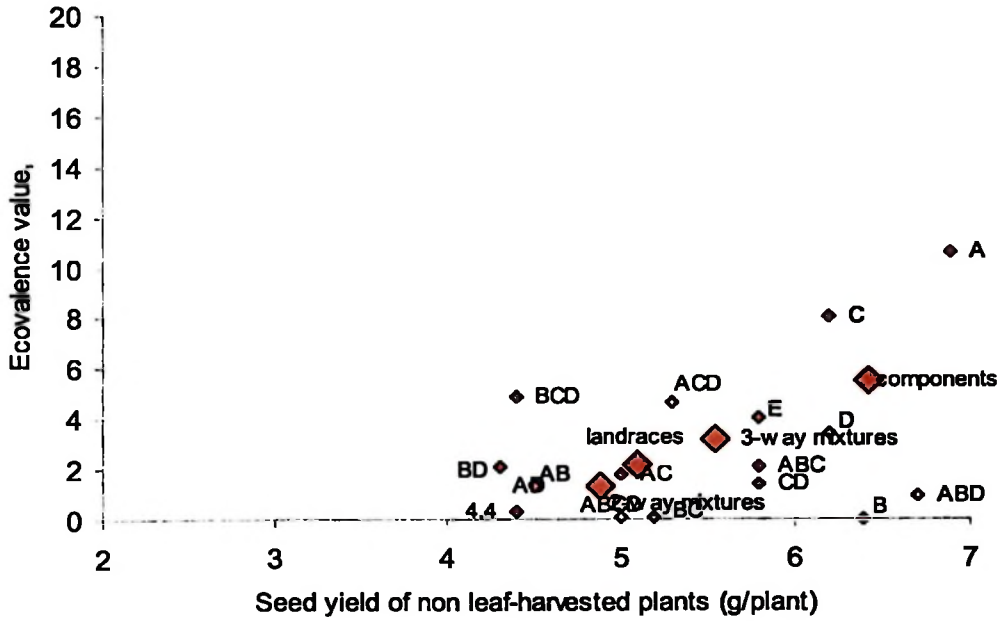
		Seed yield (g/m^2)					
	Treatment	**A**	**B**	**C**	**D**	**E**	**F**
NaSARRI Serere	NH	13.80	35.45	15.00	11.30	9.34	11.42
	H	27.98	55.12	37.74	33.36	19.41	19.15
	harvesting effect	14.17	19.67	22.74	22.06	10.07	7.73
	harvesting effect (%)	50.66	35.69	60.24	66.12	51.87	40.35
Kikota village	NH	86.97	42.94	33.60	21.71	24.59	47.77
	H	49.41	43.60	26.52	25.24	20.00	25.38
	harvesting effect	-37.56	0.66	-7.09	3.54	-4.59	-22.39
	harvesting effect (%)	-76.02	1.53	-26.74	14.01	-22.93	-88.23
Kogili village	NH	3.41	6.15	5.17	3.22	2.69	2.00
	H	9.28	11.27	12.34	4.31	3.46	4.75
	harvesting effect	5.87	5.12	7.17	1.09	0.77	2.76
	harvesting effect (%)	63.25	45.41	58.13	25.21	22.26	58.01
	Treatment	**A+B**	**A+C**	**A+D**	**B+C**	**B+D**	**C+D**
NaSARRI Serere	NH	14.40	24.65	14.26	21.82	20.47	24.38
	H	29.08	30.08	17.96	42.99	23.75	37.72
	harvesting effect	14.68	5.43	3.70	21.17	3.29	13.34
	harvesting effect (%)	50.50	18.04	20.60	49.25	13.85	35.37
Kikota village	NH	24.26	41.34	18.95	33.84	41.49	36.44
	H	37.87	28.14	31.11	43.44	44.14	34.94
	harvesting effect	13.60	-13.21	12.16	9.60	2.64	-1.50
	harvesting effect (%)	35.92	-46.94	39.09	22.10	5.99	-4.30
Kogili village	NH	5.43	4.04	3.83	3.39	2.59	2.04
	H	9.19	10.07	7.20	4.57	2.22	2.95
	harvesting effect	3.76	6.03	3.37	1.17	-0.37	0.91
	harvesting effect (%)	40.92	59.88	46.87	25.70	-16.47	30.79
	Treatment	**A+B+C**	**A+B+D**	**A+C+D**	**B+C+D**	**A+B+C+D**	**overall mean**
NaSARRI Serere	NH	16.23	31.48	28.41	20.37	16.09	19.34 ± 9.17
	H	40.63	38.93	37.37	18.15	26.57	31.53± 11.79
	harvesting effect	24.40	7.45	8.96	-2.22	10.48	12.18
	harvesting effect (%)	60.06	19.15	23.99	-12.26	39.44	38.64
Kikota village	NH	29.97	40.80	21.08	42.69	47.98	37.44± 9.78
	H	34.88	40.73	30.53	45.35	43.88	35.60± 9.31
	harvesting effect	4.91	-0.07	9.45	2.66	-4.09	-1.84
	harvesting effect (%)	14.08	-0.18	30.95	5.86	-9.33	-5.17
Kogili village	NH	3.88	3.16	1.81	3.92	2.87	3.51± 1.28
	H	7.46	7.72	3.34	5.45	5.11	6.51± 2.05
	harvesting effect	3.59	4.56	1.53	1.53	2.24	3.01
	harvesting effect (%)	48.06	59.07	45.73	28.07	43.83	46.16

Values are the mean ± s.e. seed weight per plant from three replicate cowpea plots.
Harvesting effect = NH-H; a negative value indicates an increase in seed yield due to leaf harvesting.
Harvesting effect (%) = (NH - H) / NH × 100.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

Appendix 10: Stability of seed yield of individual cowpea varieties and their possible mixtures grown at NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008. (a) Plants which were leaf harvested and (b) plants which were not leaf harvested. Refer to table 2.1 for the variety names corresponding to variety ID A, B, C, D, E and F.



(a)



(b)

Appendix 11: Mean percentage of dry matter shoot yield in relation to fresh matter shoot yield of individual cowpea varieties and their possible 2-way, 3-way and 4-way mixtures plus two landraces evaluated at three trial sites of NaSARRI, Serere, Kikota and Kogili villages in Uganda during the first cropping season of 2008.

	Percentage of shoot dry matter yield (%)							
	NaSARRI, Serere		Kikota village		Kogili village		mean	
Treatment	31 DAP	45 DAP	32 DAP	46 DAP	30 DAP	44 DAP	31 DAP	45 DAP
A	15.50	16.53	12.77	15.64	14.55	20.00	14.27	17.39
B	13.41	17.27	13.61	17.90	15.33	19.61	14.12	18.26
C	13.48	17.92	14.89	18.18	17.78	21.94	15.38	19.35
D	14.20	16.85	16.35	18.26	17.21	22.92	15.92	19.34
mean	**14.15**	**17.14**	**14.41**	**17.49**	**16.22**	**21.11**	**14.93**	**18.58**
E	14.55	14.50	12.91	18.00	15.71	18.00	14.39	16.83
F	14.14	14.03	14.47	15.63	14.08	18.67	14.23	16.11
mean	**14.35**	**14.26**	**13.69**	**16.81**	**14.90**	**18.34**	**14.31**	**16.47**
A+B	13.60	14.32	12.44	15.62	16.56	26.42	14.20	18.79
A+C	16.54	16.46	12.94	16.90	16.94	20.50	15.47	17.95
A+D	15.80	17.26	14.81	17.09	23.15	22.85	17.92	19.07
B+C	13.03	15.04	13.54	18.81	17.92	21.12	14.83	18.32
B+D	12.33	17.32	15.44	15.21	14.76	24.72	14.18	19.08
C+D	13.70	17.24	16.31	16.20	17.29	27.79	15.77	20.41
mean	**14.17**	**16.28**	**14.25**	**16.64**	**17.77**	**23.9**	**15.40**	**18.94**
A+B+C	12.87	16.60	14.22	18.14	13.18	24.94	13.42	19.89
A+B+D	13.78	16.70	13.38	15.22	17.36	17.45	14.84	16.46
A+C+D	13.79	17.40	14.82	18.77	19.32	21.57	15.98	19.25
B+C+D	14.10	16.06	13.65	18.38	16.99	17.80	14.91	17.41
mean	**13.63**	**16.69**	**14.02**	**17.63**	**16.71**	**20.44**	**14.79**	**18.25**
A+B+C+D	13.99	15.80	13.59	18.04	17.43	22.60	15.00	18.81
overall mean	**14.05**	**16.31**	**14.13**	**17.18**	**16.80**	**21.70**	**14.99**	**18.40**
SE	**1.10**	**0.97**	**1.22**	**1.21**	**2.410**	**3.93**	**1.58**	**2.04**

DAP = days after planting.
Values are the mean ± s.e. of the number of seeds per plant from three replicate cowpea plots.
Refer to table 1 for variety names corresponding to ID A, B, C, D, E and F.

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Germany

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Uganda

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Statutory Declaration

I hereby attest that I, Joshua Sikhu Okonya has written this thesis independently and I have used no other than the mentioned sources and aid.

Date: 24th March 2009, Göttingen,

Signature: