African Journal of Agricultural Research Vol. 2(6), pp. 269-278, June 2007
Available online at http://www.academicjournals.org/AJAR
ISSN 1991- 637X © 2007 Academic Journals

Full Length Research Paper

Yields and qualities of pigeonpea varieties grown under smallholder farmers' conditions in Eastern and Southern Africa

Høgh-Jensen, H.[1], Myaka, F. A.[2], Sakala, W. D.[3], Kamalongo, D.[3], Ngwira, A.[3], Vesterager, J. M.[1], Odgaard R.[4], Adu-Gyamfi, J. J.[5]

[1]Department of Agricultural Sciences, Faculty of Life Sciences, University of Copenhagen, Højbakkegaard Allé 9, DK-2630 Taastrup, Denmark
[2]Ilonga Agricultural Research Institute, P.O. Box 33, Kilosa, Morogoro, Tanzania.
[3]Chitedze Agricultural Research Station, P.O.Box 158 Lilongwe, Malawi.
[4]Danish Institute for International Studies, Strandgade 56, DK-1471, Copenhagen, Denmark.
[5]International Atomic Energy Agency (IAEA), Wagramer Strasse 5, A-1400, Vienna, Austria.

Accepted 10 June, 2007

Pigeonpea is one of the few crops with a high potential for resource-poor farmers due to its complementary resource use when intercropped with maize. A three year comprehensive comparative study on the performance of six pigeonpea (*Cajanus cajan*) varieties on farmers' fields in Eastern and Southern Africa where intercropping with maize is normal practice, was undertaken. The varieties were tested for accumulation of dry matter (DM), nitrogen (N) and phosphorus (P) in all above-ground organs for three years under farmers' conditions. The study revealed that the latest introduced ICEAP 00040 outperformed all the other tested varieties (ICP 9145; ICEAP 00020, ICEAP 00053, ICEAP 00068, and a local variety called "Babati White") under farmer-managed conditions. The harvest indices (HI), ranging from 0.08 - 0.15 on dry matter (DM) basis, were relatively low and unaffected (P>0.05) by the environmental variation. The N harvest index (NHI) was 0.28 and P harvest index (PHI) was 0.19. The better responses of ICEAP 00040 to favourable conditions could however only be realised in a minority of cases as yields generally were low. These low yields are still a major challenge in African smallholder agriculture as pulses play an important role in soil fertility maintenance as well as in the household diets.

Key words: *Cajanus cajan*; genotypic variation; ICRISAT East African pigeonpea (ICEAP); nutrient deficiencies; pigeonpea.

INTRODUCTION

Maize is a staple food in Sub-Saharan Africa where 95% of the produced maize constitutes a significant part of humans' daily diet (McCann, 2005; Miracle, 1965). In large parts of the sub-continent, smallholder agricultural production has remained consistently low and food security is catastrophically poor (Kumwenda, 1998; Sanchez, 2002) on a continent that has been importing food the last three decades (Byerlee and Eicher, 1997). Low soil fertility, limited cash resources, nutrient mining, and droughts are the main factors limiting maize productivity in Sub-Saharan Africa.

Resource poor farmers need technologies that are less labour intensive and/or less capital investments (Barrett et al., 2002). In Eastern and Southern Africa, pigeonpea (*Cajanus cajan* L. Millsp.) is often intercropped with maize (*Zea mays* L.) and the pigeonpea crop plays an important role in production, consumption and cash income in the household (Mergeai et al., 2001). Pigeonpea is one of the few crops with a high potential to enhancing productivity per unit area due to its complementarity with maize (McCown et al., 1992; Myaka et al., 2006; Nene and Sheila, 1990; Sakala et al., 2000). Furthermore, associated labour inputs are minimal and seed

---

*Corresponding author. E-mail: hhj@life.ku.dk. Tel: +45 3533 3391. Fax: +45 3533 3384.

costs are low compared to other green manure or agroforestry species (Sakala et al., 2003). The input of symbiotic fixed nitrogen (N) through the grain legume may be a major driving force for sustaining productivity in smallholder systems (Giller, 2001; Sanginga, 2003) if the legume leaves substantial amounts of residues (Adu-Gyamfi et al., 2007; Giller, 2001). However, the poor seed quality and low plant density of the pigeonpea crop often result in low yields and thus in low residual effects of nutrients particularly N and phosphorus (P) to the subsequent maize crop.

Farmers are reluctant to invest in fertilisers because they have limited access to cash and the returns may be uncertain in risky environments (Kherallah et al., 2002; Mwanga, 2004). The maize-pigeonpea intercropping technology therefore has an adoption potential by smallholders because most farmers can use their own pigeonpea seeds at low cost using the previous year's stock. In addition to its use as a food source, there is a market for improved green or matured grains. Furthermore, the system often has multiple benefits, such as weed suppression (Snapp, 1998), fodder and firewood availability, medicinal use, and soil fertility enhancement (Myaka et al., 2006). Finally, the grain qualities correspond to *Phaseolus*_beans in element content (Høgh-Jensen et al., 2006). However, there is a lack of knowledge of how the different genotypes of pigeonpea respond under farmers' cropping conditions and what qualities of the crops are. Unlike the use of agrochemicals like fertilisers, it is possible for even the poorest farmers to intercrop maize with pigeonpea varieties. This could explain why maize-pigeonpea intercropping is widely practiced in the more densely populated areas of southern Malawi and southern Tanzania.

The main genotypes of pigeonpea used by farmers are traditional landraces that are prone to soil borne fungal diseases and grain yields are of low quality. New genotypes from breeding programmes in Eastern and Southern Africa at the International Crops Research Institute in the Semi-Arid Tropics (ICRISAT) that are medium-and short-duration *Fusarium*-resistant varieties, thrive on soils of low nutrient availability, and posses the requested grain qualities. However, knowledge are still lacking about the performance of the introduced varieties across a large span of environments.

The aim of the current study was to investigate the variation among pigeonpea genotypes in accumulations of dry matter, N and P in the different organs when intercropped with maize under farmers' conditions in Eastern and Southern Africa.

MATERIALS AND METHODS

Experimental areas and participating farmers

Four study sites were selected in Tanzania and Malawi. In, Tanzania the Babati district of the Manyara Region (until 2003 it was part of the Arusha Region) (04°14 S, 35°35 E) and the Gairo Division of the Kilosa District of the Morogoro Region (06°13 S, 36°53 E) were selected. In Malawi, Nyambi (14°39 S, 35°35 E) and Ntonda (15°53 S, 34°57 E) Extension Planning Areas (EPAs) were selected. The Nyambi EPA is located within the Kawinga Rural Development Projects (RDPs) of the Liwonde Agricultural Development Division (ADD). The Ntonda EPA is located within the Blantyre Shire highlands RDP of the Blantyre ADD.

These sites were similar in the sense that fertiliser use in maize (*Z. mays* L.), the dominant food crop, were low. The sites differed however in traditions for using pigeonpea (*C. cajan* L. Millsp.). Gairo is considered a new area for pigeonpea production while Babati, Nyambi and Ntonda are traditional pigeonpea growing areas. The soils of Babati and Ntonda are classified as ferrasols, Gairo as ferralic cambisols, and Nyambi as cambisols according to FAO / UNESCO (1990).

The locations in Tanzania are characterised by a bimodal rainfall pattern with onset between November and December. The locations in Malawi have a uni-modal rainfall pattern with onset in November or December. A total of 90 farmers were selected to participate in the study. The farmers were equally distributed among the four locations. Each location encompassed 3 - 4 adjoining villages.

The trials were continued on the same plots for three consecutive growing seasons for all farmers. During the first two growing seasons, the crops were separated into their different plant components, e.g. maize sampled components included grains, husk, pits, and stovers while pigeonpea sampled components included grains, leaves, stems, pods and roots, but sampling intensity was reduced during the following season, focussing mainly on the grain yields. Some few farmers abandoned the project over the three cropping seasons mainly due to changes in land ownerships or health problems, leaving only 78 farmers at the third growing season.

Plant material

Six pigeonpea varieties were planted on the farmers' fields at the four locations. When selecting the varieties, local conditions were taken into consideration so that the commonly used landrace and two improved genotypes were used per site. The varieties used were;

(i) In Babati: ICEAP 00053, ICEAP 00040 and Babati White.
(ii) In Gairo: ICEAP 00068, ICEAP 00040 and Babati White.
(iii) In Nyambi and Ntonda: ICEAP 00040, ICEAP 00020, and ICPL 9145. ICEAP 00040, ICEAP 00053, ICEAP00020 and ICP9145 are long duration varieties while ICEAP00068 is a medium maturing variety.

Babati White is a traditional variety found in the Babati area in Tanzania. A recommended maize variety for each area was used. In Gairo, a long duration and open pollinated maize variety "Staha" was used while in Babati an open pollinated variety "Kilima" was used. In Malawi, a hybrid maize variety "SC 627" was used at all sites. "*SC 627*" is recommended for its wide adaptability, intermediate maturity and tolerance to major maize foliar diseases like Grey Leaf Spot.

Crop management

The experimental plots were primarily managed by farmers but the extension agents or technicians influenced the planting patterns. Each farmer planted three non-replicated pigeonpea varieties intercropped with maize in plots of 10 x 10 m. In Tanzania, maize rows were spaced at 90 cm apart and pigeonpea was planted between the rows of maize. Within the rows, the recommended plant spacing was 60 cm. For Malawi, maize rows/ridges were spaced at 90 cm apart and maize plants were planted at recommended plant spacing of 75 cm apart. Pigeonpeas were planted between two maize planting stations within the same rows/ridge. After two weeks of plants' emergence, plants were thinned to two plants per station. All data were collected by the technicians.

Sampling and analysis

Plants from the central 10 m^2 of the experimental plots were sampled and weighed. Sub-samples of the maize plants were divided into grains, husk, pits, and stovers. Sub-samples of the pigeonpea plants were divided into grains, pods, fresh leaves and stems. All samples were dried to constant weight at 60°C, pulverised to pass a mesh size of 0.2 mm and analysed. At randomly selected farms, the leaf litter was collected at regular intervals from a clearly marked area and dried to constant weight. After final sampling, all samples were pooled, pulverised to a fine powder and analysed.

Total N content of the plant material was analysed using an elemental analyser (ThermoQuest S.p.A., Milano, Italy) and the P content was determined by dry-ashing at 550℃ for 4 h; the ashes were then solubilized in 3 M HCl, dried and dissolved again in 1 M HNO_3 before filtering the solution. The P concentration in the plant digest was determined by UV-VIS spectrophotometry using the molybdo-phosphoric blue method of Murphy and Riley (1962).

Replicated plants from the experimental areas were sampled and weighted. Sub-samples of the pigeonpea were divided into grains, pods, fresh leaves, stems. At randomly selected farms, leaf litter were collected with regular intervals from clearly demarked areas and dried at 60°C to constant weight and stored. After the final sampling, the samples from each sampling area were pooled.

Statistical methods and calculations

An analysis of variance was carried out on the data using the GLM procedure of the SAS software (SAS Institute Inc., 1993). Mean comparisons for the individual treatments were done using a Waller-Duncan *t*-test. The approach of adaptability analysis was applied to differentiate the varieties responses to environments following Hildebrand and Russell (1996). The maize yields were not affected by pigeonpea variety and they are thus not further considered in this report but details regarding this can be found in Myaka et al. (2006).

RESULTS

Dry matter yields of pigeonpea

The trials encompassed a wide range of environmental conditions and yearly rainfall variations with mean grain yields ranging from 36 to 890 kg DM ha^{-1} in Ntonda the third season vs. the first season (Table 1). The grain yields differed between years (P = 0.0001), sites (P = 0.0001) and varieties (P = 0.001). The mean grain yields dropped from 740 kg ha^{-1} in the first season to 230 in the second season and further to 172 kg ha^{-1} in the third season. Across the seasons, the grain yields (kg ha^{-1}) ranking was Babati (489), Ntonda (442), Nyambi (330) and Gairo (216). Babati and Ntonda had better yield performance (P<0.05) than Nyambi and Gairo.

ICEAP 00040 was tested across all sites against either ICP9145 or Babati White. As ICP 9145 and Babati White were quite similar genetically and did not differ (P>0.05) yield-wise, they were combined in the further analysis. Across all sites and years ICEAP 00040 out-yielded ICP 9145/Babati White but not significantly (P>0.05); 569 vs. 412 kg ha^{-1}, respectively.

However, the quantitative importance of the different organs in terms of dry matter accumulation also demonstrates that the harvest index (HI_DM) influenced all organs in pigeonpea. The HI_DM was affected (P<0.005) by year and site. The HI_DM was 0.15 for Babati, 0.10 for Gairo, 0.09 for Nyambi, and 0.08 for Ntonda, but a *t*-test did not reveal any significant differences. The HI_DM did not differ for the two genotypes grown across all environments, that is, ICEAP 00040 and ICP 9145/Babati White.

Nitrogen accumulations in pigeonpea

The accumulation of N in the grains (Table 2) differed between years (P = 0.0001) but not between sites (P = 0.20) and varieties (P = 0.09). The mean N grain yields dropped from a first season value of 28 to 10 kg N ha^{-1} during the second season. Across the seasons, the N grain yields (N ha^{-1}) ranking was 23.8 for Babati (a), 17.5 for Ntonda (ab), 12.6 for Nyambi (b) and 7.5 for Gairo (c) and the letters in parentheses showing the significant differences.

ICEAP00040 were tested across all sites against either ICP 9145 or Babati White. Across all sites and years ICEAP 00040 and ICP 9145/Babati White accumulated similar proportion of the crop N in the grain (HI_N), which was 28%.

Phosphorus accumulations in pigeonpea

The accumulation of P in the grains (Table 3) differed between years and site (P = 0.0001) but not between varieties (P = 0.24). The mean P grain yields dropped from 2.1 to 0.72 kg P ha^{-1} from the first to the second, respectively. Across the seasons, the P grain yields (kg P ha^{-1}) ranking was 2.1 for Babati (a), 1.4 for Ntonda (ab), 0.96 for Nyambi (bc) and 0.64 for Gairo (c), and the letters in parenthesis showing the significant differences.

ICEAP00040 were tested across all sites against either ICP9145 or Babati White. Across all sites and years ICEAP 00040 and ICP 9145/Babati White accumulated the same proportion of the crop P in the grain (HI_P), which was 19%.

Variety responses to environment

In order to investigate the differences among varieties in responding to environment, i.e. the genetic x environment relation, an adaptability analysis (Hildebrand and Russell, 1996) were conducted, which included all environments and the varieties that were cropped across all environments, that is ICEAP 00040 and Babati White/ICP 9145 (Figure 1).

Table 1. Dry matter accumulations (kg ha^{-1}) in grain, shell, stem, leaves and litter of different pigeonpea genotypes that are intercropped with maize over three consecutive cropping seasons. Means of 20 observations.

		Babati			Gairo			Ntonda			Nyambi		
		ICEAP 00053	**ICEAP 00040**	**Babati White**	**ICEAP 00068**	**ICEAP 00040**	**Babati White**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**
2002	**Grain**	528	812	594	206	393	306	795	1088	794	617	719	790
	Shell	502	663	532	232	241	174	535	802	473	397	479	589
	Stem	2024	3099	2490	1186	1914	2359	6392	7258	6253	1299	1360	1688
	Leaves	292	325	365	123	58	112	484	692	478	144	137	132
	Litter	-	-	-	-	593	623	883	1066	812	487	481	577
2003	**Grain**	348	488	385	149	251	82	239	294	206	103	115	197
	Shell	208	296	215	93	145	91	192	204	157	80	101	151
	Stem	978	1327	1463	758	1357	2472	1975	2121	1517	1492	1683	2030
	Leaves	98	144	87	55	83	142	778	944	599	497	446	469
	Litter	800	1026	1088	1063	-	-	508	544	431	539	547	541
2004	**Grain**	449	306	369	195	214	121	33	38	36	164	185	245
	Shell	370	221	221	61	109	70	24	30	31	120	123	194
	Stem	449	306	369	195	214	121	33	38	36	164	185	245
	Leaves	253	477	168	33	151	122	-	-	-	-	-	-
	Litter	-	-	-	-	-	-	-	-	-	-	-	-

Germination was very poor in 2004 in Malawi but no replanting took place due to lack of seeding material.

Table 2. Nitrogen accumulations (kg ha^{-1}) in grain, shell, stem, leave and litter of different pigeonpea genotypes that are intercropped with maize over three consecutive cropping seasons. Means of 20 observations.

		Babati			**Gairo**			**Ntonda**			**Nyambi**		
		ICEAP 00053	**ICEAP 00040**	**Babati White**	**ICEAP 00068**	**ICEAP 00040**	**Babati White**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**
2002	**Grain**	18.9	27.6	21.0	7.5	14.3	11.2	26.6	36.2	26.5	21.0	23.8	26.2
	Shell	6.5	8.6	6.9	3.0	3.2	2.3	7.0	10.4	6.1	5.2	6.2	7.8
	Stem	13.6	23.6	18.0	8.3	13.1	16.3	41.9	54.2	42.8	21.0	23.9	28.6
	Leaves	9.6	11.0	12.1	4.4	2.1	4.0	10.9	15.7	10.8	3.6	3.2	3.3
	Litter	-	-	-	-	9.5	10.0	17.2	14.1	13.0	5.2	6.2	7.8
2003	**Grain**	11.2	15.9	13.1	4.6	7.4	2.5	8.6	10.7	7.6	3.5	3.8	6.5
	Shell	2.1	2.9	2.2	1.2	1.9	1.2	2.5	2.7	2.0	1.0	1.3	2.0
	Stem	78.1	10.6	11.5	5.6	9.8	17.4	19.0	21.4	14.6	14.5	16.0	19.7
	Leaves	2.8	4.2	2.5	4.1	7.3	11.4	17.5	21.2	13.8	9.3	8.4	8.9
	Litter	12.8	16.4	17.4	17.0	-	-	8.1	8.7	6.9	8.6	8.8	8.7
2004	**Grain**	16.7	11.3	13.3	7.7	7.9	4.5	1.3	1.4	1.4	6.1	6.8	9.3
	Shell	4.8	2.9	2.9	0.8	1.4	0.9	0.3	0.4	0.4	1.6	1.6	2.5
	Stem	22.4	5.0	15.2	13.6	5.4	10.4	-	-	-	-	-	-
	Leaves	7.9	14.9	5.2	1.1	4.9	3.9	-	-	-	-	-	-
	Litter	-	-	-	-	-	-	-	-	-	-	-	-

Germination was very poor in 2004 in Malawi but no replanting took place due to lack of seeding material.

Table 3. Phosphorus accumulations (kg ha^{-1}) in grain, shell, stem, leave and litter of different pigeonpea genotypes that are intercropped with maize over three consecutive cropping seasons. Means of 20 observations.

		Babati			**Gairo**			**Ntonda**			**Nyambi**		
		ICEAP 00053	**ICEAP 00040**	**Babati White**	**ICEAP 00068**	**ICEAP 00040**	**Babati White**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**	**ICEAP 00020**	**ICEAP 00040**	**ICP 9145**
2002	**Grain**	1.6	2.3	1.8	0.5	1.0	0.8	2.1	3.1	2.2	1.3	1.6	1.6
	Shell	0.5	0.6	0.5	0.2	0.2	0.2	0.4	0.6	0.4	0.3	0.4	0.5
	Stem	2.5	5.1	3.7	0.5	0.8	1.0	9.4	11.5	9.9	0.6	0.7	0.8
	Leaves	0.5	0.6	0.5	0.2	0.2	0.2	0.4	0.6	1.2	0.2	0.2	0.5
	Litter	-	-	-	-	0.6	0.6	0.9	1.2	0.8	0.5	0.4	0.6
2003	**Grain**	1.0	1.6	1.2	0.4	0.8	0.2	0.7	0.8	0.6	0.2	0.3	0.4
	Shell	0.8	1.0	1.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1
	Stem	1.4	2.0	2.2	0.3	0.5	1.0	3.2	3.5	2.5	0.8	0.6	1.1
	Leaves	0.2	0.3	0.2	0.1	0.1	0.3	3.2	3.5	2.5	0.8	0.9	0.7
	Litter	0.8	1.0	1.1	1.1	-	-	0.5	0.5	0.4	0.5	0.5	0.5
2004	**Grain**	1.6	1.1	1.2	0.5	0.4	0.3	0.1	0.2	0.2	0.6	0.6	0.8
	Shell	0.4	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.2
	Stem	4.3	0.9	2.9	0.2	0.3	0.6	-	-	-	-	-	-
	Leaves	0.6	1.1	0.4	0.1	0.3	0.3	-	-	-	-	-	-
	Litter	-	-	-	-	-	-	-	-	-	-	-	-

Germination was very poor in 2004 in Malawi but no replanting took place due to lack of seeding material.

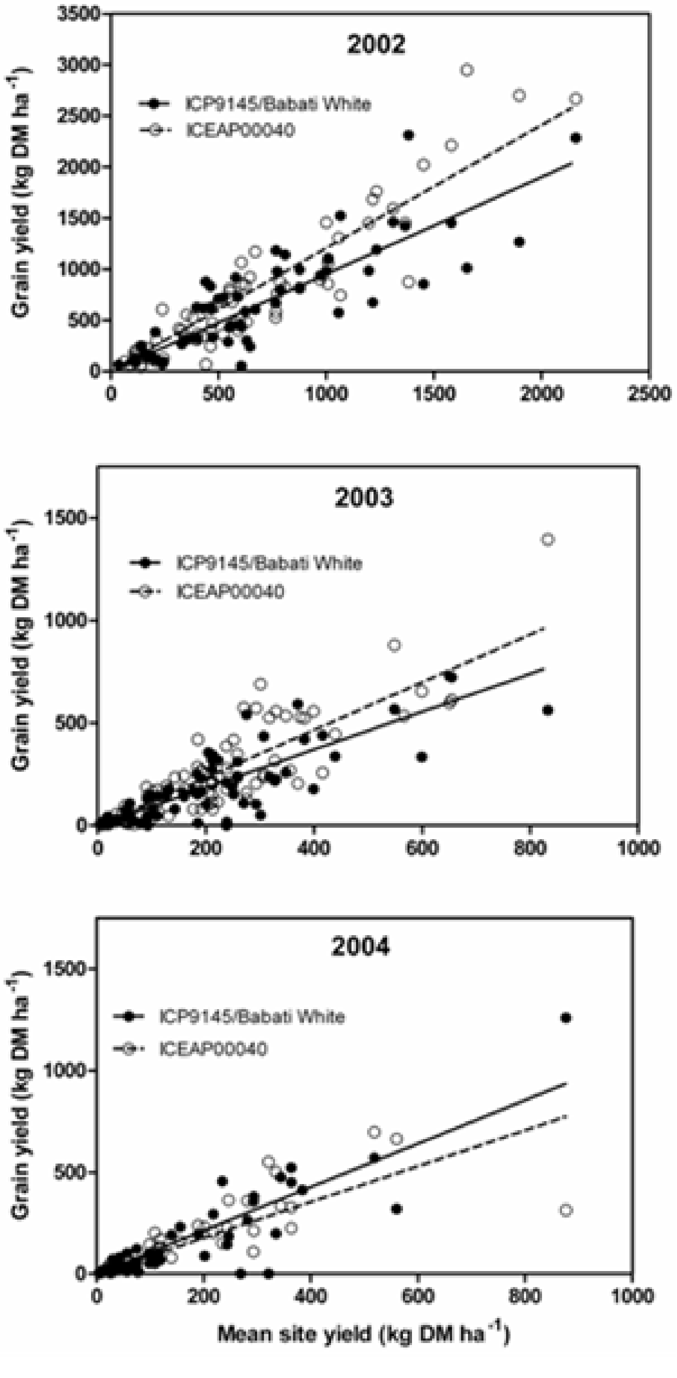

Figure 1. Adaptability analysis of pigeonpea varieties Babati White / ICP 9145 and IEACP 00040 across environments in Eastern and Southern Africa in over three consecutive cropping seasons.

The first analysis clearly demonstrates that the latest introduced variety ICEAP 00040 did respond more to favourable conditions (Figure 1) than the old genetic material. The slope of the two regression lines did differ ($P < 0.05$) in 2002 and 2003 but not in 2004. However, in many cases did the farmers not achieve grain yields above 500 kg ha^{-1}.

An adaptability analysis were further conducted for each of the four trial sites including the varieties that were cropped across all environments as well as the varieties that were specifically tested at that trial site (Figure 2). This analysis revealed that ICEAP 00040 did perform better in all environments (difference of slope, $P<0.05$) versus all genotypes except in Nyambi. In Gairo 2002, the slope for ICEAP 00040 was 1.251 ± 0.0824, vs. 0.8798 ± 0.0612 (ICEAP 00068) and 0.8526 ± 0.0611 (Babati White). In Gairo 2003, the slope for ICEAP 00040 was 1.501 ± 0.134 vs. 0.8355 ± 0.100 (ICEAP 00068) and 0.4648 ± 0.0970 (Babati White). In Babati 2002, the slope for ICEAP 00040 was 1.333 ± 0.0691 vs. 0.7849 ± 0.0889 (ICEAP 00053) and 0.8821 ± 0.0643 (Babati White). In Babati 2003, the slope for ICEAP 00040 was 1.147 ± 0.0936 vs. 0.9083 ± 0.0900 (ICEAP 00053) and 0.9364 ± 0.0702 (Babati White). In Ntonda 2002, the slope for ICEAP 00040 was 1.291 ± 0.0741 vs. 0.8686 ± 0.0455 (ICEAP 00020) and 0.8408 ± 0.0680 (ICP 9145). In Ntonda 2003, the slope for ICEAP 00040 was 1.299 ± 0.100 vs. 0.8679 ± 0.0714 (ICEAP 00020) and 0.7527 ± 0.0789 (ICP 9145). In Nyambi 2002, the slope for ICEAP 00040 was 1.028 ± 0.0570 vs. 0.8322 ± 0.0587 (ICEAP 00020) and 1.140 ± 0.0734 (ICP 9145). In Nyambi 2003, the slope for ICEAP 00040 was 0.7919 ± 0.0789 vs. 0.7170 ± 0.0627 (ICEAP 00020) and 1.474 ± 0.0856 (ICP 9145).

Entomologists did assess the crops on several occasions. However, not significant differences were noted in the degree attack or the type of pests or diseases. Generally, farmers did not consider pest and diseases a problem with the new varieties but the older genotypes were prone to *Fusarium* wilt.

DISCUSSION

Differences in response to environment

The aim of this study was to assess variances in the genotypes to perform in a wide range of environments. From the farmers point of view it is important that the pigeonpea crop does not significantly reduce yield of the associated maize crop. The tested varieties did not show any differences in terms of complementarity with the component maize crop (data not shown).

As maize crops in Eastern and Southern Africa often utilize only half of the seasonal rainfall (Barron et al., 2003), medium-to-long duration varieties of pigeonpea are better suitable than the short duration ones in the dry season because they are able to utilize the residual moisture, resulting in an additional income to the smallholder farmers (Myaka et al., 2006). Due to the low harvest indices, in terms of dry matter, N as well as P, the non-edible crop organs' especially the leaves and the extensive root systems contribute to soil fertility (Tables 1 - 3; Adu-Gyamfi et al., 2007) whereas the stems are an important source of fuel wood for the household (Table 1). The role of pigeonpea in the household is thus of a multipurpose

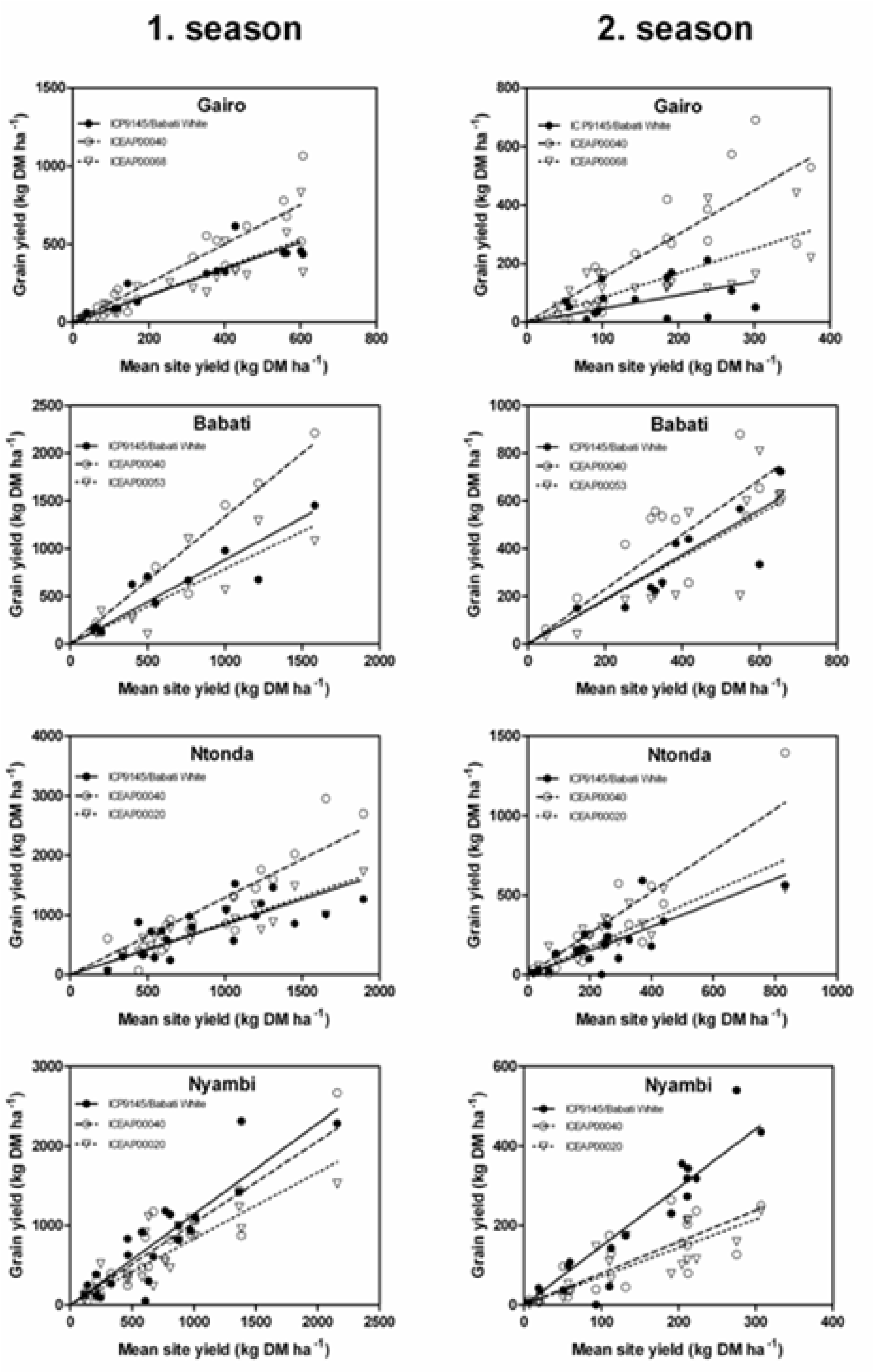

Figure 2. Adaptability analysis of pigeonpea varieties Babati White/ICP 9145 and IEACP 00040 and the new variety (ICEAP 00053 for Babati, ICEAP 00068 for Gairo and ICEAP 00020 for Nyambi and Ntonda) for each of the four study sites in Eastern and Southern Africa in over two consecutive cropping seasons.

nature which is important for resource poor stakeholders (Barrett et al., 2002; Mapfumo et al., 2001).

A statistical analysis using general linear models (SAS Institute Inc., 1993) only gave limited information on the genotypic x environment (G x E) interaction. Thus an adaptability analysis was applied to verify the G x E interactions (Hildebrand and Russell, 1996). This analysis revealed a better responsiveness to favourable conditions by the recently introduced ICEAP 00040 compared to the older genetic materials (Figure 1). However, as most farmers produce less than 500 kg grain ha^{-1}, this potential is only seldom redeemed by the producers. This is nevertheless a common feature of the semi-arid tropics and yields vary much between years. During the three consecutive growing seasons (2002-2004) the mean grain yields of pigeonpea varied between 172 and 740 kg ha^{-1} across all environments.

The yield potential of ICEAP00040 seemed constant across environments judged from the slope of the regression line (Figure 2) with the exception of Nyambi and in particular for the second cropping season. Myaka et al. (2006) identified sensitivity of pigeonpea to low soil P conditions. This could be explained by the fact that the Nyambi site had the lowest available soil P among the 4 sites (Myaka et al., 2006 for details). It was hypothesized that the older genotypic plant material that is well adapted to the local climate and soil conditions may perform better than the modern genotypes. However, in this study the only occasion where the newly introduced material ICEAP 00040 performed poorly compared to the others was at the Nyambi site for 2003 (Figure 2). Vesterager et al. (2006) tested a wide range of pigeonpea genotypes and found a substantial genotypic variation in their P use efficiencies (g DM g^{-1} P absorbed) as well as in their uptake efficiencies (uptake of P g^{-1} root). Thus, as Høgh-Jensen et al. (2006) reported that the concentration of P in the pigeonpea grain was affected when the $NaHCO_3$-extractable soil P was below 10 µg g^{-1} the may be genotypic differences to respond to critical soil P levels. Although Snapp (1998), using a value based on Mehlich III P extraction, reported that most soils in Malawi are not P deficient, the P value extracted using the Mehlich III could be two to three times as much as $NaHCO_3$ extractable P (Wolf and Baker, 1985) suggesting that the yield potential of pigeonpea crops in Malawi may be frequently limited by low soil P availability.

Differences in their potential contribution to the system

Due to the multipurpose use of the pigeonpeas, the HI, NHI and PHI have significant socio-economic implications to the crops' overall contributions to the system. The comparative responsiveness of the modern genotypes indicated that only one out of the four modern varieties was superior. Furthermore, this superiority was only expressed under favourable conditions.

It is generally understood that the inclusion of legumes in cropping systems would benefit farmers due to the use of different sources of N (Ofori and Stern, 1987) and P (Ae et al., 1990). It is noticeable that the relative organ sizes of the tested varieties were more or less similar (Tables 1, 2, 3). Thus the tested varieties will contribute similar to the nutrient balances of the systems (Tables 1, 2 and 3; Adu-Gyamfi et al., 2007). There is however no reason to believe that short duration varieties that accumulate much less biomass (see ICEAP 00068 in Table 1), will have a role to play in the intercropped systems. Further, it is important to keep the harvest index in mind in future breeding efforts as changes in those will impact on the system, mainly because less biomass may be recycled due to the relatively low harvest index for N and P (Adu-Gyamfi et al., 2007; Giller, 1998; Kumar Rao et al., 1983; Myaka et al., 2006). The harvest index of many tropical pulse species and varieties tends to be low because selection had focused mainly on yield in all seasons (Hay, 1995). The NHI and PHI were nevertheless surprisingly constant across environments in the current study which may limit its use as a tool in interpreting crop responses to different environmental impacts. The HI in terms of DM did however vary with a factor two.

Eastern Africa is considered a secondary centre of origin for pigeonpea; a crop that is characterised by an outcrossing of up to 14% (Singh et al., 1990). The maintenance of an improved variety like ICEAP 00040 in the field settings must therefore be based on a substantial supply of seed material at the local level. As the seed supply systems in Eastern and Southern Africa are poor, it is difficult to envisage that these modern varieties will make a significant change without a hitherto unknown institutional support. In areas like Gairo, where pigeonpea is a new crop, the impact is however expected to be substantial.

Conclusions

We report for the first time a comprehensive comparative study on the performance of six pigeonpea varieties in a maize-based cropping system in Eastern and Southern Africa. The study revealed that the newly introduced ICEAP 00040 outperformed all the other tested varieties (ICP 9145; ICEAP 00020, ICEAP 00053, ICEAP 00068, and a local variety called "Babati White") under farmer-managed conditions. The harvest indices in terms of DM, N and P were relatively low and unaffected by the different environments. The yields of the intercropped pigeonpeas were generally low and these low yields are still a major challenge in African smallholders' agriculture.

ACKNOWLEDGEMENT

Support from the Danish Council for Development Research is gratefully acknowledged.

REFERENCES

Adu-Gyamfi JJ, Myaka FM, Sakala WD, Odgaard R, Høgh-Jensen H (2007). Nitrogen and phosphorus budgets and nitrogen fixation in farmer-managed intercrops of maize-pigeonpea in semi-arid Southern and Eastern Africa. Plant Soil, in press.

Ae N, Arihara J, Okada K, Yoshihara T, Johansen C (1990). Phosphorus uptake by pigeonpea and its role in cropping systems of the Indian subcontinent. Sci. 284: 477-480.

Barrett CB, Place F, Aboud A, Brown DR (2002) The challenge of stimulating adoption of improved natural resource management practices in African agriculture. In Barrett CB, Place F, Aboud AA (eds.), Natural Resource Management in African Agriculture. CAB International, Wallingford. pp. 1-21.

Barron J, Rockström J, Gichuki F, Hatibu N (2003). Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agric. For. Meteorol. 117: 23-37.

Byerlee D, Eicher CK (1997). Africa's emerging maize revolution. Lynne Reinner Publishers, Boulder Colorado p.301

FAO/UNESCO (1990). FAO/UNESCO Soil Map of the World, revised legend, reprinted with corrections. World Soil Resources Rep. 60, FAO, Rome

Giller KE (1998) Tropical legumes: Providers and plunderers of nitrogen. In Bergström L, Kirchmann H (eds.), Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems. Cab International, Wallingford. pp. 33-45.

Giller KE (2001). Nitrogen fixation in tropical cropping systems. CAB International, Wallingford. p. 423

Hay RKM (1995). Harvest index: a review of its use in plant breeding and crop physiology. Ann. Appl. Biol. 126: 197-216.

Hildebrand PE, Russell JT (1996). Adaptability Analysis: a method for the design, analysis, and interpretation of on-farm research-extension, Iowa State University Press, Ames, Iowa. p.183

Høgh-Jensen H, Myaka FA, Kamalongo D, Rasmussen J, Ngwira A (2006). Effect of environment on multi-element grain composition of pigeonpea cultivars under farmers' conditions. Plant Soil 285: 81-96.

Kherallah M, Delagde C, Gabre-Madhin E, Minot N, Johnson M (2002). Reforming agricural markets in Africa. IFPRI and Johns Hopkins University Press, Baltimore. p. 201

Kumar Rao JVDK, Dart PJ, Sastry PVSS (1983). Residual effect of pigeonpea (*Cajanus cajan*) on yield and nitrogen response of maize. Exp. Agric. 19: 131-134.

Kumwenda AS (1998). Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe. In Waddington SR, Murwira HK, Kumwenda JDT, Tagwira F (eds.), Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe. Proceedings of the Soil Fert Net Results and Planning Workshop, 7-11 July 1997, Mutara, Zimbabwe. CIMMIT. pp. 263-269.

Mapfumo P, Campbell BM, Mpepereki S, Mafongoya PL (2001) Legumes in soil fertility management: the case of pigeonpea in smallholder farming systems of Zimbabwe. Afr. Crop Sci. J. 9: 629-644.

McCann JC (2005). Maize and Grace. Africa's Encounter with a New World Crop 1500-2000. Harvard University Press, Cambridge, Massachusetts. p.287.

McCown RL, Keating BA, Probert ME, Jones RK (1992). Strategies for sustainable crop production in semi-arid Africa. Outlook Agric. 21: 21-31.

Mergeai M, Kimani P, Mwang'ombe A, Olubayo F, Smith C, Audi P, Baudoin JP, Roi AL (2001). Survey of pigeonpea production systems, utilization and marketing in semi-arid lands of Kenya. Biotechnol. Agron. Soc. Environ. 5: 145-153.

Miracle MP (1965). The introduction and spread of maize in Africa. J. Afr. Hist. 6: 39-55.

Murphy J, Riley JP (1962). A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta 27: 31-36.

Mwanga W (2004). Low use of fertilizers and low productivity in sub-Saharan Africa. Nutr. Cycl Agroecosys. 45: 135-147.

Myaka FA, Sakala WD, Adu-Gyamfi JJ, Kamalongo D, Ngwira A, Odgaard R, Nielsen NE, Høgh-Jensen H (2006). Yields and accumulations of N and P in farmer-managed maize-pigeonpea intercrops in semi-arid Africa. Plant Soil 285: 207-220.

Nene YL, Sheila VK (1990). Pigeonpea: Geography and importance. In Nene YN, Hall SD, Sheila VK (eds.), The Pigeonpea. CAB International, Wallingford. pp. 1-14.

Ofori F, Stern WR (1987). Cereal-legume intercropping systems. Adv. Agron. 40: 41-90.

Sakala WD, Cadisch G, Giller KE (2000). Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. Soil Biol. Biochem. 32: 679-688.

Sakala WD, Kumwenda JDT, Saka AR (2003). The potential of green manures to increase soil fertility and maize yields in Malawi. Biol. Agric. Hort. 21: 121-130.

Sanchez PA (2002). Soil fertility and hunger in Africa. Science 295: 2019-2020.

Sanginga N (2003). Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. Plant Soil 252: 25-39.

SAS Institute Inc. (1993). SAS/STAT® Software: Syntax, Version 6, first Edition. SAS Institute Inc., Cary, NC.

Singh L, Gupta SC, Faris DG (1990). Pigeonpea: Breading. In Nene YN, Hall SD, Sheila VK (eds.), The Pigeonpea. CAB Inter., Wallingford. pp. 375-399.

Snapp SS (1998). Soil nutrient status of smallholder farms in Malawi. Commun. Soil Sci. Plant Anal. 29: 2571-2588.

Vesterager JM, Nielsen NE, Høgh-Jensen H (2006). Variation in phosphorus uptake and use efficiencies between pigeonpea genotypes and cowpea. J. Plant Nut. 29: 1869-1888.

Wolf AM, Baker DE (1985). Comparisons of soil test phosphorus by Olsen Bray P[1], Mehlich 1 and Mehlich III methods. Commun. Soil Sci. Plant Anal. 16: 467-484.