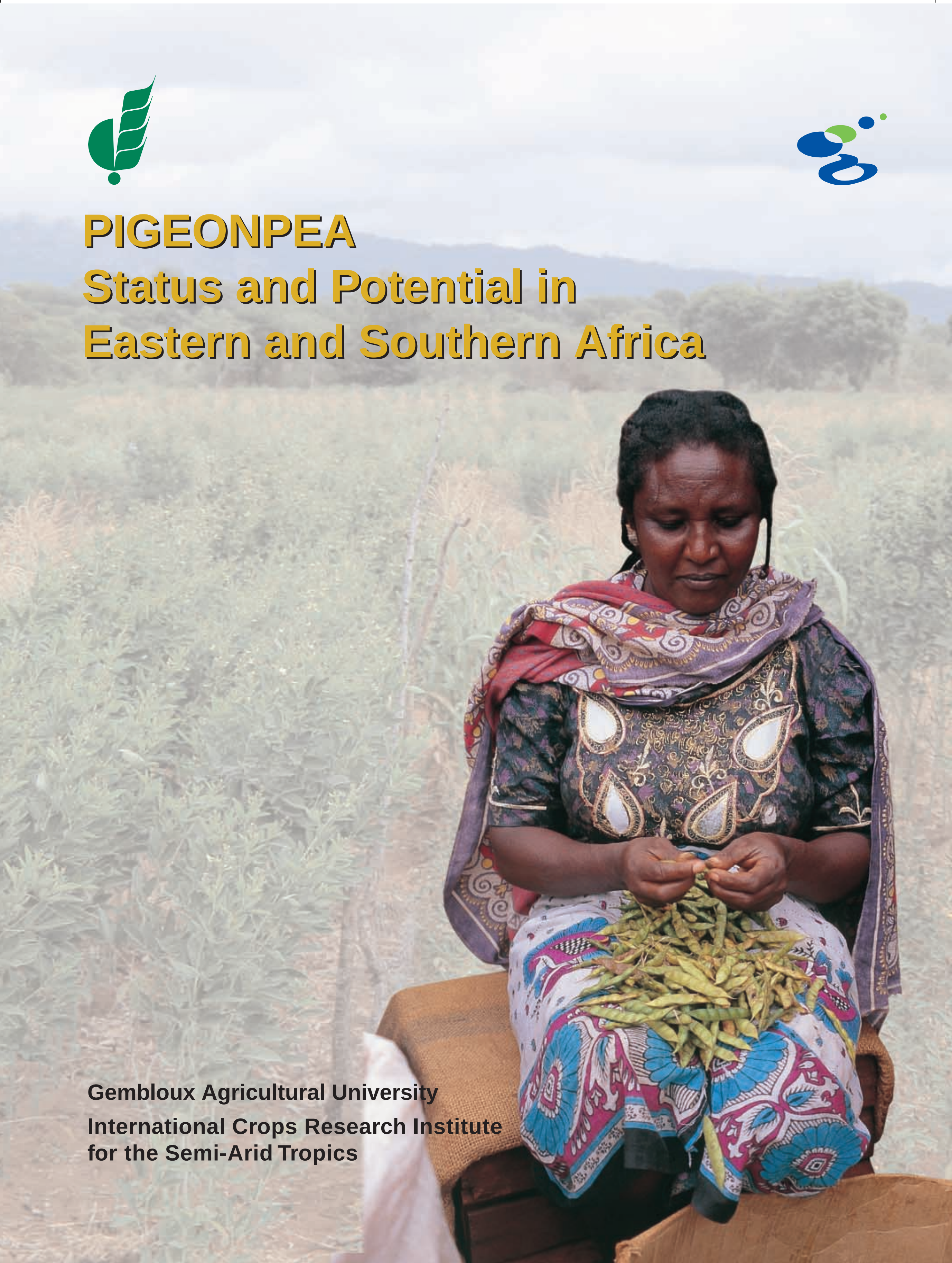
PIGEONPEA
Status and Potential in Eastern and Southern Africa



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Abstract

Pigeonpea is a multipurpose, multi-benefit crop adapted to semi-arid conditions, and an important component of traditional intercropping systems in eastern and southern Africa. This publication contains presentations, discussions, and recommendations from a workshop to review the current status and future prospects for pigeonpea in the region. The workshop, held in Nairobi in Sep 2000, attracted 29 participants from six countries, representing various stakeholder groups including national and international research institutes, universities, NGOs, and policy makers.

A range of improved technologies is available. Efforts to improve adoption must center on commercialization of pigeonpea, i.e. providing smallholder farmers with reliable market outlets, market information, and adequate incentives to invest in productivity-enhancing technologies. Participants suggested the following: (i) Consolidate research information (currently scattered in journals and reports) into a comprehensive technology inventory for the region, identify gaps in knowledge. (ii) Identify specific markets, package available technologies (variety, management) for each of these markets, establish links with marketing agencies where possible. (iii) Initiate studies to collect additional information, particularly on market opportunities, transaction costs, and comparative advantages.

Status and Potential of Pigeonpea in Eastern and Southern Africa

Proceedings of a Regional Workshop
Nairobi, Kenya, 12-15 Sep 2000

Edited by

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Welcome Address

S N Silim[1]

Dr Kiome, Director General of KARI; Prof Mukunya, Principal, College of Agriculture and Veterinary Medicine, University of Nairobi; ladies and gentlemen:

Welcome to Nairobi – *karibuni*, as we say. Many of you have traveled long distances, taking time off your busy schedules, to be here today. Thank you for your support. I hope your journey was pleasant, and that you find the celebrated Nairobi weather stimulating (but not too stimulating). We are here for this important workshop which has two major objectives – first, to review the results achieved in the past few years; and second, identify a future course of action to build on past achievements.

Let me begin with a brief background. ICRISAT has a global mandate for research and improvement of pigeonpea. The world's largest pigeonpea producer is India, where ICRISAT's headquarters are located. But five of the top six producers are in eastern and southern Africa, where pigeonpea has been grown for perhaps 4000 years. The crop is drought-tolerant, it provides multiple benefits, it can give good yields even with limited inputs – but simultaneously it is also a potential cash crop. It thus directly benefits our primary client – the resource-poor smallholder farmer, who operates in a variable, semi-arid environment and generally lacks access to technology, cash, and other resources. I believe all of us share the same mandate – to develop and promote technology aimed at the smallholder farmer. Pigeonpea fits well into the smallholder agricultural and economic system. And this workshop aims to find ways to leverage this intrinsic "good fit" into more diversified cropping opportunities, higher farm incomes, and a more sustainable farming system.

In 1992, the African Development Bank provided funding for the Pigeonpea Improvement Project for Eastern and Southern Africa. The project operated in 10 countries, implemented by a broad network of partners – national research institutes such as KARI, NGOs such as TechnoServe and Catholic Relief Services, the private sector, advanced research institutes, extension services, and farmer groups. This network of partnerships has generated impressive results.

Several improved varieties have been released, including short-duration varieties suitable for cash-cropping. Pest and disease control methods have been developed. Physiology and adaptation studies have greatly improved the targeting of varieties to specific environments. But the project's single biggest contribution has probably been in the area of capacity building. Before 1992, Kenya was the only country in the region with an active pigeonpea research program. Today, 10 countries have established R&D programs. The number of scientist-years in the region has increased five-fold since 1992. Scientists and other researchers have been sponsored for higher education. Training programs have been conducted in several countries for food technologists, manufacturers of processing equipment, farmers, and specifically women farmers (processing and utilization techniques).

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Simultaneously, the project has brought together a number of partners with complementary skills and expertise, to improve the dissemination of new pigeonpea technologies. For example, private-sector millers in Malawi and Kenya are helping us develop commercial marketing channels. As a result, we are now in a position to take on new challenges, in both research and technology dissemination.

I must express our gratitude to the various co-sponsors who made this meeting possible – the Kenya Agricultural Research Institute (KARI), ICRISAT, European Union (INC-DEV Programme), Conseil Inter-universitaire de la Communauté française de Belgique (CIUF), Makerere University, and the Universities of Nairobi, Gembloux, and Bonn. Equally important are our partners in KARI and other research institutes who led the research efforts. You will all agree that pigeonpea is a crop with enormous potential. I believe we have the technology, the collective experience, and the commitment to help realize this potential. I hope we will be able during this workshop to outline a set of concrete steps to promote pigeonpea cultivation and commercialization throughout the region.

Thank you.

Opening Address

R Kiome[1]

Ladies and gentlemen

Thank you for your invitation; it is a pleasure to be here today to discuss R&D strategies for one of the most important legume crops in the region.

I am familiar with ICRISAT's work on legumes and cereals. The Kenya Agricultural Research Institute (KARI) has always been a strong supporter of pigeonpea research programs because of the importance of the crop. Last August, I toured Machakos District and other parts of Eastern Province, where pigeonpea was the only crop that survived and produced grain. Two consecutive droughts have caused great hardship to farmers, especially smallholders; and the advantages of growing drought-tolerant crops are more evident than ever. The benefits of drought tolerance in pigeonpea are widely recognized. But this aspect has not been sufficiently emphasized by the research community, or by policy makers, in order to promote pigeonpea. In addition to the many other benefits this crop provides, we must emphasize its advantages as an "emergency" crop, capable of providing food in drought situations. Perhaps we need to lay greater emphasis on this aspect even in breeding and agronomy research.

Good work has been done on variety improvement, but some challenges remain:

Adoption. Adoption rates are poor, despite the significant yield improvements that the new varieties offer. Pigeonpea has not been able to compete with other crops, especially cash crops. We need to address these issues, and devise ways to increase adoption and impact of new technologies.

Socio-economic factors. The farmer is interested in food supply and cash, not in any particular crop. Decisions are made based on cash, labor and other inputs needed, and the returns from investment in inputs. Thus, we need to examine the cost-effectiveness of pigeonpea production, and offer farmers economically advantageous options. More information is needed on various aspects – impact assessments, adoption surveys, socio-economic factors such as resource availability, market access and so on. Farmer-participatory studies in these areas will help document the advantages of pigeonpea and identify specific traits (e.g. vitamin content) that can be improved, for example using biotechnology.

Systems approach. One unfortunate aspect of many crop improvement programs is that the sorghum breeder tries to promote sorghum, the pigeonpea breeder emphasizes the advantages of pigeonpea, and so on. Rather, we need a systems approach. Research programs must determine how well any potential variety or technology fits into the cropping system.

Future projections. What are the projections for future expansion/adoption, what is pigeonpea's comparative advantage relative to other crops? It clearly has an adaptive

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advantage in semi-arid areas; how can we build on this advantage to promote the crop more widely? We must remember that this advantage may not last indefinitely. For example, breeders are now trying to develop drought-tolerant maize, which could challenge pigeonpea's dominance in dry areas. Simultaneously, we must ensure that our own research remains cost-effective and relevant to farmers' needs.

KARI strongly supports ICRISAT's pigeonpea work, evidenced by the presence of KARI scientists at this meeting, and their close association with the pigeonpea project over the years. I note there are participants from Uganda and Tanzania as well, indicating that other countries in the region (e.g. ASARECA members) are supportive of these efforts to improve food security in eastern and southern Africa. KARI will continue to support ICRISAT's efforts to promote pigeonpea. The crop is very much a part of traditional cropping systems; it has wide consumer acceptance, it is adapted to conditions in the region, and can offer both food security and cash income. Working together, we can build on these inherent advantages to improve the technology options available to smallholder farmers throughout the region.

I am sure this meeting will lead to the development of a clear strategy for pigeonpea research and dissemination in the future, and that agricultural development in the region will benefit as a result. I now officially declare this workshop open.

Thank you.

Approaches to Pigeonpea Research

D M Mukunya[1]

Ladies and gentlemen

Thank you for giving me the opportunity to attend this meeting, and interact with legumes scientists from a range of disciplines. I think I know most of you already, and we have worked together in the past. I began my academic career with the University of Nairobi, working with grain legumes – I can say without exaggeration that my heart belongs to grain legumes.

I recently toured the Eastern and Central Provinces. Crops have been devastated after two seasons of severe drought, and even weeds were struggling! The only green thing we could see in the fields was pigeonpea, thanks to its drought tolerance.

Pigeonpea research in the region has been fairly successful. A number of improved varieties have been either released or are under advanced on-farm testing in several countries. In Kenya, we have lines such as NPP 670 and Kioko, developed by Onim, Kimani, and others; Kat 60/8 developed by Omanga; and several other lines developed or introduced by ICRISAT. This represents very hard work over a long period – such persistence in research is important, especially in a semi-arid environment like ours, where replicability of conditions is so difficult.

If we have been successful, it is in large measure due to collaboration with different partners. We began collaboration many years ago – that is why we survived. Collaboration was developed through various avenues. First, between organizations in Kenya – for example, KARI and the University of Nairobi work together, as we should. We target the same farmer, so we need to work together as one institution, and forge even closer links. We sent students to ICRISAT-India for MSc and PhD degrees through an informal Memorandum of Understanding, and training activities expanded greatly after ICRISAT established an office in Nairobi. The European Union (notably Belgium and Germany) also provided some funding. We have long worked with national programs in the region as well –in fact, Kabete Research Station, one of Kenya's oldest, belongs to Makerere University in Uganda! This synergy is important, because with synergy, 1 plus 1 makes 3.

Future research must build on these achievements and partnerships. If we are to aim for new technologies and new varieties, we need clear objectives, a pro-active approach, and long-term commitment from all partners.

Research facilities in Kenya are sadly lacking. Lack of funding means that it is difficult to procure new equipment, and often even to maintain existing facilities. By collaborating we get not only ideas and expertise from our partners, but also access to equipment and facilities.

Let me thank you all for your work, and your approach to agricultural development; and in particular, ICRISAT, KARI, and Gembloux University, who made this meeting possible.

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Technology Development

Strategies and Experiences in Pigeonpea Variety Development for Eastern and Southern Africa

S N Silim[1]

Introduction

Pigeonpea is one of the major grain legume crops grown in the tropics and subtropics. It is usually grown rainfed in areas prone to drought. In these areas, daylength varies from 11 to 14 h and large differences in temperature are experienced, largely due to variations in altitude and latitude. The traditional varieties grown are mainly medium- and long-duration types, which are intercropped with cereals such as maize and sorghum and various short-duration legumes such as cowpea and beans (Ali 1990, Silim et al. 1991). These traditional varieties are extremely sensitive to photoperiod and temperature, with plant height, vegetative biomass, phenology, and grain yield being the traits most affected (Byth et al. 1981, Whiteman et al. 1985). The sensitivity of pigeonpea to temperature and photoperiod is a major constraint to the development of stable and predictable management practices, cropping systems, and varieties (Whiteman et al. 1985). Concerted research efforts by ICRISAT and its partners have resulted in the development of extra-short and short-duration varieties that escape drought and are less sensitive to photoperiod than traditional medium- and long-duration types (Singh et al. 1990). This has increased the flexibility of pigeonpea cultivation and facilitated its use in different cropping systems (Nene 1991).

ICRISAT's efforts to develop photoperiod-insensitive extra-short and short-duration varieties have unwittingly resulted in the development of varieties adapted to warm temperatures (Omanga et al. 1995) and sensitive to low temperature. For example, attempts in 1990 and 1991 by ICRISAT to introduce short-duration pigeonpea in rotation with wheat in the highlands of Kenya, where temperatures are cool, were not successful because the low temperature caused a delay in pigeonpea phenology and hence interfered with the cropping sequence.

During the initial stages of the Pigeonpea Improvement Project for Eastern and Southern Africa, we realized that the requirements for pigeonpea varieties are specific to the region. Varieties in eastern and southern Africa show a different adaptation from those in the Indian sub-continent. Medium- and long-duration varieties developed at ICRISAT-Patancheru in India and which have shown potential there, often performed poorly and were not always well adapted to the region. Large, cream and speckled grains are preferred in the region whereas small to medium-sized brown grains are the common types in India. A regional approach was therefore required to ensure that varieties developed are adapted to the region and meet end user requirements.

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Influence of Temperature and Photoperiod on Adaptation

Five strategic locations in Kenya were used, representing both traditional (Katumani, Kiboko) and non-traditional (Mombasa, Kabete, Muguga) pigeonpea-growing areas. Altitude at the experimental sites varied from 50 m to about 2100 m, with corresponding variation in temperature (Table 1). Latitude ranged from $1^{o}10'$ to $4^{o}25'$ S. There were three light treatments: natural daylength (about 12.6 h) at all locations, and artificially extended daylength of 14.5 h (Kiboko, Katumani, Kabete) and 16 h (Kiboko and Kabete). Daylength was extended by using 100 W incandescent bulbs suspended 2 m above the ground and 1.5 m apart. The daylength treatments were sited at least 50 m from each other. This approach allowed us to understand the influence of temperature and photoperiod on crop phenology and yield, and thus target varieties to areas of their best adaptation.

Determination of germplasm for suitability. A large number of germplasm lines from the region, accessions from the ICRISAT genebank, and improved varieties developed mainly by ICRISAT in India were evaluated at Kiboko under natural daylength to select lines with acceptable grain characteristics. The test material was drawn from all maturity groups, extra-short, short-, medium- and long-duration. This approach allowed us to exclude lines with unacceptable grain traits, mainly small (100-seed mass <10 g) brown grains, and also reduce the number of accessions to manageable levels.

Modulation of phenology by temperature and photoperiod. Germplasm, improved varieties, and accessions from different parts of the world in each duration group were grown at five locations (Table 1) to determine their performance under varying temperature and photoperiod. We measured environmental effects on phenology, the most important being time taken to a particular event. Summerfield et al. (1991) described a series of models used to predict phenological events (flowering in this case) not as time to flower (f) but rates of

Table 1. Latitude, altitude, long term temperatures and rainfall at 5 study sites, Kenya.

Location	Latitude (S)	Altitude (m)	Season*	Temperatures (^{o}C)			Rainfall (mm)
				Max	Min	Mean	
Mombasa	4^{o} 25'	50	SR	31.4	23.2	27.3	370
			LR	28.9	21.5	25.2	679
Kiboko**	2^{o} 20'	900	SR	29.4	17.7	23.5	464
			LR	27.8	15.5	21.6	140
Katumani	1^{o} 35'	1560	SR	25.6	14.4	20.0	467
			LR	23.6	12.9	18.2	244
Kabete	1^{o} 15'	1825	SR	24.6	12.9	18.7	478
			LR	22.1	12.2	17.1	518
Muguga	1^{o} 10'	2100	SR	21.9	11.5	16.8	461
			LR	19.5	10.1	14.9	500

* SR = Short rains (Oct-Feb); LR = Long rains (Apr-Sep)
** Received supplemental irrigation

progress towards flowering (i.e. 1/f, the reciprocal of the time taken) as influenced by photoperiod and temperature. The temperature range in which plant growth and development occurs is characterized by a base temperature T_b below which the rate of development is zero, an optimum temperature T_o at which the rate of development is most rapid, and a warmer ceiling limit T_{ce} beyond which development again ceases (Summerfield et al. 1991). Similarly, for short-day plants such as pigeonpea, flowering response to photoperiod is defined by the critical photoperiod P_c, which is the daylength beyond which flowering is delayed. With further increase in daylength, a ceiling photoperiod P_{ce} is reached, when days to flowering reaches a maximum (Summerfield et al. 1993). Rates of progress from sowing to flowering were calculated as 1/f for each variety, using the protocol developed by Summerfield et al. (1991).

Use of the model made it easy to define the adaptation of pigeonpea. It showed that the area where the germplasm was collected or the variety was developed has a strong influence on adaptation of the plant (Table 2). The study led to the following conclusions. The groups are listed in decreasing order of sensitivity to temperature:

Table 2. Influence of temperature on phenology of pigeonpea of different duration groups, Kenya.

	Days to 50% flowering				
	Muguga	Kabete	Katumani	Kiboko	Mombasa
Extra short duration	88	90	76	60	80
Short duration	90	85	80	62	80
Medium duration	125	117	112	96	127
Long duration	120	125	140	240	Did not flower

- Extra-short-duration varieties developed by ICRISAT- Patancheru in India (17°N, 78°E, 500 m elevation) were the least sensitive to photoperiod and had the highest T_o of 26°C. Time to flower and mature is delayed by cool temperature; this group is the most sensitive to low temperature.
- Short-duration varieties developed by ICRISAT-Patancheru are relatively insensitive to photoperiod and had a high T_o of about 24° C. Time to flower and mature is delayed most by cool temperature.
- Medium-duration germplasm or varieties from low-elevation areas near the equator are sensitive to daylength and will flower only under short photoperiod. The optimum temperature for early flowering is about 24°C. This sensitivity to photoperiod means that medium-duration varieties, if planted away from the equator, will flower only when daylength is short, i.e. towards autumn.
- Medium-duration varieties developed by ICRISAT-Patancheru or in peninsular India are sensitive to photoperiod. Optimum temperature for early flowering is about 22°C. Like the previous group, these varieties, if planted away from the equator, will flower only when daylength is short.

- Long-duration germplasm or varieties from near the equator or subtropics are sensitive to daylength and will flower only under short photoperiod. The optimum temperature for early flowering is about 18°C. These varieties are best suited to medium to high elevation near the equator, and areas in the subtropics where daylength is short and temperatures are low during winter.
- For long-duration germplasm or varieties from low-elevation areas in northern India, the plant is subjected to large variations in conditions – temperatures are >40°C in summer and < 0°C in winter. Days are long in summer and very short (<11 hrs) in winter. These varieties are insensitive to temperature but sensitive to photoperiod. This group can be grown in areas where there is large variation in temperature, and will flower when daylength is short.

Within each duration group we were able to determine variation in response of different genotypes to temperature and photoperiod. While evaluating for adaptation, we were also simultaneously selecting for high grain yield and bold cream-colored seeds. Improved, high-yielding varieties of known adaptation and with farmer- and market-acceptable traits have been selected, constituted into nurseries, and targeted where they are most likely to do well. This approach reduced the workload of national programs. As a result, within the short span of only 6 years, a number of improved varieties have been identified by NARES; some have been released, while others are being tested on-farm (Table 3).

Screening for Disease Resistance

The major pigeonpea disease in the region is fusarium wilt (*Fusarium udum* Butler), while cercospora leaf spot (*Cercospora cajani* Hennings) can also cause serious damage (Reddy et al. 1990). The project used the protocol developed at ICRISAT-Patancheru (Nene et al. 1981) to screen for wilt resistance. A set of germplasm, improved varieties, accessions from different parts of the world, and resistant and susceptible controls were evaluated in wilt-sick plots at Kiboko and Katumani in Kenya. Wilt-resistant varieties with acceptable characteristics were constituted into regional nurseries for further evaluation by NARS. Resistant lines identified in Kenya were evaluated further in wilt-sick plots developed in Malawi and Tanzania. Four long-duration (ICP 9145, ICEAP 00020, 00040, and 00053) and five medium-duration (ICEAP 00540, 00550, 00555, 00556 and 00557) wilt-resistant varieties identified using this screening method are now in on-farm trials in Kenya, Malawi, Mozambique, and Tanzania. A breeding program has been initiated to develop high-yielding,wilt-resistant lines.

Integrated Pest Management

Surveys conducted in Kenya, Malawi, Tanzania, and Uganda have provided valuable information on pigeonpea pest populations. Pod borers, podfly, and pod-sucking bugs were identified as important constraints, causing yield losses varying from 17 to 27%. Silim-Nahdy et al. (1999) reported that pod hairiness reduced infestation by bruchids. Other reports suggested that pods borne singularly, as opposed to those in clusters, suffered low damage from pod borers. It had also been suggested that hard pods reduced infestation by insect pests.

Table 3. Varieties selected by national programs for on-farm testing or release.

	Short duration	Medium duration	Long duration
On-farm testing			
Kenya		ICP 6927 ICP 12734 ICEAP 00068	ICEAP 00020 ICEAP 00040 ICEAP 00053
Malawi	ICPL 87091 ICPL 87105 ICPL 87109 ICPL 86005	QP 38 Royes	ICEAP 00020 ICEAP 00040 ICEAP 00053
Mozambique	ICPL 87091		ICEAP 00020 ICEAP 00040 ICEAP 00053
Sudan	ICPL 87091 ICPL 87109 ICPL 90028 ICPL 86005		
Tanzania	ICPL 86005		ICEAP 00020 ICEAP 00040 ICEAP 00053 ICP 9145
Uganda		ICP 6927 ICEAP 0068	
Released varieties			
Kenya	ICPL 87091 Kat 60/8		
Malawi			ICP 9145 ICEAP 00040
Uganda	ICPL 87091 Kat 60/8		
Tanzania	ICPL 87091		

Research has started on screening germplasm for resistance to insect pests and in determining the mechanisms of resistance. Eventually, these components will be combined into an integrated pest management strategy.

Breeding Varieties for Different End-User Needs

We now know the influence of temperature and photoperiod on performance of different duration groups, and also the extent of genotypic variation within each duration group. Although it is now known that the phenology of extra-short and short-duration varieties is delayed by cool temperatures, there are no varieties that mature sufficiently quickly in cool environments – yet these are high potential areas where pigeonpea can give very high yields. In cool environments where long-duration pigeonpea is intercropped with maize, pigeonpea yields are reduced because phenology is accelerated and plants do not recover fully from competition with maize. There is need to develop long-duration varieties with slower phenology that would mature later than maize, thus reducing competition and increasing pigeonpea yield. There are few improved varieties with resistance to diseases; and if there were to be a major disease problem, we may lose them. In addition, the region currently does not have farmer and market acceptable extra-short or short-duration varieties with resistance to fusarium wilt.

Building on the knowledge gained, a breeding program is underway with the following objectives:

- For short-duration varieties, maintaining key traits (relative insensitivity to photoperiod, early flowering and maturity) and incorporating the ability to grow and mature early at low temperature. This would permit farmers to grow pigeonpea at high elevation and latitude.
- For medium-duration varieties, maintaining optimum temperature for time to flower at about 24°C, and incorporating relative insensitivity to photoperiod. This will ensure that if the crop is grown in areas away from the equator but within latitude 20°N or S, flowering is not delayed by long days during summer.
- For long-duration varieties being developed, the objective is to incorporate delay in maturity at low temperature. This will allow farmers in high elevation areas to intercrop maize with long-duration pigeonpea, such that maize matures earlier than pigeonpea, thus reducing competition between the two crops.
- For long-duration varieties, widen the genetic base by incorporating wilt resistance into high-yielding but susceptible varieties.

Objectives one to three (above) involved making crosses between the best short-duration variety ICPL 87091 and the best long-duration varieties (ICP 13076, ICEAP 00020, ICEAP 00040) that have resistance to fusarium wilt. The long-duration varieties are of African origin while the short-duration variety is of Indian origin. The progenies in different duration groups are being tested at two locations in Kenya; Kiboko (warm, 980 m altitude) and Kabete (cool, 1825 m altitude) and the results are extremely exciting:

- For short-duration types, which are now in F_5 the Project has identified progenies which are insensitive to cool temperature and whose phenology is not delayed in cool environments. In addition, seed mass has been increased substantially.
- For long-duration types, which are in F_5 , yields are substantially higher than the parents, and seed mass has not been reduced. In addition, progenies have been identified that mature later than the long-duration parents in cool environments (Table 4).
- Progenies with tolerance to fusarium wilt have been identified in all duration groups.

Table 4. Performance of long-duration genotypes under development (f_5 generation) at Kabete, Kenya, 1998/99 cropping season.

Genotype	Days to 50% flower	Days to 75% maturity	Plant height at maturity (cm)	100-seed mass (g)	Grain yield (t ha^{-1})
IAPX 95001-18-2-13-F5B	120	177	172	24.3	6.72
IAPX 95001-19-3-10-F5B	111	172	164	20.5	6.29
IAPX 95002-7-18-10-FB5	114	172	156	19.0	5.51
IAPX 95001-16-2-11-F5B	114	172	192	19.5	5.22
IAPX 95001-13-7-14-F5B	119	177	160	21.8	5.00
IAPX 95001-11-20-19-F5B	119	177	173	21.4	5.16
IAPX 95001-21-14-7-F5B	115	172	205	20.1	5.13
IAPX 95001-17-8-21-F5B	120	178	138	22.4	4.43
IAPX 95001-16-13-10-F5B	102	167	163	19.3	4.18
IAPX 95002-9-32-18-F5B	113	172	159	22.7	3.99
IAPX 95002-8-12-8-F5B	113	172	137	20.9	3.89
IAPX 95002-11-14-9-F5B	112	170	142	19.3	3.26
IAPX 95001-6-16-15-F5B	113	172	125	17.6	2.94
IAPX 95001-18-2-14-F5B	112	170	158	18.3	2.86
IAPX 95001-14-7-10-F5B	101	167	128	19.3	2.61
ICEAP 00053	114	170	141	19.6	2.46
IAPX 95001-17-8-25-F5B 115	112	170	113	19.4	2.43
IAPX 95001-21-25-10-F5B	113	170	165	17.7	2.41
ICEAP 00020	114	170	156	20.2	2.29
ICEAP 00040	111	170	126	19.9	2.28
Grand Mean	113	172	154	20.1	3.96
SE±	0.9	1.1	9.6	0.9	0.79
CV (%)	1.1	0.9	8.8	6.5	27.8

f_5 generation; crosses made between short-duration ICPL 87091 and long-duration varieties (ICEAP 00020, ICEAP 00040, ICP 13076)

Priorities for the Future

Pigeonpea will continue to be grown by farmers who are resource-constrained; and both green peas and dry grain will remain important. Eastern Africa is a secondary center of diversity, where the crop has distinct characteristics and specific adaptation. A breeding strategy specifically for the region is therefore necessary.

Dual purpose extra-short and short-duration varieties

Efforts will need to target farmers with relatively better resources and more endowed environments, with varieties aiming at the green pea and dry grain markets. Without pest resistance, judicious use of pesticides will continue to be the only way to control pests. Incorporation of insensitivity to cool temperatures will allow the expansion of this duration group into high-elevation areas near the equator and high-latitude areas where pigeonpea currently cannot be grown due to cool temperatures during the reproductive stage. It is envisaged that with intensification of production, fusarium wilt will become a major constraint – and control should therefore be an important priority. Use of molecular biology approaches to alleviate biotic and abiotic constraints should also be explored, particularly for control of pests. This will involve collaboration with advanced research institutions.

Medium-duration varieties

Medium-duration varieties are mostly intercropped, and grown in areas with warm temperatures unsuitable for long-duration varieties. Near the equator, efforts should focus on developing varieties with good ratoonability so that farmers can obtain two crops a year. The major beneficiaries will be Kenya, Uganda, and Tanzania. In currently available medium-duration varieties, phenology is delayed in areas away from the equator, e.g. Malawi and Mozambique. Thus, we are unable to extend production into non-traditional areas where long-duration varieties fail due to terminal drought. It is important to incorporate insensitivity to photoperiod in medium-duration types. The major beneficiaries will be southern Tanzania, middle Malawi (Lilongwe plateau), northern Mozambique, Sudan, Ethiopia, and Eritrea. Wilt resistance and tolerance to insect pests should also be incorporated, using biotechnological tools where conventional approaches are unsuccessful.

Long-duration varieties

These varieties are mostly intercropped, and grown in low-latitude, high-elevation areas (near the equator, >900 m) and in areas slightly away from the equator (within 17°N and S) where temperatures are warm during the vegetative stage and cool during the reproductive stage. Efforts should be continued in developing improved varieties incorporating high yield, acceptable grain characteristics, resistance to diseases, mainly fusarium wilt, and tolerance to insect pests. Where a conventional approach is not possible, biotechnological tools should be used. For areas near the equator with elevation >1400 m, and where maize is the main crop, research should aim to incorporate insensitivity to cool temperature to allow the crop to mature later and thus reduce competition between maize and pigeonpea.

Vegetable pigeonpea

There is a growing niche market for green (vegetable) pigeonpea. No varieties have been specifically bred for this market, but dual-purpose varieties have been found to be acceptable. We are still in the process of getting information on market needs, traits associated with quality, shelf life etc, which will be used to develop varieties specifically for vegetable pigeonpea.

Hybrid pigeonpea

As the crop becomes more commercialized, yield, market traits, and seed issues will become increasingly important. Private seed companies will become interested in pigeonpea only if there is the potential for developing hybrids. The technology is available in ICRISAT-Patancheru and should be transferred to the region.

Protecting biodiversity and collections

Given the present low number of *ex situ* collections from the region, it is highly probable that traditional germplasm from the region will be lost if farmers were to shift (even in the short term) to new crops or varieties. The extent of genetic erosion is not known and the uniqueness of the material has not been determined. As we develop new varieties, we need to ensure that local germplasm is preserved through collections, characterization, and preservation in regional genebanks, and through agreements a duplicate sample deposited with ICRISAT.

Teamwork

ICRISAT believes research should be demand driven and that each research partner should bring in a comparative advantage. A careful analysis as the starting point of a collaborative project generates confidence among partners as well as development investors. This process requires the participation of NARS, civil society, private sectors, NGOs, advanced research institutes, and farmers, to ensure that the work remains relevant and on track.

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Pigeonpea Breeding: Objectives, Experiences, and Strategies for Eastern Africa

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Introduction

Pigeonpea is probably the most important grain legume in the semi-arid areas of Eastern Africa. Reports indicate that it is grown in 37 African countries at altitudes ranging from sea level to 2050 m. The leading producers in Africa are Kenya (164,000 ha), Uganda (113,000 ha), Malawi (110,000 ha), Tanzania (33,000 ha) and Mozambique. Pigeonpea is mainly produced by smallholder farmers in mixtures with maize, sorghum, cotton, finger millet, and other legumes such as beans. In most parts of Africa, pigeonpea is grown as a multi-purpose grain legume; eaten as grain or as a vegetable.

Yield-Limiting Factors and Breeding Objectives

Grain yield on farmers' fields in Eastern Afria average 450-670 kg ha^{-1}, compared to 2.6-4.3 t ha-^{1} reported from research trials in Kenya (Onim and Ruhaihayo 1975, Onim 1984). A number of biotic and abiotic constraints contribute to this gap between potential and actual yields. Correspondingly, the major objectives of pigeonpea breeding programs in the region include:

- Grain yield
- Early maturity and reduced height
- Resistance to diseases, especially fusarium wilt
- Resistance to insect pests, especially pod borers, pod suckers, and podfly
- Seed characteristics, especially size and color
- Tolerance to drought
- Suitability for intercropping
- Enhanced nitrogen fixing potential and survival in infertile soils
- Special-purpose varieties for agroforestry and forage types
- Adaptation to different ecological zones.

Yield potential. Until the early 1980s no improved varieties were available to farmers in the region. Although several improved varieties are now available, adoption is limited and most farmers grow low-yielding, late-maturing landraces. Yields of up to 4.6 t ha^{-1} have been reported in on-farm trials of new varieties, indicating that productivity can be substantially improved with new varieties and better crop management.

Early maturity. Late-maturing varieties (typically 8-11 months) leave farmers with little time to prepare the field for the next crop. To avoid such delays farmers often plant widely

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spaced rows of pigeonpea, and sow other fast-maturing crops in between (wide row spacing also facilitates land preparation and weeding). The long duration may be a disadvantage for subsistence farmers who have to wait nearly a year to harvest. Varieties with different maturity durations should be developed to fit different cropping systems and agro-ecological zones, but early-maturing cultivars should be given priority.

Plant height. Most local varieties are tall (over 2 m), and are thus difficult to harvest and spray. They cannot be grown in close association with shorter plants due to shading effects unless wide spacing is used or by exploiting their slow early growth. They also tend to lodge – therefore short or medium-statured varieties may be more desirable.

Diseases. Several pigeonpea diseases have been reported in Eastern Africa. Fusarium wilt is by far the most important: Kannaiyan et al. (1984) reported incidence of 5-60% in Kenya and 36.3% in Malawi (range 0-90%). Leafspot caused by *Mycovellosiella cajani* causes severe defoliation and yield losses of up to 80% especially during wet years (Onim 1981). It has been reported as a serious problem in Kenya, Zambia, and Uganda. Chemical control is often not viable for subsistence farmers; the best option is probably the development of resistant varieties.

Insect pests. Pigeonpea is attacked by a number of insect pests. Pod borers (*H. armigera, M. vitrata*), pod suckers (*C. tomentosicollis*), and the podfly *M. chalcosoma* are the most serious, causing losses of 26-63%. Most farmers do not spray their crops due to the high cost of insecticides. Consequently, yield losses will depend on infestation levels and the natural tolerance of the plant. Efforts to develop pest-resistant varieties have met with little success; and there is still limited understanding of insect-host relationships and control methods. There is an urgent need to develop pigeonpea varieties tolerant of both field and storage pests as a component of integrated pest management strategies.

Seed and pod characteristics. Consumers and producers in the region prefer large, white/cream seeds and large pods (5-7 seeds/pod). Much of the local germplasm is large-seeded, with 100-seed mass >15 g, and can be used to developed improved cultivars with the necessary characteristics.

Drought stress. Pigeonpea is grown mainly in semi-arid areas with unreliable rainfall, where crop failures are frequent. Although pigeonpea is drought tolerant, it grows best with rainfall of 600-1000 mm. Yields are substantially reduced under drought. This can be overcome by developing either early-maturing varieties or varieties with tolerance to drought.

Soil fertility. Although pigeonpea grows on a wide range of soil types it gives optimum results in deep loam, almost neutral soils of pH range 5-7. Soils outside this range or those lacking nutrients will not produce good yields. Most smallholders do not apply fertilizer on pigeonpea; and animal manure is not used in adequate quantities. Pigeonpea also suffers because of badly drained soils.

Crop management. Late planting, inadequate weeding, poor land preparation, and low plant populations contribute to the low yields. Future efforts in Eastern Africa must concentrate on disseminating the improved technologies already available.

Agroforestry and soil conservation. Pigeonpea is a multipurpose woody legume with great potential in agroforestry. The plant supplies not only food, but also forage and wood for fuel, fencing and construction materials. The deep root system also helps in stabilizing soil conservation terraces.

Adaptability. Pigeonpea is successfully grown in a range of environments, but each maturity group has its specific area of adaptation. Phenology is affected considerably by temperature (altitude) and daylength (latitude), and varieties could fail to flower or yield if grown outside their areas of adaptation. It is therefore important to test new varieties over as wide an area as possible to determine the areas of optimum productivity. It would also be useful to define and characterize pigeonpea-growing environments in the region so that breeders can target cultivars to specific environments.

Socio-economic factors. Pricing, marketing, and infrastructure indirectly determine how much effort and investment farmers will make in pigeonpea production. There are no organized marketing systems for pigeonpea; export markets have not been exploited fully, and price incentives are limited. Poor roads, poor seed delivery systems, and lack of storage and transport facilities make it difficult for farmers to intensify production. Labor shortages are severe, because most children and young adults, who traditionally provided family labor, have migrated to urban areas.

Development of Pigeonpea Breeding Programs

The earliest pigeonpea program in Eastern Africa was initiated in Uganda in 1968. Two programs were later started in Kenya in 1975 and 1980; and subsequently in other countries in the region.

Breeding methods in Eastern Africa

Most national pigeonpea breeding programs in Eastern Africa are in their early stages. These programs have generally followed a similar pattern from introduction, through mass selection to hybridization and selection, with a corresponding degree of complexity and demand for skills and resources.

Introduction. Virtually all programs started by introducing cultivars and advanced breeding lines from ICRISAT-India and other diverse sources. In many cases, the materials introduced between 1970 and 1990 failed to meet farmers' requirements (large cream or white seeds); and adoption was poor. In the early 1990s, ICRISAT provided white-seeded lines, some of which were released in the late 1990s.

Mass selection. In a few cases, the introduced early-maturing germplasm was grown together with local long-duration landraces. This generated segregating populations with variable maturity duration (Shakoor et al. 1983). The medium-duration Kat 60/8, which is now grown by farmers in Kenya and Uganda, was selected from such a population. Local landraces were also collected and selections made either through simple mass selection or mass selection with progeny testing (Onim 1981). Germplasm collection missions were concentrated in Kenya, Tanzania, and Malawi. Selections from landraces were evaluated both on-station and on-farm. Long-duration cultivars such as Munaa and Kioko (released in Kenya) and ICP 9145 (released in Malawi) are selections from local landraces. Others such as

ICEAP 00068 and ICEAP 00040, both selected from landraces, have been recommended for release.

Hybridization and selection

Only a few national programs (Kenya, Malawi) have been successful in combining useful traits from the diverse germplasm into new cultivars. Introduction and mass selection limits the breeder to identification of the best genotype in the breeding collection. Most national programs have no organized breeding scheme with provision for creating segregating populations from which useful recombinants can be selected. Development of well-designed breeding programs will be a major challenge for African pigeonpea breeders in this millennium.

Another challenge is the high degree of outcrossing in pigeonpea; as a result breeding procedures differ from those used for predominantly self-pollinated crops (Kimani 1987). Outcrossing also poses serious problems in the maintenance of pure lines under open-pollinated conditions. Controlled production of self-pollinated seed by bagging, while necessary for maintaining purity, is costly, time-consuming, and produces only limited amounts of seed. This method is not economical for large-scale seed production.

Review of Breeding Programs in the Region

The following section reviews the more important pigeonpea breeding programs in the region.

Makerere program, Uganda

The first pigeonpea program in the region was initiated in 1968 at Makerere University, Uganda, to breed short-duration, high-yielding cultivars of the dry grain type. Since most of Uganda has two distinct growing seasons, short-duration cultivars would enable farmers to plant two pigeonpea crops in a year, or alternatively fit it into rotations in a double cropping system (Khan and Rachie 1972).

Germplasm was collected from India, the Caribbean, the Philippines, and other sources. The collection of about 5400 accessions was evaluated, and 500 selected for breeding work. Breeding methods at Makerere emphasized introduction, selection, and to a lesser extent hybridization. Single-plant selections from the germplasm and from segregating populations were evaluated; and reasonably uniform elite lines were bulked and entered in yield trials during 1969 and 1970.

A number of high-yielding lines were identified, representing two plant types: “spray” and “bush” types. “Spray” types had secondary branches almost as long as the main stem, with very little tertiary branching (i.e. spreading types). The erect bush type was recommended for reduced row spacing (80 cm), which increased plant populations and hence gave higher yields. The new lines gave yields substantially higher than the national average (Dunbar 1969). Most of these promising lines were of Indian parental stock but their yields in Uganda were modest compared to the high yields reported in India.

Population improvement. Makerere started a population breeding program that was believed to be more appropriate due to the high outcrossing, easier to conduct, and offered consistent improvements in future (Khan 1973). The natural populations in Uganda had a rather restricted base. Two populations were therefore formed, an Early Composite and a Medium Composite.

The Ugandan program was disrupted by civil strife between 1973 and 1986. Some of the materials were used to initiate the breeding program at the University of Nairobi in 1975.

Nairobi and Katumani programs, Kenya

Pigeonpea improvement work was initiated at the Department of Crop Science, University of Nairobi, in 1975 and the National Dryland Farming Research Centre, Katumani, in 1979. The early stages of the program focused on germplasm collection and evaluation, followed by selection and later on hybridization and selection.

Germplasm collection. Collections have been made in virtually all provinces of Kenya. Between 1975 and 1977, 607 accessions were collected by the University of Nairobi through local collections, and from Makerere, ICRISAT-India, IITA-Nigeria, University of West Indies, Trinidad, and Sudan. This germplasm showed tremendous variability for various agronomic characters and one entry was completely male sterile. More accessions were added in 1997 and the collection now has about 1000 accessions.

Selection from local landraces. Germplasm collected in farmers' fields was evaluated in 1977 and several single plants were selected and selfed. In on-farm tests, local and improved cultivars (single plant selections) performed similarly in most characteristics except grain yield, where the selections yielded 94% more than local cultivars.

Population improvement. This approach was used because of the high degree of outcrossing. Onim (1981) compared two population improvement methods, namely stratified mass selection (SMS) and mass selection with progeny testing (MSPT). These methods were evaluated on an early-maturing composite population between 1975 and 1978. The composites, originating from the Makerere University program, were evaluated after two to four cycles of selection for grain yield and drought tolerance. In a wet season, the unimproved population yielded as well as the SMS-C4 and MSPT-C2 improved populations; but the improved populations were superior in a dry season. Both population methods were successful in improving grain yield under marginal rainfall conditions. Progress per cycle was 2.3% for SMS populations after four cycles of selection, compared to 4.3% under MSPT. The slightly better response in MSPT was attributed to progeny testing and a higher selection pressure of 5% versus 10% in SMS. The SMS method was just as good as MSPT, takes a shorter time per cycle, and is easier to operate.

Development of early-maturing cultivars. Until the early 1980s, no early-maturing pigeonpea cultivars were available to farmers in Kenya. Earlier attempts to popularize early-maturing cultivars from India failed because farmers rejected the varieties – despite their early maturity and short stature – due to seed size and color. Also, the Indian cultivars were not suitable for intercropping, losing up to 80% of their grain yield when intercropped with maize (Onim 1981).

The first early-maturing cultivar developed in Kenya was NPP 670, which originated from crosses made in 1977 between early-maturing lines from ICRISAT and locally adapted landraces. It has been adopted in parts of Mbeere, Machakos, Embu, and Kitui districts, where it is popularly known as 'Katumani' pigeonpea. It is popular primarily because of its early maturity and large cream seeds (19 g per 100 seeds). NPP 670 yields about 1 t ha^{-1} on farmers' fields, but is highly susceptible to insect pests – spraying is essential.

Since farmers value other traits in addition to earliness, attempts were made in 1983/84 to combine seed traits from local material with earliness from Indian genotypes through controlled crossing in the glasshouse, and in a nursery established at Kiboko. The segregating populations were advanced to F_7 through bulk breeding procedures, promising lines tested for wilt tolerance, and yield trials conducted at several locations. The selected lines were shorter and matured much earlier than the local long-duration improved and traditional varieties. They are large seeded (>13.5 g per 100 seeds), but seed mass is lower than that of check cultivars. All the lines are tolerant to wilt; three lines showed a high degree of resistance. They were similar to NPP 670 in maturity duration and pod size, and gave higher yields.

Tanzania

Pigeonpea research in Tanzania started in the early 1960s, when varieties collected from Ukiriguru (Tanzania) were grown in observation plots at the Agricultural Research Institute (ARI), Ilonga in 1962/63 to screen for wilt resistance. This work was discontinued following the departure of scientists involved in crop research, but resumed in 1974/75 when the National Grain Legumes Research Program (GLRP) was started at ARI-Ilonga. Sixty lines, including six dwarf, short-duration genotypes from ICRISAT, were evaluated that season. These lines formed few or no branches, fruited profusely on the main stem, and the best lines gave grain yields of up to 2 t ha^{-1} (Laxman Singh 1990).

The next phase began in 1986/87 when a Pigeonpea Germplasm International Trial was conducted jointly with ICRISAT scientists at ARI-Ilonga, Gairo (Kilosa district), and the Sokoine University of Agriculture. The most promising lines flowered in 55-60 days and matured in 110-115 days. Although the data are limited, it appears that early-maturing pigeonpea has potential under Tanzanian conditions.

Ethiopia

Pigeonpea research in Ethiopia was started early in the 1970s by the Institute of Agricultural Research (IAR) at Nazret National Horticultural Centre, with short-duration cultivars introduced from Makerere University, the Dominican Republic and later from Guyana, IITA, and ICRISAT-India (Amare Belay, pers comm). The main objective was to identify high-yielding, disease and pest tolerant cultivars. During 1973-77 the introductions were tested in nurseries, variety trials, and national yield trials at Nazret, Arelkasa, Adam, and Koko in Central Ethiopia by the Welayta Agricultural Development Unit (WADU) in southern Ethiopia, Kobo in northern Ethiopia, and Humera in northwestern Ethiopia. Yields were inconsistent in different years at most locations except at WADU and to some extent at Melkasa.

Further evaluations of local and exotic collections from the Genetic Resources Unit of Ethiopia, International Livestock Centre for Africa (ILCA), and ICRISAT were conducted between 1986 and 1990. Most of these cultivars have yet to reach many farmers due to inadequate extension and seed production and distribution systems. Little information is available on the status of traditional Ethiopian varieties, local preferences for seed size and color, and farmers' reactions to the new short-duration cultivars.

Rwanda

Pigeonpea research in Rwanda began in 1983 with the introduction of early-maturity seeds from the cross NPP 610, originally made at the University of Nairobi (Price and Cishahayo 1986). About 75 seeds from this cross as well as seeds of other Kenyan landraces, were supplied by the International Development Research Centre (IDRC), Nairobi. In the same year, several Tanzanian landraces were obtained from the Tanzania Agricultural Research Organization at Ilonga. Several distinct phenotypes were isolated from the cross NPP 610. Material with desirable characters – early maturity, large seeds, reduced plant height, drought tolerance, high yield potential, adaptability to poor soils – were selected and tagged from the segregating NPP 610 and Tanzania selections. Three individual plants selected from NPP 610 were crossed in all combinations. Intrapopulation recurrent selection aimed at improving grain yield and adaptability was employed for three cycles on the segregating populations. Variability after cycle 3 was maintained by the very high natural outcrossing. The population RK101 (short, early maturing) was derived by this method.

Selections from medium-duration types from Tanzania were crossed to produce the population RT 201 which was medium in height, early to medium duration, large-seeded, and adapted to the region. RKT 120, a tall, large-seeded, long-duration perennial type, is derived from single plant selections within a population of landraces received from Kenya. The improved varieties have larger seeds and more seeds per pod than the local varieties (Price and Cishahayo 1986), but the impact of these varieties is yet to be determined.

Sudan

Studies on crop improvement and agronomy were started at Hudeiba Research Station during 1975-80, supported by IDRC (Nourai 1987). The main objectives of the program were to select high-yielding, adapted pigeonpea varieties, and to obtain information on maturity, plant type, and seed size and color. Forty early, medium, and late-maturing entries from ICRISAT were compared to the standard local variety Baladi for three seasons. Three introduced varieties outyielded Baladi by over 100%.

Somalia

The status of grain legume research in Somalia was reviewed by Abikar (1990, unpublished). The Somali diet consists of cereals and tubers which are rich in starch and low in protein. Although pulse crops have potential and production fails to meet demand, little research has been conducted on pulses. Recently the Central Agricultural Research Station at Afgoi and

Bonka developed a program for grain legume production including pigeonpea. However, little progress has been made due to the political instability in Somalia since 1991. The fate of improved lines sent to Somalia in 1988 is not known.

Burundi

No genetic improvement work on pigeonpea has been done in Burundi (Ntukamazina and Nzimenya 1987). Most varieties grown by farmers were introduced (source unknown), with Burundi farmers adopting them where they proved adaptable. Farmers distinguish two maturity groups: long and short duration.

Future Prospects and Strategies for Pigeonpea Breeding

Pigeonpea improvement programs in Eastern and Southern Africa have relied heavily on advanced lines and varieties from ICRISAT and other breeding programs in the region, and also made selections from their own landraces. Although varieties released from these materials have served the immediate need of farmers, major deficiencies still exist. There is need to develop cultivars that combine several novel traits to better meet the changing needs of pigeonpea growers and consumers. It is unlikely that cultivars combining multiple desirable traits will be found from existing germplasm collections. The challenge for breeders will be to examine a wide range of genotypes and construct new varieties meeting criteria for each agro-ecological zone and addressing consumer needs. New strategies will have to be developed and implemented in partnership with other stakeholders. Some potential strategies are suggested below.

Breeding for variable maturity duration

Because most of the landraces grown by farmers are late-maturing, new short- and medium-duration cultivars have received wide acceptability. A few such varieties have been developed, e.g. short-duration ICPL 87091, but the number of such examples is limited. Varieties in the early-medium and medium-duration groups include NPP 670, Kat 60/8, ICEAP 00068, and ICP 6927. The early-maturing cultivars were developed for purestand cropping while the medium-duration types were intended primarily for intercrop systems, and late-maturing improved cultivars such as ICEAP 00040 and ICEAP 00020 were intended for two-season intercrop systems. Future research will need to focus on correcting deficiencies in these cultivars. For example, ICPL 87091, NPP 670, Kat 60/8, ICEAP 00068, ICP 6927, and ICEAP 00020 are susceptible to fusarium wilt. Determinate cultivars such as ICPL 87091 and NPP 670 are very susceptible to insect pests. Seed size of ICPL 87091 and Kat 60/8 requires further improvement, from 11-12 g to over 15 g per 100 seeds.

Multiple constraint breeding

Pigeonpea growers face a number of biotic and abiotic constraints often acting in combination. Diseases, pests, and adverse climatic and soil conditions can be present in the same field at the same time. It is not uncommon to find more than one disease on the same plant during one or more developmental stages. Such multiple constraints reduce yield and quality and increase instability of production. This also increases the cost of control measures. Thus, the need for multiple-stress resistance is particularly relevant in pigeonpea, which is grown largely by smallholder farmers who can rarely afford costly inputs (fungicides, insecticides, fertilizers etc) for a low-priced crop such as pigeonpea.

Attempts to accumulate in one line, resistances to various stresses date back many years. But until recently this approach was used only to a limited extent, partly because of lack of suitable resistance sources, screening procedures, and proven breeding methods to simultaneously handle multiple traits. As a result most breeding programs have used a stepwise procedure to solve the different problems one by one, starting with the problem which is most yield limiting. Among the weaknesses of this approach is the lengthy period required to incorporate resistance to several stresses. In addition, "resistant" cultivars tend to be resistant to one stress but susceptible to others. Although this approach is still in use, there is increased interest in breeding programs attempting to simultaneously introduce genes for multiple resistances. Selecting for multiple traits becomes more difficult with an increasing number of traits to be improved. National programmes and their partners need to develop suitable breeding schemes for multiple constraint improvement of pigeonpea.

Marker-assisted selection

Plant breeders are increasingly using DNA markers to increase the efficiency of recovering genes for desirable traits. Target genes in a segregating population can be identified and selected using marker-assisted selection (MAS). However, use of MAS requires detailed information on the pigeonpea genome and mapping of agriculturally important "target" genes. In contrast to conventional direct selection, MAS selects individuals carrying target genes in a segregating population based on patterns of tightly linked markers rather than on their phenotypes (Zheng et al. 1995). Therefore, the population can be screened at any growth stage and in various environments. Screening for resistance to a disease can be done without artificial inoculations if markers for that resistance gene(s) are available. In addition, MAS can eliminate interference from intra-locus or inter-locus interactions and thus increase the efficiency and accuracy of selection, especially for traits that are difficult to assess. However, MAS will not be available to pigeonpea breeders until saturated genetic maps and suitable DNA markers have been developed. In addition simple, rapid, accurate, cost-effective procedures must be established which are complementary to existing breeding protocols.

Inter-genepool crosses

Although pigeonpea is now believed to have originated from the Indian subcontinent, it has been grown and selected in East Africa for many thousand years and the area is regarded as the chief secondary center of domestication and diversity (Remanandan et al 1982). The result of this long period of domestication and selection are landraces with unique features such as long duration, perennial habit, large leaflets, high number of seeds per pod, large cream or speckled or mottled seeds, which contrast sharply with materials originating from the Indian subcontinent. For example the world collection at ICRISAT contains two landraces with the highest known 100-seed mass, collected from Kenya (26.92 g) and Tanzania (26.47 g). Similarly, 3-5 seeds/pod is usual in Asian genotypes, while East African landraces average 5-7 seeds/pod. It is likely that even more significant differences can be detected at the molecular level or by analysis of biochemical composition. These evolutionary differences suggest that there may be at least two major genepools in pigeonpea – African and Asian. The complementary characters of these genepools have been used only to a limited extent. Future breeding activities will need to generate more variability from inter-genepool crosses.

Hybrid pigeonpea

The first hybrid pigeonpea cultivar was developed by ICRISAT and released for cultivation in India in 1990. The hybrid had a 20-40% yield advantage over open-pollinated varieties. Production was facilitated by the discovery of male sterility and inbred lines developed in India. This technology was subsequently taken up and commercialized by several seed companies. Since hybrid vigor is generally associated with genetic diversity, crosses between the genetically diverse African and Asian genepools may have considerable heterosis. To our knowledge, this opportunity has not been explored. We propose that national programs including universities and their partners should devote at least part of their efforts in this direction.

Conclusions

National agricultural research institutes and universities in Eastern, Central and Southern Africa in collaboration with ICRISAT, Institut de Agronomiques of Gembloux, and the University of Bonn have made considerable progress in developing improved pigeonpea cultivars and management practices in the last two decades. New early and medium-duration varieties are now being grown in semi-arid regions. However, widespread dissemination is seriously hampered by inadequate seed delivery systems. Although the improved cultivars have helped increase productivity, they have important deficiencies that are likely to reduce their yield potential in some environments and their appeal to consumers and producers. The deficiencies include small seed size and susceptibility to wilt, cercospora leafspot, and insect pests. So far, national breeding programs have relied on nearly finished lines from ICRISAT and selections from their landraces – few have developed their own crossing programs. Future activities should therefore include a capacity building component for NARS. The next generation of varieties is likely to originate from well designed breeding schemes, which should be based on creating recombinant populations from intra- and inter-genepool crosses with the aim of redressing limitations of the current varieties. Various strategies (multiple constraint breeding, marker-assisted selection, TCM, hybrid development from inter-genepool crosses) offer new opportunities to increase efficiency in cultivar development and enhance productivity in pigeonpea.

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New Regional Initiatives in Pigeonpea Improvement

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Introduction

Two major regional initiatives for pigeonpea improvement were started in the last decade, with similar objectives, i.e. to enhance pigeonpea productivity on smallholder farms. One was a collaborative program involving 10 countries in Eastern and Southern Africa, supported by the African Development Bank and coordinated by ICRISAT. This program began in 1991 and was completed in 1999. The second initiative was an inter-university program initiated in 1996, involving Gembloux, Bonn, Makerere, and Nairobi universities supported by the European Union and the Belgian Agency for International Cooperation. The program was implemented in collaboration with ICRISAT and the national research and extension programs in Uganda and Kenya. Papers elsewhere in these proceedings have described progress under the first initiative and the work done by various partners under the second initiative. This paper focuses on work done at the University of Nairobi under the second regional initiative.

Characterization of Regional Germplasm Resources

Much of the germplasm collected in Eastern Africa has been characterized to some degree. It shows wide variability in a range of characters that may be useful in future crop improvement programs. To complement the previous collections, additional germplasm was collected in 1997 from pigeonpea-growing districts around Mount Kenya and the coastal lowlands of Kenya (Kimani et al. 2000). All the new and old accessions conserved at the Department of Crop Science, University of Nairobi, and Gembloux Agricultural University, Belgium, were initially grown in observation nurseries and further characterized in trials at Kibwezi (altitude 900 m), Thika (1600 m), and Kabete (1890 m) over a 3-year period. The main features of these materials are summarized below.

Growth habit. Most are erect, tall, compact to semi-spreading. They vary in height from about 1 to 4 m. Branching is variable but above 1 m on the stem is common. Some show profuse branching (4-28 primary branches) and leaflets are generally large.

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Maturity duration. Most are long-duration, usually 8-11 months, and perennial. Some early-maturing types resulted from outcrosses with exotic early-maturing germplasm.

Stem color. Usually purple or green.

Flowers. There is considerable variability for flower color. Flowers may be yellow to red, ivory and with variable densities of streaks on the standard. Some have no streaks, others show uniform coverage.

Pods. Most landraces show a high number of seeds per pod: 5-7 is common. Landraces from the coastal lowlands have 6-8 seeds/pod. A range of 3 to 9 seeds/pod has been reported. Pods may be green or purple or a mixture of purple and green, and formed in large bunches that are easy to harvest. Pods per plant vary from 15 to over 1000.

Seeds. The landraces have large seeds with an average 100-seed mass of about 17 g. A landrace collected in Kenya has the highest seed mass in the world collection: 26.92 g per 100 seeds, exceeding the previous record of 26.47 g from a Tanzanian landrace (Remanandan et al. 1982). The range reported is 7.68 to 26.92 g. The seeds are plain white or beige, mottled, speckled, or mottled and speckled. Seeds are round or oval-shaped. Landraces from the coastal lowlands showed wide variability in seed size and seed coat color (from black to white), possibly due natural outcrossing with introductions from the Indian sub-continent.

Disease and insect resistance. Traditionally, farmers have been growing pigeonpea year after year in the same field. As a result fields have become natural wilt-sick plots. This may have resulted in high selection pressure in favor of wilt resistance. Some local landraces such as KO-31 and ICEAP 00040 showed high levels of resistance in successive evaluations in a wilt-infested field at Kiboko. There is some variability in insect pest damage with some genotypes showing limited susceptibility and others showing severe damage. It is possible that local germplasm may have different degrees of tolerance to insect pests.

Breeding

The breeding component of the program has focused on creating new populations combining wilt and leafspot resistance, seed characteristics, phenology, growth habit, and adaptability to intercropping systems. Well-adapted cultivars such as NPP 670, ICPL 87091, Kat 60/8, ICP 6927, and ICEAPs 00068, 00020, and 00040 are used as parents. The crossing block has 41 parental lines including landraces, advanced breeding lines from the region, and accessions from ICRISAT. They represent considerable variability from the African and Asian genepools. Crossing is carried out in insect-proof greenhouses at Kabete Field Station. Over 24 F_2 populations, 11 three-way and 17 double-cross populations combining various desirable traits have been created. The segregating populations are being selected for wilt resistance using artificial inoculation at Kabete and wilt-sick plots at Kiboko. Selection for other characters is being carried out at the National Horticultural Research Centre, Thika. The populations will be advanced through gamete selection and bulk breeding procedures in a multiple constraint breeding strategy.

A second component of the breeding program involves selection of segregating populations under sole cropping and when intercropped with maize. The base population originated from crosses between short-duration, white-seeded ICRISAT lines and large-seeded, wilt-resistant African landraces. The F_2 to F_4 generations were advanced in wilt-sick fields at Kiboko to identify recombinants with wilt resistance. The F_5 lines were separated into four bulk populations on the basis of growth habit and maturity. The four populations were subjected to two cycles of selection under both sole and intercropped conditions in the 1998/99 and 1999/2000 short rains at Thika. The selected lines will be further evaluated to determine the effect of cropping system on their performance.

A third component of the program involved pedigree selection with progeny testing from other breeding nurseries and variety evaluations. Several early, early-medium, and medium-duration lines have been selected both in Kenya and Uganda in the last 2 years. Preliminary yield trials are planned during the 2000/01 short rainy season. The fourth part of the program has focused on inheritance of wilt resistance and other qualitative and quantitative traits. This work is reported by Odeny elsewhere in this publication.

Crop Protection

Disease and pest management research in this project has focused on identifying and characterizing pathogenic variation of *Fusarium udum* using morphological and cultural characteristics, pathogenicity on different pigeonpea varieties, and with amplified fragment length polymorphism (AFLP). Pest management studies have been carried out to determine the efficacy of botanicals in reducing yield losses, especially in intercrop systems. Results of this work are reported by Smith et al. elsewhere in this publication.

Crop Management and Socio-Economic Aspects

Studies in crop management were designed to identify practices that would optimize productivity in intercrop systems. They are described by Mergeai et al. elsewhere in this publication.

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Recent Developments in Pigeonpea Breeding in Uganda

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Introduction

Pigeonpea is considered the most important grain legume in northern Uganda and the second most important (after cowpea) in the northeast. Despite the importance of the crop to a large section of the population both as a source of income and a diet supplement, research efforts in recent years have been limited. Apparently all the short-duration cultivars developed in the 1970s have been lost and only long-duration (6-9 months) landraces can be found – Apio Elena, Adong, Adyang, and Agogi. These landraces give low yields on farmers' fields: 300-600 kg ha^{-1}, compared to over 2.5 t ha^{-1} achievable on-station with new high-yielding cultivars (Obuo et al. 1996).

Pigeonpea research in Uganda was initiated at Makerere University in 1968 with a grant from the Rockefeller Foundation. Over 5000 lines were introduced from all over the world and these formed the basis for a subsequent research program that included breeding work and allied studies. The main objective of the breeding program then, was to develop high-yielding short-duration cultivars adapted to Ugandan conditions. Considerable success was achieved and a number of promising advanced lines were identified. Other work included: a search for male sterility, studies on disease resistance, and development of composite materials (Musaana et al. 1992).

Recent Efforts in Crop Improvement

Pigeonpea research efforts were abandoned in 1979 and resumed only in 1989 following the initiation of the Pigeonpea Improvement Project for Eastern and Southern Africa by ICRISAT, with funding from the African Development Bank. The project has implemented some work in Uganda. Silim et al. (1991, 1993) conducted surveys on traditional farming systems, the predominant pigeonpea cultivars, and the most important pest and disease problems in the major pigeonpea-growing areas. The surveys revealed that production in traditional farming systems was very low, but could be improved by adopting better genotypes, better farming systems, and finding the most appropriate and cost-effective means of pest control. Out of these surveys came a recommendation to resume pigeonpea research in Uganda.

Surveys were also carried out in Aug-Sep 1997 under a project sponsored by the European Union. The surveys were implemented using a PRA approach and semi-structured questionnaires. The main objective of this project was to identify the major cropping systems and production (biotic or abiotic) constraints to pigeonpea, and develop

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cheap and cost-effective pest control packages. To achieve these objectives, research was initiated at three locations: Makerere University Agricultural Research Institute at Kabanyolo (MUARIK), Serere Agriculture and Animal Research Institute (SAARI), and Ngetta experimental station to assess the performance of the new short-duration, high-yielding selections in both sole and intercrop systems, and their response to pest attack.

Screening trials

During the 1990s, varieties were screened for agronomic traits, yield characters, adaptation to farming systems in north and northeastern Uganda, time to maturity (short- and medium-duration lines selected), and insect resistance. Over 200 breeding lines from ICRISAT and Nairobi University were evaluated at Serere and a few lines identified for on-farm testing. Kat 60/8, ICPL 87091, and ICP 6927 were found adapted to intercrop situations and recommended for restricted release (Okurut-Akol et al. 1996). Several genotypes are also currently being evaluated to identify lines with good intercropping ability.

Kat 60/8, ICPL 87091, and ICP 6927 were evaluated during the 1997B and 1998A seasons in intercrops with finger millet and sorghum. The results showed that row ratios of pigeonpea:finger millet/sorghum of 2:2 were the optimal combination, giving Land Equivalent Ratios of up to 1.6 (Rubaihayo et al. 2000). Similar results were later reported in the 1999 seasons at both MUARIK and Ngetta (Owere 2000). These results clearly suggest that the new pigeonpea lines are compatible in the pigeonpea/finger millet and pigeonpea/sorghum intercrops common in the traditional system.

Eighty-four lines selected from screening trials at MUARIK and SAARI were planted in the 1999B season and evaluated for yield, agronomic characteristics, and pest damage. The results are being analyzed. The crop was ratooned in the 2000A season to determine the ratoonability of the lines. The selected lines will be tested for their intercropping ability.

Genetic fingerprinting

A collection of the African and Asian pigeonpea germplasm is being screened using the AFLP technique. African and Asian landraces and two local accessions were planted in the 2000A season for this study. This study will help determine the genetic diversity and evolutionary relationship between the Asian and African accessions, which will help in further research in pigeonpea breeding.

Pest management

Observations on pest management indicated that for optimal (cost-effective) control, pigeonpea should be sprayed at the following times: ICPL 87091 during flower bud initiation to pod formation, Kat 60/8 during pod formation to pod maturity (Rubaihayo et al. 2000). The results also indicated that determinate lines like ICPL 87091 were more susceptible to pest attack than indeterminate lines like Kat 60/8. Akongo (2000) has shown that intercropping pigeonpea with finger millet at different spatial arrangements had no effect on pod borers, while pod-sucking bugs were significantly ($p<0.05$) reduced in a pigeonpea:finger millet intercrop, 3:3 row pattern. Studies on the effect of plant extracts neem and Tephrosia showed a significant ($p<0.05$) reduction in pod damage, with greater reduction of damage at higher concentration of the plant extracts. The results further indicated that Tephrosia was more cost-effective than neem.

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Discussions – Technology Development

Introduction of short-duration material

Long-duration varieties were part of the traditional cropping system in Eastern and Southern Africa. In addition to medium- and long-duration varieties, the Pigeonpea Project sought to promote short-duration varieties that were new to the region. This was done for three reasons.

- There was a clear need to improve yield and other characteristics of pigeonpea in traditional cropping systems. In research terms it was easier to improve the phenology of short-duration varieties (and thus fit them into traditional systems) than to improve yield and other characteristics of medium- and long-duration varieties.
- Considerable experience and germplasm was available from ICRISAT-India on high-yielding short-duration pigeonpea.
- Although most indigenous germplasm was of long duration, some lines with medium and short duration were collected from Eastern Africa, which could provide a base for genetic improvement.

Note that the Project did not focus exclusively on short-duration varieties. Considerable effort went into medium- and long-duration types: disease/pest management, phenology, adaptation, yield, ratoonability, and other farmer-preferred characteristics.

Both short and medium/long duration groups have their advantages and disadvantages. In terms of adoption, it may be easier to promote a crop type that promises a large, visible difference (e.g. earliness) rather than new medium- or long-duration types where improvements will be incremental and not always apparent to farmers. On the other hand, medium- and long-duration types could be promoted by emphasizing the continuous harvest they provide, in addition to other benefits such as fuelwood, nitrogen fixation, suitability for intercropping, and ratoonability.

Variety release

Variety releases are sometimes targeted at the wrong regions or the wrong socio-economic groups (e.g. ICPL 87091 in Uganda). Varieties are usually released for cultivation country-wide, although targeted release in a few districts would be more appropriate. In some cases farmers, after growing a released variety that is unsuitable for the area (either poorly adapted or not suited to local cropping priorities), are skeptical about new research products.

A new variety must be released together with a management package, without which farmers will be unable to benefit fully from the high yield potential of the variety. For example, varieties are tested on-farm with pest management, but released without accompanying recommendations on pest control.

Phenology

Manipulation of phenology does not necessarily mean accelerating the growth cycle, but adjusting the cycle to maximize benefits. For example, in cool areas away from the equator, long-duration types may flower or mature before the maize harvest. In such cases it is necessary to slow down their phenology to avoid competition in the maize/pigeonpea intercrop.

Crop Protection

Inheritance of Resistance to Fusarium Wilt in Pigeonpea

D A Odeny[1]

Introduction

Pigeonpea is one of the major pulse crops of the tropics and sub-tropics. It performs well in marginal environments and has the inherent ability to withstand environmental stresses, especially drought. In recent years, it has become one of the most sought after crops in plant introduction trials aimed at bringing new areas under cultivation. This is due to its ability to grow and produce grain under conditions where most other crops do not survive. Despite its importance in Kenya and elsewhere in the region, little concerted research effort has been directed at either crop improvement or technology transfer. Yields on farmers' fields are low and a number of factors are responsible – drought, lack of improved cultivars, poor crop husbandry, pests, and diseases (Ndiritu 1994).

Pigeonpea diseases have been reported to be of minor importance in the past in Eastern Africa (Acland 1971). However, recent surveys in major pigeonpea-growing areas of Kenya show that fusarium wilt and cercospora leaf spot are diseases of economic concern (Kannaiyan et al. 1984, Songa et al. 1991). Fusarium wilt (*Fusarium udum* Butler) is the most important soilborne disease throughout the pigeonpea growing areas of Kenya – average reduction in plant stand of 10% (Songa et al. 1991) and 16% (Kannaiyan et al. 1984) have been reported. Surveys carried out in 1980 estimated wilt incidence to be 60% in Kenya, 36% in Malawi, and 24% in Tanzania with annual losses of US$ 5 million in each of these countries (Subrahmanyam and Tuwafe 1995). Although it has been suggested that wilt incidence can be reduced by various practices, for example pigeonpea-cereal rotation, fallow, green manuring, zinc application, rotation with tobacco, and time of planting, host-plant resistance is probably the cheapest and most effective management practice.

Understanding the inheritance of characters in pigeonpea would enable breeders to improve selection efficiencies with respect to a particular trait. Inheritance of fusarium wilt resistance is not well understood. Relatively little work has been reported on the genetics of resistance despite the fact that breeding programs aimed at developing wilt-resistant pigeonpea have been conducted since the early 1900s. The few reports available are conflicting and have failed to provide a complete picture of the genetics of resistance beyond indicating that a few genes are involved (McRae and Shaw 1933, Green et al. 1981). It is only when this is known that a correct breeding program can be designed. This experiment was carried out in order to achieve this objective.

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Materials and Methods

Four wilt-resistant lines (ICP 8863, ICPL 87119, ICEAP 00040, ICEAP 00536) and four susceptible lines (Kat 60/8, NPP 670, ICPL 93027) were studied. All the parental lines were grown under glasshouse conditions. A single 3 m row for the first planting, double 3 m rows for the second planting, and triple 3 m rows for the last planting represented each cultivar. Planting was done at an interval of 1 month to ensure synchronization of flowering among the early, medium, and long-duration groups. Frequent weeding and spraying against insects and diseases was done to reduce losses.

Crossing. Crossing was done under glasshouse conditions using hand emasculation and pollination. F_1 seeds were divided into three. The first lot was planted and allowed to self and F_2 harvested. The second lot was planted and backcrossed to both the resistant and susceptible parents. The third lot was kept.

Evaluation for resistance. All the F_2, Backcross 1 (BC_1), Backcross 2 (BC_2), and F_1 were evaluated in sick pots under glasshouse conditions. BC_1 was a cross between F_1 and the resistant parent while BC_2 was a cross of F_1 to the susceptible parent. On average, 40 seeds each for the parents and F_1, 200 seeds for the F_2 and 40 seeds for each backcross generation were used.

Preparation of inoculum. An isolate of the fusarium wilt fungus from Kiboko, a major pigeonpea-growing area in Kenya, was used. A single conidial culture was multiplied on 100 mL of potato dextrose broth in a petri dish that was placed on a rotary shaker for 10 days at 25-30°C. The contents of the flask were diluted with sterile distilled water to a final inoculum concentration of 1×10^6.

Preparation of the pots. Soil was mixed with sand at a ratio of 3:1, respectively. The mixture was sterilized in an autoclave for 4 h. It was then placed in pots in the glasshouse. Seeds were first pre-germinated in sterile riverbed sand. The seedlings were transplanted a week after germination. The pots containing soil and sand mixture were thoroughly watered a day before transplanting. Moisture level was maintained at or near field capacity. The inoculum was harvested and placed in a beaker. During transplanting, the seedlings were gently removed from the sand, the roots cleaned, then trimmed with a sterile surgical blade, and dipped into the inoculum for 10 minutes before finally transplanting into the pots. The roots were trimmed to provide a point of entry for the pathogen. Controls of both susceptible and resistant lines were used for every batch. The controls were divided into two lots: one inoculated and the other non-inoculated. Pots were kept in the glasshouse for two months and wilting of the host observed. The pathogen was re-isolated from the wilted plants and its pathogenicity re-confirmed.

Data collection and plot design. All the test lines were grown in a randomized complete block design with four replicates. Disease onset and progress was monitored and the wilted plants recorded every week for 2 months. A 1-9 disease scale was used, where 1 = no visible symptoms and 9 = very severely diseased or dead. The various segregation ratios were calculated and tested using Chi-square ($P < .05$).

Results and Discussion

The fourth week data was considered the most reliable to use in the analysis because during this period, all the susceptible controls had wilted. Results are shown in Tables 1, 2, and 3.

In Table 1, data from one cross (ICPL 93027 x ICEAP 000536) showed 9S:7R (susceptible/resistant) segregation ratios for the F_2, 1:1 for backcross 1, and all susceptible for backcross 2. This confirmed a case of duplicate recessive genes for resistance with the following possibilities:

Resistant parent	aabb
Susceptible parent	AABB
F_1	AaBb
F_2 – 9/16: Susceptible	A_B_
7/16: Resistant	A_bb, aaB_, aabb

Table 2 gave a segregation ratio of 13:3 for the F_2, 1:1 for BC_1 and all susceptible for BC_2. This meant that for this particular cross, there was complete dominance at both gene pairs but the susceptibility gene when dominant was epistatic to the resistant gene. Therefore the dominant A gene for resistance did not produce an effect in the presence of a dominant susceptibility gene (inhibitor). The possible genotypes therefore were:

Susceptible parent	aaBB
Resistant parent	AAbb
F_1	AaBb (susceptible)
F_2	A_bb: 3/16 resistant
	A_B_: 9/16 susceptible
	AaB_: 3/16 susceptible
	Aabb: 1/16 susceptible

Table 3 gave segregation ratios of 10:6 for F_2, 1:1 for $BC_1$and 1:3 for BC_2. This meant that for all the crosses included in Table 3, there was partial dominance at both gene pairs and that for each partially dominant gene, there was an additive effect. Resistance would therefore be at different levels. Possible genotypes were:

AAbb – Susceptible parent
aaBB – Resistant parent
AaBb – F_1: Susceptible
F_2 would have the following segregation:
1/16: AABB – Resistant level 10
2/16: AABb – Resistant level 8
2/16: AaBB – Resistant level 7
1/16: AAbb – Resistant level 6
4/16: AaBb – Resistant level 5
1/16: aaBB – Resistant level 4
2/16: Aabb – Resistant level 3
1/16: aabb – Resistant level 1

The first four resistant levels were considered resistant while the last four were susceptible.

Table 1. Segregating ratio between wilt-resistant and susceptible plants in various generations and backcrosses.

Pedigree	Generation	Observed R*	Observed S*	Expected R*	Expected S*	X^2	P
ICPL 93027	P1	-	56	-	56		
ICEAP 000536	P2	148	-	148	-		
ICPL 93027 x ICEAP 00536	F_1	-	14	-	14		
ICPL 93027 x ICEAP 00536	F_2	38	59	42	55	0.67	5%
F_1 x ICEAP 000536	BC_1	3	9	3	9	-	
F_1 x ICPL 93027	BC_2	-	14	-	14		

Table 2. Segregating ratio between wilt-resistant and susceptible plants in various generations and backcrosses.

Pedigree	Generation	Observed R*	Observed S*	Expected R*	Expected S*	X^2	P
NPP 670	P1	-	65	-	65		
ICEAP 00040	P2	24	-	24	-		
NPP 670 x ICEAP 00040	F_1	-	71	-	71		
NPP 670 x ICEAP 00040	F_2	30	147	33	144	0.33	5%
F_1 x ICEAP 00040	BC_1	6	11	8.5	8.5	1.46	5%
F_1 x NPP 670	BC_2	-	35	-	35	-	

Table 3. Segregating ratio between wilt-resistant and susceptible plants in various generations and backcrosses.

Pedigree	Generation	Observed R*	Observed S*	Expected R*	Expected S*	X^2
Kat 60/8	P1	-	38	-	38	
ICPL 87119	P2	49	-	-	49	
Kat 60/8 x ICPL 87119	F_1	-	14	-	18	
Kat 60/8 x ICPL 87119	F_2	74	133	78	129	0.33
F_1 x ICPL 87119	BC_1	28	35	31.5	31.5	0.78
F_1 x Kat 60/8	BC_2	16	43	15	45	0.17
Kat 60/8	P1	-	20	-	20	-
ICP 8863	P2	51	-	51	-	-
Kat 60/8 x ICP 8863	F_1	-	17	-	17	-
Kat 60/8 x ICP 8863	F_2	82	135	81	136	0.0196
F_1 x ICP 8863	BC_1	7	10	8.5	8.5	0.029
F_1 x Kat 60/8	BC_2	10	34	11	33	0.324

R* = resistant, S* = susceptible
Chi at 5% level of confidence, 1 df = 3.84

The differences in the segregation values seen above for Tables 1, 2 and 3 could be explained by the fact that the source of resistance used in every table was of different origin. In Table 1, the source of resistance was of African origin but had been improved using Indian material. In Table 2, the source of resistance was of East African origin. The rest were rather uniform because the sources of resistance were all of Indian origin.

The results from these experiments showed that the genes for this trait are controlled differently depending on the origin of the resistance source used in a particular cross. It was also observed that there are genetic differences between pigeonpeas of Indian origin and those of African origin.

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Yield Losses due to Field Pests and Integrated Pest Management Strategies for Pigeonpea – a Synthesis

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Introduction

Pigeonpea is a major legume crop in the tropics and sub-tropics, and accounts for 5% of world legume production (Hillocks et al. 2000). It is still a neglected crop in terms of the amount of research done on it, despite its many uses. There is great potential for the expansion of the crop in the semi-arid regions of Africa, where it could counteract declining soil fertility. One main constraint to expansion of pigeonpea production is its susceptibility to insect pests and diseases. The most important insect pests in the region are those that attack the crop at the reproductive stage and during storage; they include the pod-sucking bugs (dominated by *Clavigralla tomentosicollis* Stål), pod borers (*Helicoverpa armigera* Hubner, *Maruca vitrata* (= *testulalis*) Geyer, *Etiella zinckenella* Treitschke, *Lampides* spp), pod fly (*Melanagromyza chalcosoma* Spencer), and bruchids (*Callosobruchus* spp) (Table 1).

Considerable work has been done by national programs in Eastern and Southern Africa and by ICRISAT in developing high yielding short-, medium-, and long-duration pigeonpea

Table 1. Major field insect pests on pigeonpea in Kenya, Malawi, Tanzania, and Uganda.

		Pest status*			
Order/Scientific name	Family	Kenya	Malawi	Tanzania	Uganda
Diptera					
Melanagromyza chalcosoma Spencer	Agromyzidae	1	3	1	1
Hemiptera					
Clavigralla tomentosicollis Stål	Coreidae	1	1	1	1
Lepidoptera					
Helicoverpa armigera Hubner	Noctuidae	1	1	1	1
Maruca vitrata (= testulalis) Geyer	Pyralidae	1	1	2	1
Etiella zinckenella Treitschke	Pyralidae	2	2	2	2

* 1 = Serious, widely distributed, causes heavy economic losses. 2 = Common, causes widespread concern. 3 = Occasionally serious, sporadic or of local importance
Source: Minja et al. 1999

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genotypes. These have been tested at various locations in each country. The short-duration genotypes have great potential in areas with reliable irrigation and can escape drought in a truncated rainy season. However, the determinate types that mature in 3-4 months have disadvantages to smallholder farmers because their determinancy makes them more vulnerable to flower- and pod-feeding insects.

Yield losses due to field insect pests on pigeonpea in farmers' fields in Eastern and Southern Africa during 1995/96 are shown in Table 2. Analysis of damage levels by each pest group indicated that pod-sucking bugs caused more damage in Malawi and Kenya, while pod borers caused more damage in Tanzania and Uganda (Table 3). Pod fly caused more damage in Kenya than in the other countries. Pod fly damage was high in crops maturing during cool weather; pod borer damage was high on crops maturing during warm weather, and damage from pod-sucking bugs was high regardless of weather conditions. Greater variations in losses were observed between locations in Kenya, Malawi, and Tanzania than in Uganda. Warm and dry locations had smaller yield losses than warm and humid, cool and dry, or cool and humid locations (Minja et al. 1999).

Losses Associated with Pest Groups

Pod-sucking Hemiptera

A large number of Hemiptera, mainly in the families Alydidae, Coreidae, and Pentatomidae, feed on pigeonpea and are commonly referred to as pod-sucking bugs (Lateef and Reed 1990). A few species are widespread and serious pests of pigeonpea. The most important are coreids, *Clavigralla* (= *Acanthomia*) spp, *Anoplocnemis* spp, *Riptortus* spp, and *Mirperus* spp. Research efforts have concentrated on three *Clavigralla* species:

Table 2. Mean yield losses (%) due to field insect pests on pigeonpea in farmers' fields, 1995 and 1996.

Country	Mean yield loss
Uganda	16
Kenya	22
Tanzania	14
Malawi	15

Table 3. Contribution (%) of field pest groups to pigeonpea yield losses in four countries.

Pest group	Uganda	Kenya	Tanzania	Malawi
Pod-sucking bugs	30	52	47	69
Pod borers	53	22	50	28
Pod fly	17	26	3	3

C. tomentosicollis Stål which is widespread in sub-Saharan Africa, *C. scutellaris* Westwood which is found from Kenya through Yemen, Oman, Pakistan and India (Dolling 1979), and *C. gibbosa* Spinola which is restricted to India and Sri Lanka. Three additional *Clavigralla* species are also associated with pigeonpea: *C. shadabi* in Western and Central Africa, *C. elongata* Signoret in Eastern and Southern Africa, and *C. horrida* Germar in Zimbabwe and South Africa. The last two species are similar and often confused in the field and in literature (Shanower et al. 1999).

Adults and nymphs feed on pigeonpea by piercing through the pod wall and extracting nutrients from the developing seeds. Damaged seeds are dark and shriveled, they do not germinate, and are not acceptable for human consumption (Materu 1970). In Tanzania, Materu (1970) reported that more than 50% of pigeonpea seeds were disfigured and unmarketable because of pod-sucking bug damage. In Malawi, pod-sucking bugs accounted for 60% and 75% of pigeonpea seed losses in farmers' fields in 1995 and 1996, respectively. In Kenya, Tanzania, and Uganda losses ranged between 35 and 65% (Minja 1997).

Pod-feeding Lepidoptera

Worldwide, over 30 species of Lepidoptera in six families feed on the reproductive structures of pigeonpea (Shanower et al. 1999). The most important species in Eastern and Southern Africa are *Helicoverpa armigera*, *Maruca vitrata*, *Etiella zinckenella*, and *Lampides* spp. *H. armigera* larvae feed on seedling foliage, flower buds, flowers, and developing seeds. *M. vitrata* and *Lampides* larvae feed on flower buds, flowers, and developing seeds. *E. zinckenella* larvae feed on maturing and drying seed inside the pods. No detailed studies have been conducted on pigeonpea pod borers in the region. Results from surveys in farmers' fields in Kenya, Malawi, Tanzania, and Uganda, and on-station trials in Kenya and Malawi, have indicated that pod-feeding Lepidoptera larvae accounted for 5-35% of the seed losses on pigeonpea genotypes (Minja 1997).

Seed-feeding Diptera

The larva of the pigeonpea pod fly, *Melanagromyza chalcosoma*, feed on developing seeds within the pod (Minja 1997). A second species, *M. obtusa* Malloch, appears to be restricted to Asia. Both species feed only on pigeonpea and related species within the subtribe Cajaninae. Pod fly damage has been reported from several countries. Extensive studies have been conducted on *M. obtusa* in Asia (Shanower et al. 1998). Although *M. chalcosoma* has not been studied as extensively, it seems to occupy a similar ecological niche (Minja 1997). The difference between these two species is that a single seed locule contained more than 2 larvae/pupa of *M. chalcosoma* (up to 40 larvae/pupa were observed per pod of five seeds in Kenya) compared to 1 or 2 for *M. obtusa* in India. In Eastern and Southern Africa, pod fly accounted for up to 4%, 7%, 13%, and 46% of seed losses in Malawi, Tanzania, Uganda, and Kenya, respectively (Minja 1997).

Influence of Sowing Date on Yield Losses

The influence of sowing date on yield losses was studied at three locations in Kenya. Two short-duration genotypes, determinate ICPL 87091 and indeterminate Kat 60/8, were sown in Nov, Jan, and March at Kiboko. The Jan and March sowings were planned to coincide with the maturity times for medium- and long-duration genotypes, respectively. In another study, short-, medium-, and long-duration genotypes were sown at Mtwapa (50 m altitude), Kiboko (920 m), and Kabete (1825 m). The crops were grown with and without insecticides to enable the assessment of avoidable yield losses.

Mean grain yield losses increased with delayed sowing: 62%, 68%, and 74% respectively for Nov, Jan, and Mar sowing dates (Table 4). Grain yield losses for Kat 60/8 were similar for different sowing dates, while losses on ICPL 87091 increased with delay in sowing. Mean yield losses across locations were similar, 40-46% in crops planted in April at Mtwapa, March at Kiboko, and Oct at Kabete (Table 5).

Yield losses due to pod borers were higher on crops flowering and maturing during warm weather than on crops maturing during cool weather (Table 6). In contrast, losses due to pod fly were very low during warm weather and high during cool weather. Losses due to pod-sucking bugs were high in all weather conditions.

Table 4. Mean yield losses (%) due to field insect pests on two short-duration pigeonpea genotypes sown on different dates at Kiboko, Kenya, 1995 and 1996.

Genotype	Nov sown	Jan sown	Mar sown
ICPL 87091	63	70	82
Kat 60/8	60	67	67
Mean	62	68	74
SE±	1.7	1.3	2.6
CV (%)	11.7	9.2	17.1

Table 5. Mean pigeonpea yield losses (%) due to field insect pests at three locations in Kenya, 1995 and 1996.

Genotype	Mtwapa	Kiboko	Kabete
ICPL 87091	42	35	36
Kat 60/8	36	29	32
ICP 12734	39	43	64
KAT 81/3/3	45	51	53
Mean	40	40	46
SE±	1.2	2.8	3.4
CV(%)	10.1	15.7	34.4

Table 6. Mean yield losses (%) due to field pests on pigeonpea maturing at different dates at Kabete and Kiboko, Kenya.

	Kabete			Kiboko		
	Nov	Jan	Mar	Nov	Jan	Mar
Pod-sucking bugs	6	14	23	22	38	37
Pod borers	2	7	8	9	4	3
Pod fly	8	11	10	9	5	5

Management Strategies

Pigeonpea pest management is complicated by several factors. The crop is attacked by at least three pest groups with very different biologies. These differences include host range (oligophagous to highly polyphagous), apparency (feeding on the plant versus concealed feeding), and feeding mode (chewing versus piercing and sucking). The pests also have highly variable population dynamics across years and locations, and at least one, *H. armigera*, has developed high levels of resistance to several insecticides (Shanower et al. 1999). The key pests are all direct pests, feeding on the portion of the crop most valued by humans, and each is capable of completely destroying a crop. Economic thresholds have not been developed for any pest of pigeonpea. Another obstacle to progress in pigeonpea pest management is that it has been considered a marginal crop or is the neglected component of a mixed cropping system and is thus given less attention by farmers, crop protection specialists, and policy makers.

The primary focus of pigeonpea pest management has been on *H. armigera* and *M. obtusa* in India, with emphasis on chemical control and host plant resistance (Lateef and Reed 1990). A major change in farmers' pest management practices has been the widespread adoption of synthetic pesticides as the primary method of pest control in some areas (Shanower et al. 1999). In India, calendar sprays are recommended and followed, with the first application at 50% flowering and the second and third applications at 15-day intervals. Farmers in southern India now apply pesticides 3-6 times per season (Shanower et al. 1999). This change has occurred over a period of about 10 years, and there are indications that pigeonpea farmers in Africa may follow a similar trend (Minja 1997). The rapid increase in pesticide use on pigeonpea is alarming and emphasizes farmers' concern with insect pests. The trend also highlights the need for safe and effective management strategies.

The use of alternative insecticides such as plant-derived products (e.g. neem, *Azadirachta indica*) and insect pathogens, particularly the *Helicoverpa* nuclear polyhedrosis virus (NPV), is considered to be safer for humans and the environment, and to cause less damage to beneficial organisms than conventional insecticides. Neem products have traditionally been used in storage in India. Commercially formulated neem products are available in many countries, although results on pigeonpea have been inconsistent. The use of NPV to control *H. armigera* has received much attention, particularly in India, though reliable control on pigeonpea has not been obtained (Shanower et al. 1999). Both neem and NPV products suffer from poor and highly variable quality and a more limited distribution network than conventional insecticides. These problems must be overcome before these products can be considered effective and practical alternative control methods. The possibility of farmers or farmer cooperatives producing and using plant-derived or insect pathogen products on a local scale should attract the attention and resources of a number of organizations.

The development of insect-resistant and/or tolerant genotypes has been a high priority for both national and international research programs for many years. Pigeonpea lines with resistance to either or both pod borers and pod fly have been reported, but little progress has been made in incorporating resistance in genotypes that are widely cultivated by farmers. Frequently the resistant lines are less preferred in terms of taste, seed color, and/or size, and are often susceptible to diseases (Shanower et al. 1999).

Traditional pigeonpea landraces are medium- to long-duration and may have been selected to avoid peak pest attack. Selecting companion crops or cultivars has also been investigated as a means to minimize pest damage (Lateef and Reed 1990). The widespread practice of intercropping longer-duration pigeonpea genotypes with one or more companion crops may have evolved through farmers' desire to reduce risks of insect or other losses. The companion crops are usually harvested before pigeonpea flowers. Thus, when pigeonpea is most attractive to the key pests, it is functionally a sole crop and there is seldom any reduction in pest damage relative to sole-cropped pigeonpea (Shanower et al. 1999). Recently developed short-duration pigeonpea genotypes, which mature in less than 4 months, may offer new opportunities for cultural or agronomic manipulations to minimize insect damage.

Improving the impact of natural control agents is perhaps the most neglected area of pigeonpea pest management research. Although a number of natural enemies have been recorded from the key pests of pigeonpea (Minja et al. 1999, Shanower et al. 1999), little is known of their effect on pest population dynamics. No reliable or comprehensive life table study has been published that evaluates the role and impact of natural enemies of any insect pest on pigeonpea. A number of pigeonpea characters that inhibit natural enemies have been identified. Developing genotypes that lack these characters would be a practical approach to improving natural enemy impact. Much more needs to be known of the pests and their natural enemies, particularly in this region, before the feasibility of natural enemy impact can be determined.

Knowledge of the impact, dynamics, and ecology of the pests and their natural enemies is essential before effective control strategies can be developed. These studies must focus on cropping systems as pigeonpea is frequently one component of a complex farming system. Other tropical legumes are particularly important because they share a number of pests and natural enemies with pigeonpea. There is no short-cut or magic bullet to reduce losses due to insect pests immediately. Progress will be incremental, and in the short term, the greatest impact may come from improving insecticide application. This would involve enhancing the skills needed to scout fields and properly mix and apply insecticides and providing unbiased information on the relative risks and benefits of different insecticides. A strategy for the medium term should concentrate on developing improved genotypes that combine high yield and disease and insect resistance into backgrounds with consumer-and market-preferred agronomic characters. Longer term solutions must focus on ways to enhance natural enemy control processes, either by introducing exotic natural enemy species or by enhancing the effectiveness of endemic species.

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Past and Current Studies on Ecology and Management of Insect Pests of Pigeonpea

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Introduction

Pigeonpea is an important source of protein in the drier areas of Uganda. Yields on farmers' fields average 300-600 kg ha^{-1}, compared to 1.4 t ha^{-1} obtained at experimental stations (MAAIF 1992). One of the causes of low pigeonpea yields in most regions of the world is heavy insect damage. Over 200 arthropod species have been reported to feed on the crop (Reed and Latif 1990), but most of these are regarded as minor (Reed et al. 1989). Insect pests damage all parts of the pigeonpea plant from roots to flowers, pods, and seeds. This paper summarizes previous and ongoing studies on the ecology and management of pigeonpea pests in Uganda.

Previous Work

Pest species

The earliest attempt to document insect pests of pigeonpea in Uganda was by Le Pelly (1959), who listed 51 species as feeding on the crop – 23 hemiptera, 23 lepidoptera, 1 dipteran, 3 coleoptera, and 1 orthopteran. Thirty-five years later, Night and Ogenga-Latigo (1994) recorded 19 insect species as either common or rare pests of pigeonpea in Uganda, of which they considered eight to be important – *Aphis craccivora, Clavigralla* sp, *Helicoverpa armigera, Maruca testulalis, Exelastis atomosa, Lampides boetius, Etiella zinckenella* and *Melanagromyza chalcosoma*. They claim to have found seven species as new records on the crop in the country. However, they did not study the distribution of the various species. More importantly, the study was conducted in a predominantly non-pigeonpea growing area, and therefore may not represent the correct or typical situation.

In 1995 and 1996, surveys conducted in farmers' fields in Uganda (Minja 1997) identified six insect species as the major field pests – *Melanagromyza chalcosoma, Clavigralla tomentosicollis, Etiella zinckenella, Helicoverpa armigera, Maruca testulalis,* and *Maruca vitrata*.

The difference in the number of species between these two studies may be due to differences in study areas and varieties: Minja studied mainly landraces, while Night and Ogenga-Latigo used improved short- and medium-duration varieties, which may be susceptible to a wider range of pests. Also, Night and Ogenga-Latigo considered all pests, while Minja focused on pests that occur regularly (as opposed to species that occur sporadically but cause heavy damage).

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Losses caused by insect pests

No detailed yield loss assessment studies have been conducted. However, Minja (1997) reported that 14% and 16% of pods in Apac and Lira districts respectively were damaged by pod borers; while sucking bugs were responsible for 3% and 6% seed damage in Apac and Lira respectively. Podfly caused 4.4% and 2.0% damage in Apac and Lira. Rubaihayo et al. (2000) demonstrated that applying chemical insecticides during the flowering and podding stages controlled damage due to pod-sucking bugs, pod borers, and pod fly, and resulted in a 43% increase in pigeonpea grain yield. However, no attempt was made to apportion the total losses among different pests, or to establish economic injury levels.

Control of insect pests

Surveys by Minja (1997) have shown that very few farmers in northern Uganda control field insect pests of pigeonpea. Apart from insecticides there are no established control methods for pigeonpea pests in Uganda.

Ongoing Research

It is apparent that information is lacking in several areas:

- Damage-yield relationships and threshold (economic) injury levels for different pests
- Appropriate intervention methods
- Population dynamics and ecology of insect pests.

Some of these aspects are being handled under the European Union Project, with additional funding from NARO, which focuses on pod borers and pod-sucking bugs. Project activities include:

- Effect of intercropping on population densities of pod borers and pod-sucking bugs
- Effect of planting time on pest incidence and damage
- Assessment of losses
- Effects of biorationals.

Effect of intercropping

Effects of intercropping pigeonpea with finger millet on pest occurrence/damage at podding were studied at two locations – Makerere University Agricultural Research Institute Kabanyolo (MUARIK) and Ngetta, a traditional pigeonpea-growing area. Two intercropping patterns and sole crop were studied. The intercrop patterns were (i) 2 rows of finger millet alternating with 2 rows of pigeonpea, (ii) 3 rows of finger millet alternating with 3 rows of pigeonpea.

Results are shown in Table 1. Pod borers were not affected by the intercropping pattern, but pod-sucking bugs were reduced by widely spaced pigeonpea rows. The proportion of seed damage was lowest in the 3:3 intercrop. Damage in the sole crop and the 2:2 intercrop were high and similar. Thus, while the data on 2:2 versus 3:3 patterns are not conclusive, it is likely that widely spaced rows (or groups of rows), e.g. 3:3, will reduce insect damage.

Table 1. Effect of intercropping on total percentage seed damage by pod and seed pests, MUARIK and Ngetta, Uganda.

Cropping system	MUARIK	Ngetta
Sole crop	23.2 ± 4	21.4 ± 1.05
Millet:pigeonpea intercrop 2:2	22.8 ± 2.1	23.8 ± 0.2
Millet:pigeonpea intercrop 3:3	19.5 ± 2.7	17.0 ± 2.7

Table 2. Effect of planting time on percentage seed damage by pod and seed pests, MUARIK and Ngetta, Uganda.

	Planting time	Pod borers	Pod-sucking bugs	Pod fly
MUARIK	Onset of rain	8.8 ± 1.75	10.9 ± 3.75	1.7 ± 0.2
	2 weeks after onset of rains	7.4 ± 1.75	8.4 ± 1.4	1.3 ± 0.15
	4 weeks after onset of rains	4.9 ± 2.25	13.3 ± 1.35	1.1 ± 0.25
Ngetta	Onset of rain	9.9 ± 3.60	13.1 ± 2.95	5.3 ± 0.35
	2 weeks after onset of rains	8.8 ± 0.70	11.0 ± 1.0	4.6 ± 0.45
	4 weeks after onset of rains	7.8 ± 2.45	15.5 ± 0.55	3.1 ± 0.55

Effect of planting date

Late planting increases damage by pod suckers but reduces damage by pod borers (Table 2). Thus, appropriate cultural practices will depend on the relative importance of the pests at a given location. This is true for planting date, and to some extent for intercropping pattern.

Effect of insecticide application on pest damage and yield

Application of dimethoate (400 g ai ha^{-1}) significantly reduced damage due to pod borer, pod suckers, and pod fly at both locations. This increased yields by 64% and 30% in the first and second rains respectively at MUARIK; and by 110% and 30% at Ngetta in the first and second rains respectively (Fig. 1).

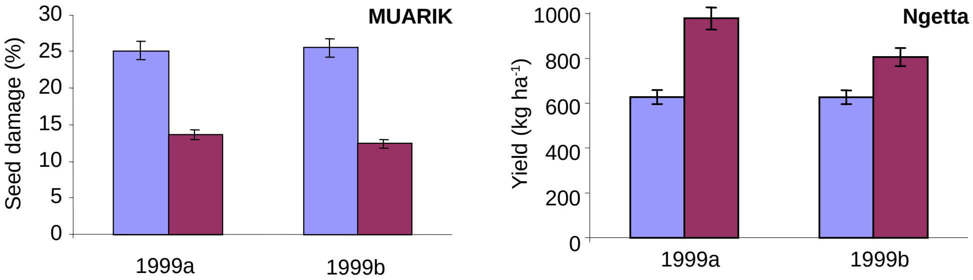

Figure 1. Effect of dimethoate application on pigeonpea yield and pest damage at MUARIK and Ngetta, first and second seasons 1999.

Effects of biorationals

The effect of neem and Tephrosia on pest population densities was studied. The chemicals were applied at three different concentrations – recommended rate, half the recommended and twice the recommended rate. Recommended rates are: dimethoate 400 g ai ha^{-1}, neem 36 g ai ha^{-1}, Tephrosia 134 kg leaves per ha.

Tephrosia and neem did not significantly reduce the population density of pod borers or pod-sucking bugs, while dimethoate significantly controlled the population density in both pests, the effect increasing with increasing concentration (Table 3).

Although the botanicals did not significantly reduce pest population density, they reduced pod damage significantly. Better control was obtained at higher concentration of the botanicals.

The reduction in pod damage was reflected in higher yield. In all cases grain yield increased with increase in concentration of chemicals. Application of dimethoate gave better yields than biorationals. Applying dimethoate at double the recommended rate increased yield by 64%. At the highest concentration, applying Tephrosia resulted in higher grain yield than application of neem.

Table 3. Effects of neem and Tephrosia extracts on pigeonpea pest population, MUARIK and Ngetta, Uganda.

	Concentration	Pod borers per plant	% pod damage	Pod suckers per plant	% pod damage	Yield (kg ha^{-1})
Muarik						
Untreated control	0	5.5	36.1	1.7	19.2	306.1
Neem	18	5.5	33.2	1.8	18.4	479.0
(g ai per ha)	36	5.0	23.3	1.7	15.7	583.3
	72	4.8	19.5	1.7	12.3	616.4
Fresh Tephrosia	67	5.6	27.7	1.5	18.0	458.3
(kg leaves per ha)	134	5.5	25.7	1.5	15.7	510.3
	268	4.8	19.3	1.7	8.6	671.9
Dimethoate	200	2.4	23.3	0.9	14.5	736.5
(g ai per ha)	400	1.9	13.3	0.1	9.5	839.2
	800	0.5	12.1		5.0	908.5
Ngetta						
Untreated control	0	2.0	42.8	1.8	34.7	155.0
Neem	18	1.8	33.3	1.4	19.7	263.9
(g ai per ha)	36	1.8	31.4	1.3	15.3	359.0
	72	1.7	21.0	1.5	10.9	374.9
Fresh Tephrosia	67	1.8	30.1	1.5	20.5	213.0
(kg leaves per ha)	134	1.8	27.4	1.5	13.8	270.3
	268	1.8	14.3	1.5	9.1	417.3
Dimethoate	200	1.1	7.4	0.8	21.8	695.6
(g ai per ha)	400	0.7	3.8	0.4	17.2	785.5
	800	0.6	2.2	0.2	7.7	875.5

Discussion

The present results indicate that damage caused by insect pests is significant and warrants control. In commercial farming, use of chemical insecticides would have been the solution. In such a situation the concern of the scientist would be to establish the economic threshold and economic injury levels of the various pests and thus determine the appropriate application rates.

Pigeonpea in Uganda is grown largely by subsistence farmers who cannot afford pesticides; cheaper control methods are therefore needed, and Tephrosia would appear to be appropriate. The present studies showed that both neem and fresh Tephrosia significantly reduced pod damage by the major insect pests; but benefit:cost analysis indicated that Tephrosia was more cost-effective. The campaign to plant Tephrosia shrubs in pigeonpea-growing areas needs to be intensified. However, we also need to look at the different methods of preparing Tephrosia at farm level, and select the best method.

The results have also demonstrated the effects of cultural practices on pest management. Intercropping did not affect pod borers, but reduced pod-sucking bugs. Early planting increased pod borer damage but reduced damage by pod suckers. Therefore to be able to utilize cultural practices in pest management, it is important to establish which group of pests causes most damage. This suggests the need for more detailed studies on the damage/yield relationship in different pest species.

The ecology of pod borers and pod-sucking bugs on pigeonpea has not been well studied in Uganda. Consequently the “push and pull” approach cannot be easily put to use. We need to understand what factors promote the colonization of pigeonpea (pull) and what discourages colonization (push). Understanding of these factors is a prerequisite for designing appropriate integrated pest management strategies.

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Cercospora Leafspot in Eastern Africa, and Strategies to Reduce Yield Losses

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Introduction

Pigeonpea is grown in several countries in Africa, the main producers in Eastern and Southern Africa being Kenya, Malawi, Mozambique, Tanzania, and Uganda. Yield-limiting factors include diseases, which cause considerable losses. After wilt, Mycovellosiella leafspot is the most important pigeonpea disease in Eastern Africa, and occurs in all countries in the region. Severity ranges from severe to low (Reddy 1991). The disease is particularly severe in Uganda (Onim and Rubaihayo 1976), Zambia (Kannaiyan and Haciwa 1990), and Kenya (Kimani 1988, Songa 1991).

Mycovellosiella leafspot is known to cause yield losses as high as 75-85%, depending on location and season (Reddy et al. 1993). Combined attacks of Mycovellosiella leafspot and powdery mildew have been reported to cause 32% yield losses in Malawi (Subrahmanyam 1994).

Extensive literature reviews on Mycovellosiella leafspot are available (e.g. Kimani 1996). In Kenya, the disease was first reported by Muller (1950). It is recognized as the most common leafspot of pigeonpea in areas with high rainfall or during wet growing seasons in drier areas (Khan and Rachie 1972, Rubaihayo and Onim 1975, Onim and Rubaihayo 1976, Onim 1980). The disease is widely distributed and causes considerable yield losses. In Kenya, regular occurrence has been reported in farmers' fields and experimental plots in the lower semi-arid areas of Kiambu, Muranga, Embu, and Kitui districts (Kimani 1988, Songa 1991, Songa and King 1994). It occurs in epidemic proportions in high-altitude areas (1200-1700 m) in years when rainfall is heavy and the rainy season extended (Songa et al. 1991). In Malawi the disease is prevalent in all major pigeonpea-growing areas, especially those with high humidity (Subrahmanyam 1994).

Etiology of Mycovellosiella Leafspot

Mycovellosiella leafspot is caused by the fungus *Mycovellosiella cajani* (Henn.) Rangel ex Trotter syn. *Cercospora cajani* (Henn.) = *Vellosiella cajani* (Rangel) (Deighton 1974). Conidia of *M. cajani* isolates attacking pigeonpea in Kenya have been described by Njoya (1991) and Gatheca (2000). Their morphological characteristics are similar to those described by Deighton (1974) for the genus *M. cajani*. The conidia are borne at the tip of the conidiophore, forming chains or acting as conidiophores. Conidia vary considerably in size, ranging from 9-36 μ by 4.5-6 μ. The shape is also variable: sub-cylindrical, slightly obclavate-cylindric, straight, rarely curved, or shoe-shaped. Distinct conidial scars are

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observed at the ends. Most conidia are aseptate or have one septum; occasionally conidia with 3-4 septa are observed. Conidiophores appear pale brown, smooth, septate or continuous, straight or slightly flexuous, irregular, cylindrical, and frequently narrowing at the base. There is some variation in conidiophores. Some are short, some are terminal, and others arise as lateral branches of secondary mycelial hyphae. Slight differences in dimensions and shapes observed from those described by Deighton (1974) were attributed to natural variations within the pathogen and environmental conditions.

Culture Requirements

Several workers have reported that *Cercospora* species do not sporulate easily in culture; a medium suitable for one species may not prove satisfactory for another (Goode and Brown 1970, Smith 1971). However, to create artificial epidemics, a quick method for spore production is a prerequisite. Experiments were therefore conducted to establish suitable environmental factors for the growth and sporulation of *Mycovellosiella cajani* in culture (Njoya 1991). Six media were inoculated with a suspension of spores (2×10^5 conidia mL^{-1}) from a sporulating colony of *M. cajani*. Numerous colonies occurred on pigeonpea leaf decoction agar (PLDA), and a fair number on carrot leaf decoction agar and potato dextrose agar. There were very few or very small colonies on potato carrot agar, carrot agar, and pigeonpea meal agar. All cultures were more or less similar in morphology, ranging from 1 to 3 mm in diameter (Njoya 1991). Colonies of *M. cajani* appear gray on PLDA (Njoya 1991, Gatheca 2000). *Mycovellosiella cajani* sporulated over a wide rage of pH levels (pH 4-10), but optimally at pH 5. Sporulation occurred in all the three light regimes tested – 24 h dark, 24 h light, and 12/12 h light/dark – but more colonies (higher sporulation) appeared in the plates incubated in a 24 h light regime. Since sporulation occurred in continuous darkness, it appears that no particular wavelength of light is necessary for spore production. *M. cajani* was more fastidious in nutritional requirements for growth than for sporulation. Sporulation occurred in all media, temperature, pH, and light regimes tested so long as there was colony growth. Successive selective subculturing of the sporulating sections of the colonies resulted in cultures with higher sporulation capacity (Njoya 1991).

Host-pathogen relationship

Conidia of *M. cajani* germinated at different rates. Germinated conidia on the leaf surface were first observed 6 h after inoculation of 120-day old plants (pigeonpea cultivar NPP 670) in the glasshouse. Each conidium usually had 1-2 germtubes emerging from the cells. On rare occasions more than two germtubes per conidium were formed. Although most conidia had germinated by the end of the 12 h period, penetration was observed 24 h after inoculation. Germtubes did not form appresoria and penetration was accomplished through the stomata (Njoya 1991).

Gatheca (2000) studied penetration and colonization of *M. cajani* on resistant and susceptible pigeonpea cultivars. She observed differences in spore germination and colonization between resistant and susceptible cultivars. On the susceptible cultivar MKS KO 161/1, spore germination occurred 3 h after inoculation. Germtube growth was rapid, side branches were produced near the stomata and grew directly into the opening. On the resistant cultivar KZ 56, germtube growth was also rapid and extensive but no stomatal ingress was observed. Instead, growing germtubes passed above or beside them. More penetration occurred in the susceptible cultivar 24 h after inoculation. Fifty days after plant inoculation, conidiophores were observed in susceptible and moderately resistant varieties, intertwined to form rope-like structures. No conidiophores were observed in resistant varieties.

Colonization of the plant differed among susceptible and resistant genotypes (Gatheca 2000). *M. cajani* grew rapidly in susceptible cultivars and was observed in adjacent epidermal cells from the site of penetration, deep into the mesophyll and near the epidermis of the leaf within 12 h of inoculation. Cell collapse was seen in the mesophyll directly below the penetration site and in surrounding tissue 24 h after inoculation. In resistant varieties, hyphae are limited to the epidermal cells or a few adjacent cells penetrated first at about 18-24 h after inoculation, after which growth of hyphae apparently ceased. The fungus penetrated the host mostly through the stomata. However, direct penetration was also observed using a transmission electron microscope. Depressions on the cuticle were evident, indicating pathogen ingress into the leaf tissues. Penetration channels were narrower than the hyphae diameter, and fungal ingress was associated with slight wall displacement. Direct penetration of the leaf appears to be through mechanical pressure, as indicated by inward depression of the cell wall at the point of penetration. Results from this study indicate that resistance to *M. cajani* is due to limited conidial germination and limited and delayed sporulation on resistant genotypes (Gatheca 2000).

Symptomatology and plant infection

M. cajani attacks all above-ground plant parts except flowers. Disease symptoms initially appear only on the leaves but later lesions develop on stems, petioles, and pods. On the leaves, the first evidence of the disease is either the appearance of breached irregular spots or dark brown to black spots of less than 1 mm in size on the upper leaf surface. The spots are either numerous or isolated on the leaflets and may or may not have a halo around them. Some of the leaves turn yellow and drop without further enlargement of the spots. Yellowing of leaves is not related to the number of spots.

In some cases the leafspots spread to form a circular lesion 9 mm or more in diameter. The larger spots are dark brown or gray. Some spots have concentric rings while others do not. On the petioles, stems, and pods, the spots are dark and mainly circular or slightly elongated. Later these lesions develop gray centers.

In the field, lower leaves get infected first and infection progresses upward to the top leaves. In some short-statured genotypes such as NPP 670, the disease can progress very rapidly if the outbreak is severe, and all leaves become severely infected. In glasshouse-inoculated plants, leaves are usually equally susceptible regardless of their position. The disease causes severe defoliation both in glasshouse-inoculated plants and in the field. In most cases infected plants drop before turning yellow.

In case of very severe attack, leaves may develop blight symptoms, though this is not very common. The blighted areas first appear as faded green patches that later turn to gray lesions which enlarge rapidly in favorable weather. Blight symptoms were observed at Kabete in the field and in 1- and 2-month old glasshouse-inoculated plants (Kimani et al. 1994).

Epidemiology

Infection by *M. cajani* is favored by prolonged periods of high moisture (Muller 1950, Khan and Rachie 1972, Onim 1980). Serious disease outbreaks occur in seasons when rainfall is high or extended late into the season, or when cloudy conditions persist even after the rains (Songa 1991). Conidia germinate at temperatures of 15-30°C (Njoya 1991). In culture (pigeonpea leaf decoction agar), growth and sporulation was best at 10 days of incubation; the optimum conditions for incubation are temperature 20-25°C, 24 h light regime, and pH 5 (Njoya 1991).

Screening Techniques

Two methods have been used in Eastern Africa to screen for leafspot resistance:

- Field screening under natural epidemics
- Artificial inoculation followed by screening in the glasshouse and in the field.

Screening under natural epidemics

This procedure was first used in Makerere University, Uganda, during 1971-75 (Onim and Rubaihayo 1976). A total of 2107 cultivars were planted in single rows. Disease reaction was scored 60 days after planting, and 134 single plants (early-maturing, resistant plants with good yield potential) were selected at the pod-filling stage. Eleven lines from these selections were evaluated at five locations in Uganda and Kenya. Disease reaction in the progeny rows was assessed by randomly plucking 18 leaflets of approximately the same age (1 leaflet per plant) from the main stem, halfway up the plant, and counting the number of leafspots on each leaflet. All 11 lines were attacked by Mycovellosiella leafspot at all locations. However, four lines (UC 796/1, 251/2, 2113/1, and 2568/1) showed promise, with a combination of resistance and high grain yield. The marked difference in disease level and grain yield observed between locations was closely associated with the amount and duration of rainfall, with the disease being severe in wet areas.

Other workers have also evaluated pigeonpea lines for resistance (Songa 1991, Njoya et al. 1991, Gatheca 2000). Songa (1991) evaluated 197 lines at Katumani, Kenya after a serious outbreak of the disease in all pigeonpea fields around the station. The rapid spread of the disease was attributed to high rainfall that extended late into the season, and cold cloudy conditions that persisted even after the rains. A 9-class scoring scale was used, 1 = highest level of resistance, 9 = extreme susceptibility. Most lines succumbed to the disease and none could be considered highly resistant (the best score was 4). However, 15 lines with low to very low resistance were selected for further evaluation at different locations and seasons.

Njoya et al. (1991) also reported that out of 101 lines evaluated at Katumani, 13 lines were found to be resistant, 20 moderately resistant, and 33 tolerant. Of the 60 lines evaluated at Kiboko, 8 lines were resistant, 8 moderately resistant, and 13 lines tolerant. It was observed that in early-maturing cultivars, susceptibility increased with physiological age after flowering – at the pod-filling stage all five lines tested showed high susceptibility. In contrast, in late-maturing cultivars susceptibility did not seem to depend on the stage of plant growth. The two late-maturing cultivars used in the inoculated experiments showed high susceptibility although they were still in the vegetative growth stage. So long as there was enough inoculum and environmental conditions in the field were favorable, the late-maturing cultivars were severely affected. It thus appears that early-maturing cultivars should be scored at mid-pod filling in order to avoid erroneous ratings due to delayed onset and development of the disease (Njoya et al. 1991). Thus, a standardized rating scale should include the age at which pigeonpea germplasm should be evaluated for leafspot resistance.

Artificial inoculation under controlled environment and field screening

Numerous resistance screening techniques have been developed for other crops under controlled conditions. The advantage of controlled environments is that screening can usually be done throughout the year, and the process is relatively quick. A technique for screening pigeonpea germplasm for *M. cajani* resistance was evaluated in the glasshouse in Kabete (Njoya 1991). Inoculum was prepared by pipetting 1mL of conidial suspension (2 x 10^5 conidia mL^{-1}) and spreading it evenly onto plates of host leaf decoction agar medium. The plates were incubated at 20°C for 14 days. At the end of the incubation period 20 mL of sterile distilled water was added to each culture plate and conidia were detached by gently rubbing the culture surface with the sterile edge of a microscope slide. Inoculation in the glasshouse and in the field was accomplished by spraying pigeonpea plants with conidial suspension (2 x 10^6 conidia mL^{-1}). Inoculation was repeated after 48 h. High humidity was maintained after inoculation by covering the plants with polythene bags for 48 h in the glasshouse. At the time of inoculation it was raining at Kiboko and Kabete, and conditions were favourable for infection. There was also a lot of natural infection in the fields.

Njoya (1991) found no correlation in leafspot severity between germplasm inoculated when 2 weeks old, and those infected in the field at Kabete and Kiboko. However, Gatheca (2000) inoculated germplasm in the glasshouse at the flowering stage. She evaluated 50 pigeonpea lines at Kabete, Katumani, and in the glasshouse, and found a positive correlation between field and glasshouse ratings for reaction of pigeonpea germplasm to *M. cajani*.

Control of Mycovellosiella Leafspot

There is little information available on control of this disease. This is possibly due to the fact that until recently it was not considered serious and relatively little work was done on many aspects. Experiments conducted in Eastern Africa indicate that it can be controlled either by use of chemicals or by growing resistant cultivars.

Chemical control

Onim (1980) evaluated five foliar fungicides for control of Mycovellosiella leafspot in Uganda – Karathane (i.e. 25% karathane), Dithane M-45 (80% mancozeb), Bavistin (50% carbendazim), Benlate (50% benomyl) and Captan (50% captan). Benlate and Bavistin caused slight stunting of plants and depressed grain yield possibly due to their phytotoxic effects. Karathane also was ineffective in controlling leafspot. Dithane M-45 was the most effective. It significantly reduced leaf fall and increased grain yield. However, there were no significant differences in grain yield at spraying intervals of 7, 14, and 21 days during the 5-month study. Plant growth was most luxurious on plots sprayed with Dithane M-45. With Benlate, all spraying intervals significantly reduced leaf-fall, but leaf fall was highest when spraying was done at 7-day intervals, perhaps due to phytotoxic effects. It was concluded that spraying intervals in the range of 7-21 days for Dithane and 14-21 days for Benlate would be beneficial. It was also shown that spraying with Dithane gave 85% more grain yield than the unsprayed control. Onim (1980) concluded that although Benlate and Dithane are effective, their application for the management of leafspot may not be economical.

Use of resistant cultivars

Use of resistant pigeonpea cultivars should provide the most practical, economical, and long-lasting management strategy. Selection for resistance to *Mycovellosiella cajani* in the field and in the glasshouse has been reported by several workers (Onim and Rubaihayo 1976, Rodriguez and Melendez 1984, Songa 1991, Kimani et al. 1994, Gatheca 2000). Khan and Rachie (1972) and also Onim and Rubaihayo (1976) have reported wide variation in resistance among pigeonpea lines, suggesting that resistance to *M. cajani* may be polygenic. The number of genes conferring resistance may vary among cultivars, being higher in resistant cultivars. A few sources of resistance have been identified, including UC 2515/2, 769/1, and 2113/1 from Uganda (Onim and Rubaihayo 1976) and ICP 8869, 12792, and 12165 from Zambia (Kannaiyan and Haciwa 1990). Several resistant lines have been identified in Kenya (Songa 1991, Njoya et al. 1991, Gatheca 2000). Songa (1991) identified resistant genotypes belonging to different maturity groups: KCC 50/3, 60/8, 119/6, and 1423/13 (short duration); KCC 81/3/1, 576/3, 657/1,777 and ICP 13081 (medium duration); and KCC 66, 605, 666, and ALPL 6-2 (long duration). Lines KO 174/7 and KB 43 were found to be resistant to *M. cajani* at Machakos (Njoya 1991). Gatheca found a high positive correlation for resistance to *M. cajani* in greenhouse and field inoculated plants. She found lines KZ 56, KO 31, ICPL 93015, and ICPL 87091 to be resistant in the greenhouse and in the field both at Kabete and Katumani.

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Discussions – Crop Protection

Fusarium wilt resistance

The study on the genetics of wilt resistance has a number of implications for future research. There are two scenarios to consider:

- Digenic inheritance in two cases (9:7 and 13:3) – it is possible to fix this type of inheritance and transfer it to susceptible genotypes using modified backcrossing procedures.
- The third set of crosses suggests some form of quantitative inheritance (although with di-hybrid segregation). It appears that it is additive. This implies the possibility of selecting for increasing the number of desirable alleles or combinations in a population.

Marker-assisted studies can help accelerate progress in breeding for resistance. However, use of markers will be possible only after we have at least a rough understanding of the pigeonpea gene map, and the location of Quantitative Trait Loci (QTLs). This knowledge is not currently available. There is an urgent need for gene mapping studies, particularly because wilt resistance is controlled by multiple genes, the QTLs for which may be scattered in different parts of the map.

Insect pests

Several pests are important, but the critical issue, particularly for short-duration pigeonpea, is insect pests. Some pests like flower beetles or thrips are sporadic, but can cause 100% loss in some years. Others like the pod borer *Maruca* cause smaller losses but occur almost every year. The relative importance of different pest species varies considerably between areas, even within the same country. Information on threshold levels and optimal spray regimes is lacking some countries.

Effect of intercropping

Some presentations noted that pod borer populations were high in a maize/pigeonpea intercrop. One factor could be the shade and micro-environment provided by the tall maize plants. This encourages pod borers to stay within the intercrop, causing them to feed on pigeonpea for longer periods.

Botanical control methods

Tephrosia has given good results in several studies, and could be promoted more widely. The active ingredient is rotenone, which can act as a contact poison (when it touches the skin of the target pest) or through ingestion. Neem is another possibility. Considerable information is available on neem from studies in India. It has not proved cost-effective in

India, but could be tried under African conditions. However, presentations at the meeting noted that expensive, factory-prepared neem extract was not much more effective than a crude formulation of Tephrosia, which presumably contained limited quantities of active ingredient. Neem is likely to be useful only in high-value crops. Tephrosia may be cheaper even though large quantities must be prepared – however, labor constraints could be a problem in collecting and crushing the leaves.

Farmer interest in Tephrosia has been encouraging. The shrub can provide multiple benefits – green manure and large improvements in soil fertility, acting as a wind-break, etc. In parts of Eastern Africa it is traditionally planted on field borders to control moles, which eat the roots and are poisoned. However, more information is needed on residual effects and cost-effectiveness.

Strategic versus applied research

There are still gaps in our knowledge of pest control. For example, does damage increase the susceptibility of a pod to attack by other pests? What pests occupy what niches in the cropping system? Will different pests attack the same pod? These questions can only be answered by detailed studies. Most important is the need for more research on natural enemies.

Comparative advantages must be identified and exploited. For example, academic institutes (e.g. universities) have the advantage in strategic research and detailed studies; ICRISAT could focus on broad control measures and on the economics of implementation; NGOs could help stimulate adoption. With multiple partners involved, we should aim to maximize synergy in order to develop cost-effective control methods and stimulate adoption.

Chemical control

Endosulphan and dimethoate are widely available and generally effective. In contrast, synthetic pyrethroids are broad-spectrum contact poisons that kill non-target organisms, even spiders and small lizards. They should be used only when pest populations increase to unmanageable levels and cannot be controlled with less powerful insecticides. There may be need to identify (i) specific active ingredients that work against high population levels of a single pest, with minimal non-target damage, (ii) cheap chemicals that will control a wide range of pests at low or moderate populations.

General approach

In general, farmers lack sufficient understanding of pest control methods and especially of threshold levels. We must focus on educating farmers about pest control. For such a campaign to be effective, farmers must be given simple instructions, e.g. “When you see Lampides eggs in large numbers, a severe pest attack is imminent.” We must focus on 2-3 insecticides that are easily available, cheap, and easy to use. Information can also be disseminated through Farmer Field Schools. In parallel, detailed research can continue; but we must aim to disseminate available technology. Studies have shown that available technology packages for pest control offer benefit:cost ratios of above 1.5, and are thus suitable for promotion.

Crop Management

Improved Management Practices to Increase Productivity of Traditional Cereal/Pigeonpea Intercropping Systems in Eastern Africa

G Mergeai[1], S N Silim[2], and J P Baudoin[1]

Introduction

Among the traditional cropping systems involving pigeonpea in Eastern and Southern Africa, the pigeonpea/cereal intercrop is the most common. The cereal (maize, sorghum, finger millet in different regions) is generally the main crop. Pigeonpea is regarded as a "bonus" crop and an insurance against total crop loss due to poor rainfall. Management practices are orientated to maximize the cereal yield. In most regions, planting is generally done in rows at fairly low density (30 000 to 60 000 plants ha^{-1} for maize or sorghum and about 10 000 plants ha^{-1} for pigeonpea), one row of pigeonpea alternating with several (from 2 to 10) rows of cereal (Le Roi 1997). In Uganda, long- and medium-duration pigeonpea landraces are generally broadcast with finger millet (Silim et al. 1995). Traditional pigeonpea cultivars take from 6 to 10 months to mature and are well suited to this cropping system because they grow very slowly at the beginning of their cycle, flowering only after the main crop is harvested, and providing very little competition for light, water, or nutrients (Sivakumar and Virmani 1980).

Improved long-, medium-, and short-duration pigeonpea cultivars developed during the last 15 years by the University of Nairobi, Kenya Agricultural Research Institute (KARI), and ICRISAT are becoming increasingly popular with farmers (Le Roi 1997). Due to their much shorter vegetative cycle (4-5 months) and their smaller growth habit, short- and medium-duration varieties are much more sensitive to competition from the companion crop than long-duration varieties and, therefore, are not normally suitable for intercropping with tall cereals. Moreover, they are very sensitive to insect pests because their reproductive stage coincides with the seasonal peaks in insect populations. The crop can be completely destroyed if no pest control is done. In spite of these constraints, a large proportion of East African farmers who receive seed of short-duration pigeonpea varieties, intercrop with maize or sorghum as they do with their long-duration landraces. A series of experiments have been conducted in the region in recent years to improve the productivity of cereal/pigeonpea intercropping systems by modifying the spatial arrangement and plant population of the components crops. In this paper, we review the results obtained from these experiments, identify areas where complementary investigations are needed, and discuss constraints to the adoption of improved cropping systems.

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Improved Management Practices for Traditional Intercropping Systems

Before making a recommendation on improved management practices, numerous factors must be taken into consideration – the intercrop components and their compatibility, environmental conditions, possible spatial arrangements, planting sequences, plant populations, productivity, and farmers' preferences. The large number of these factors, and possible interactions amongst them, make it difficult to formulate precise recommendations (Willey 1979). After gaining an understanding of these factors in a given farming system, the next stage is to define the best spatial arrangement, planting sequence, and plant populations of the different components so as to minimize competition (Ali 1990). The less complicated and less risky a new management practice, the higher the probability that it will be adopted by smallholder farmers.

In most traditional cereal/pigeonpea intercropping systems, pigeonpea single rows alternate with several rows of tall cereal (maize or sorghum). Both components are planted simultaneously at the beginning of the most reliable rainy season. After harvest of the cereal, pigeonpea plants are left in the field to finish their growth cycle during the second and less reliable annual rainy season. Due to their low plant population (about 10 000 plants ha^{-1} on average) they usually produce low yields, varying between 300 and 700 kg ha^{-1} (Le Roi 1997).

In order to identify a spatial arrangement that would significantly improve pigeonpea yield without greatly affecting productivity of the cereal component, six arrangements were compared on-station by ICRISAT at two sites in 1993/94. Traditional and improved long-duration pigeonpea varieties were intercropped with maize (data not shown). The best results were obtained with a paired row of pigeonpea alternating with three rows of maize. In paired rows, two pigeonpea rows are sown without an intervening cereal row, and spaced 40-50 cm apart. By contrast, in the traditional intercropping system all rows, whether maize or pigeonpea, are equally spaced 80-100 cm apart.

The most common traditional intercropping system is 3 cereal rows + 1 pigeonpea row. In the paired row arrangement, pigeonpea occupies an area almost similar to that in the traditional arrangement, but pigeonpea plant population is doubled. Thus, this arrangement can better exploit the space left after the cereal harvest.

The paired-row system was tested on-farm for 2 years, 1994/95 and 1995/96, at six sites in eastern Kenya with a total of 25 farmers. The farmers compared traditional versus improved management practices on their landraces and on an improved long-duration variety Kat 81/3/3.

Improved management: one paired row of pigeonpea intercropped with three rows of maize. Distance between pigeonpea rows 50-60 cm depending on soil moisture availability. Distance between maize rows 80 cm. *Traditional management:* one single row of pigeonpea intercropped with 3 to 5 rows of maize with a constant distance of 80-100 cm between rows.

Both components of the intercropping system were planted at the same time using an ox-drawn moldboard plow. Using the improved practice, farmers achieved on average over 50% increase in pigeonpea yield – with no decline in maize production and no extra labor

Table 1. Comparison of traditional versus improved intercropping systems, involving maize and long-duration pigeonpea.

	Maize yield (kg ha^{-1})	Pigeonpea yield (kg ha^{-1})
Traditional practice		
Traditional pigeonpea varieties	1459	1091
Improved long-duration pigeonpea Kat 81/3/3	1231	811
Improved practice		
Traditional pigeonpea varieties	1539	1497
Improved long-duration pigeonpea Kat 81/3/3	1252	1460
Average gains from improved practice (%)		
Traditional pigeonpea varieties	5.48	37.21
Improved long-duration pigeonpea Kat 81/3/3	1.71	80.02

Improved system = paired pigeonpea rows alternating with maize
Data pooled from 25 farmers across 5 sites in eastern Kenya

cost (Table 1). Interestingly, the pigeonpea landrace gave higher yields than the improved long-duration variety, which was bred for sole cropping at higher altitudes. With its bushy habit, the improved long-duration variety competed too strongly with maize. When breeding long-duration pigeonpea for intercropping systems, it is thus advisable to look for compact genotypes with a rather low competitive ability.

Improved Management Practices for New Intercropping Systems

Most farmers who receive seed of improved short- and medium-duration pigeonpea tend to grow them in intercrop systems, the same way they do with their traditional varieties. Therefore, it was important to identify suitable systems where the new varieties could be intercropped with maize, sorghum, or finger millet. Different spatial arrangements and plant populations were tested for these intercropping systems in several experiments in Kenya and Uganda. A summary of the main results is presented below.

Maize/short-duration pigeonpea intercropping systems

In Kenya, ICRISAT carried out a preliminary trial in 1995 at Kiboko research station (altitude 900 m) in order to determine optimal plant density and spatial arrangement. Short-duration pigeonpea ICPL 87091 was intercropped with maize (Katumani hybrid) using various arrangements. These included sole crops, intercrops consisting of nonpaired rows at different row ratios (1:1, 1:2, 2:4, 2:2 and 2:1), and intercrops with paired rows. In the latter, maize rows were paired, and intercropped with 1, 2, or 3 rows of pigeonpea; and all rows were spaced at 40 cm.

In the sole crops, spacing was 80 x 30 cm for maize and 40 x 10 cm for pigeonpea. In all systems, the distance between maize and pigeonpea rows was kept constant at 40 cm. Table 2 shows the results of this experiment. All intercrops gave LERs above 1, but in general better results were obtained from treatments involving paired maize rows. The best system appeared to be paired rows of maize alternating with 2 rows of pigeonpea. This arrangement gave the second highest LER of 1.30, and also gave high maize yields.

Another trial was conducted at Thika research station (altitude 1580 m), Kenya, by Gembloux Agricultural University, during the long rainy season (Mar-June) of 1999. In this experiment, 2:2 rows were planted at different intra-row spacings, with inter-row spacing kept constant at 60 cm. No paired rows were used. Two pigeonpea varieties, Kat 60/8 and ICPL 87091, were tested. The results were disappointing. Pigeonpea plants were stunted due to the low temperature and high maize plant population, and pigeonpea yields were low. Consequently, although maize yields were high (5.9 t ha^{-1} in sole crop, and >4 t ha^{-1} in many intercrop treatments), the total LER of the intercrop treatments was low, either below or marginally above 1.

Sorghum/short-duration pigeonpea intercropping

Several experiments were carried out in Uganda by Makerere University and Gembloux Agricultural University in order to develop improved sorghum/short-duration pigeonpea intercropping systems. We used the same approach as described above for maize/ pigeonpea. First, trials were conducted at Kabanyolo to compare various row arrangements. Then a second trial was conducted at Serere, using only the best row arrangement, to study the effects of inter-row spacing and plant population.

Two intercropping trials were carried out at Kabanyolo (altitude 1200 m) during two consecutive rainy seasons – planted in Aug 1997 and Feb 1998. The treatments included sole crops, and intercrops consisting of nonpaired rows at different row ratios (1:1, 2:1, 2:2). Inter-row spacing was kept constant at 60 cm. Intra-row spacing was also kept constant in all treatments, except that for sorghum, it was reduced from 20 cm to 15 cm between sole and intercrop situations. The varieties used were sorghum Seredo, and pigeonpea Kat 60/8 and ICPL 87091. Results are shown in Table 3. The best results, with a remarkably high LER of 1.47, came from a 2:2: row arrangement of Seredo and Kat 60/8.

Another trial was conducted at the Serere Agricultural and Animal Research Institute (altitude 1100 m) by Gembloux Agricultural University, in the long rainy season of 1999, i.e. planted in March 1999. In this experiment, 2:2 rows were planted at different intra-row spacings, with inter-row spacing kept constant at 60 cm. No paired rows were used. The same three varieties were tested – sorghum Seredo, pigeonpea varieties Kat 60/8 and ICPL 87091. The results were not convincing. Due to lush growth in sorghum, pigeonpea was suppressed: pigeonpea yields ranged from 331 to 536 kg ha^{-1}, and pigeonpea LERs from 0.26 to 0.58. Total LERs in all intercrops were below 1, with the exception of one treatment with Seredo-Kat 60/8, which gave an LER of 1.08.

Finger millet/short-duration pigeonpea intercropping

Intercropping trials involving finger millet and short-duration pigeonpea were carried out in Uganda by Makerere and Gembloux Universities from early 1999 to early 2000. As in the other experiments, the first step aimed at identifying the optimal spatial arrangement under different plant populations of both components.

A trial was planted at two sites (Kabanyolo and Ngetta, altitude 1100 m) in two consecutive seasons, i.e. planted in Mar and Aug 99. The early to medium-duration pigeonpea cultivar Kat 60/8 was intercropped with finger millet variety Pese 1, at various row ratios and plant populations. Paired rows were not used. The treatments included two row ratios (millet:pigeonpea 2:2: and 4:1) and four levels of plant population. Sole crops were also tested. Inter-row spacing was 30 cm between finger millet rows, 60 cm between pigeonpea rows, and 45 cm between millet and pigeonpea rows.

Results are shown in Table 4, averaged across the four trials. Again, the 2:2 row ratio gave the best results.

The superiority of 2:2 for short-duration pigeonpea was confirmed in another trial where improved short-duration ICPL 87091 and early to medium-duration Kat 60/8 were intercropped with finger millet Pese 1. Millet:pigeonpea row ratios of 2:2, 2:1, and 4:1 were tested, along with broadcasting, which is a common farmer practise. This trial was conducted thrice–twice at Kabanyolo, planted in Feb and Aug 1999; and once at Ngetta, planted in Mar 1999. Table 5 shows the results averaged across the three trials. As in the previous experiment, the inter-row spacing was 30 cm between finger millet rows, 60 cm between pigeonpea rows, and 45 cm between millet and pigeonpea rows. The results confirmed that for both pigeonpea varieties, the 2:2 row ratio gave the best yields.

Discussion and Conclusions

The experiments tested three types of intercropping – tall cereal (maize or sorghum) with long-duration pigeonpea, tall cereal with short-duration pigeonpea, and short cereal (finger millet) with short-duration pigeonpea. The results clearly showed that maize/long-duration pigeonpea and finger millet/short-duration pigeonpea systems are beneficial. With tall cereals/short-duration pigeonpea, the benefit is much less evident.

The arrangement with paired rows of medium- or long-duration pigeonpea alternating with three unpaired rows of maize drastically increased productivity. This is only a minor modification of traditional farmer practice, does not present major risks, and is well suited to the current situation, where most farmers regard pigeonpea as a food-security crop. Considering the simplicity of this new planting technique, which is within the capabilities of every small farmer, one can assume that dissemination should not be too difficult. Ideally, an evaluation of adoption near the six sites where paired rows were introduced in 1995 should be conducted before starting dissemination on a large scale.

Intercropping short- and early-medium duration pigeonpea with finger millet using a 2:2 row ratio can increase productivity by nearly 30% when the right plant populations of both components are used. However, effective pest control is an essential prerequisite. In addition, adoption of this system would be complicated in the traditional finger millet/ pigeonpea areas, mainly located in northern Uganda, because it is totally different from current smallholder practice, which is to broadcast both crops. Moreover, considering the susceptibility of determinate short-duration pigeonpea varieties to insect pests, it is

Table 2. Identification of the best spatial arrangement for intercropping maize with short-duration pigeonpea, Kiboko, Kenya.

	Density (plants ha^{-1})		Yield (kg ha^{-1})		LER		
	Maize	Pigeonpea	Maize	Pigeonpea	Maize	Pigeonpea	Total
Sole maize (M) 80 cm inter-row spacing	41 667	ñ	3567	ñ	1.00		1.00
Sole short-duration pigeonpea (PP) ICPL 87091 - 40 cm spacing	ñ	250 000	ñ	3044		1.00	1.00
Intercrop M and PP, 1:1 ratio	41 667	125 000	2811	1306	0.79	0.43	1.22
Intercrop M and PP, 1:2 ratio	27 778	166 667	2856	1583	0.80	0.52	1.32
Intercrop M and PP, 2:4 ratio	17 857	142 857	2222	1472	0.62	0.48	1.10
Intercrop M and PP, 2:2 ratio	25 000	100 000	2756	1100	0.77	0.36	1.13
Intercrop M and PP, 2:1 ratio	31 250	62 500	3300	844	0.93	0.28	1.21
Intercrop paired rows M (40 cm spacing) and 1 row PP (40 cm spacing)	55 556	83 333	3422	789	0.96	0.26	1.22
Intercrop paired rows M (40 cm spacing) and 2 rows PP (40 cm spacing)	41 667	125 000	3033	1378	0.85	0.45	1.30
Intercrop paired rows M (40 cm spacing) and 3 rows PP (40 cm spacing)	33 333	150 000	2333	1756	0.65	0.58	1.23

Table 3. Identification of the best spatial arrangement for intercropping sorghum with short-duration pigeonpea, Kabanyolo, Uganda.

	Density (plants ha^{-1})		Yield (kg ha^{-1})		LER		
	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Total
Sole sorghum variety Seredo (S)	83 333		3211.5		1.00		1.00
Sole short-duration pigeonpea ICPL 87091 (PP1)		83 333		1019.5		1.00	1.00
Sole early to medium-duration pigeonpea Kat 60/8 (PP2)		55 556		1118.5		1.00	1.00
Intercrop S-PP1, 1:1 ratio	55 556	41 667	1669.5	366	0.52	0.36	0.88
Intercrop S-PP1, 2:1 ratio	74 074	27 778	2584.5	467	0.80	0.46	1.26
Intercrop S-PP1, 2:2 ratio	55 556	41 667	2786	691	0.87	0.68	1.55
Intercrop S-PP2, 1:1 ratio	55 556	27 778	1859.5	383	0.58	0.34	0.92
Intercrop S-PP2, 2:1 ratio	74 074	18 519	2584.5	410.5	0.80	0.37	1.17
Intercrop S-PP2, 2:2 ratio	55 556	27 778	2885	641.5	0.90	0.57	1.47

Table 4. Determination of optimal spatial arrangement and plant populations for intercropping finger millet with short-duration pigeonpea, Kabanyolo and Ngetta, Uganda.

	Density (plants ha^{-1})		Yield (kg ha^{-1})		LER		
	Millet	Pigeonpea	Millet	Pigeonpea	Millet	Pigeonpea	Total
Intercrop finger millet: pigeonpea,	55 556	28 778	555	780	0.35	0.72	1.07
2:2 row ratio, at various plant populations	74 074	37 037	674	800	0.43	0.74	1.17
	111 111	55 556	648	830	0.41	0.76	1.17
	222 222	111 111	478	629	0.31	0.58	0.89
Intercrop finger millet: pigeonpea,	55 556	13 889	1054	385	0.67	0.35	1.02
4:1 row ratio, at various plant populations	74 074	18 519	1182	429	0.75	0.39	1.14
	111 111	27 778	1171	479	0.75	0.44	1.19
	222 222	55 556	886	345	0.57	0.32	0.89
Sole pigeonpea at various plant populations		41 667		978		1.00	1.00
		55 556		1086			
		83 333		1026			
		166 667		771			
Sole finger millet at various plant populations	166 667		1379		1.00		1.00
	222 222		1566				
	333 333		1449				
	666 667		1085				

Finger millet variety Pese 1, pigeonpea variety Kat 60/8

Table 5. Determination of optimal spatial arrangement and plant populations for intercropping finger millet with short-duration pigeonpea, Kabanyolo and Ngetta, Uganda.

	Density (plants ha^{-1})		Yield (kg ha^{-1})		LER		
	Millet	Pigeonpea	Millet	Pigeonpea	Millet	Pigeonpea	Total
Pigeonpea variety Kat 60/8							
Intercrop millet: pigeonpea, 2:2 row ratio	111 111	37 037	809	973	0.41	0.87	1.28
Intercrop millet: pigeonpea, 2:1 row ratio	166 667	27 778	1060	607	0.54	0.54	1.08
Intercrop millet: pigeonpea, 4:1 row ratio	222 222	18 519	1520	451	0.78	0.40	1.18
Intercrop millet: pigeonpea, both crops broadcast	166 700	27 800	839	459	0.43	0.41	0.84
Sole pigeonpea		55 556		1121		1.00	1.00
Pigeonpea variety ICPL 87091							
Intercrop millet: pigeonpea, 2:2 row ratio	111 111	55 556	916	691	0.47	0.83	1.30
Intercrop millet: pigeonpea, 2:1 row ratio	166 667	41 667	1145	428	0.59	0.51	1.10
Intercrop millet: pigeonpea, 4:1 row ratio	222 222	27 778	1480	252	0.76	0.30	1.06
Intercrop millet: pigeonpea, both crops broadcast	166 700	41 700	988	407	0.50	0.49	0.99
Sole pigeonpea		83 333		834		1.00	1.00
Sole finger millet	333 333		1957		1.00		1.00

Finger millet variety Pese 1, pigeonpea varieties Kat 60/8 and ICPL 87091 advisable to use indeterminate short-duration pigeonpea in this type of intercropping system. The 2:2 arrangement needs to be tested further under on-farm conditions before dissemination.

Contradictory results were obtained regarding the intercropping of short- and early to medium-duration pigeonpea with tall cereals (maize or sorghum). Some trials showed interesting productivity gains in intercrops compared to sole crops, while others showed no LER advantage under intercropping. Among the various spatial arrangements tested, two arrangements often gave good results – paired rows of maize alternating with 2 rows of pigeonpea, and 2:2 row ratio of (unpaired) maize and pigeonpea.

In this study, paired-row sowing was used as a way to improve the traditional intercropping system which involves long-duration pigeonpea. However, paired-row sowing is usually used to reduce competition from dominant tall crops against the dwarf component crop in an intercrop (Ali 1990). Moreover, it is thought that increased intra-specific root competition induced by paired rows leads to reduced root growth and slower depletion of soil moisture in the early stages of the crop vegetative cycle, which in turn leads to more water availability during the grain-filling stage (Rowland and Whiteman 1993). In semi-arid conditions, Blum and Naveh (1976) observed that alternate paired-rows of sole sorghum (planted 40 cm apart with 160 cm between row pairs) produced significantly greater yields than single rows (planted 100 cm apart) in 50% of years, and similar yields in the other 50%. As yield was increased in the dry years with the same evapotranspiration, they concluded that competition in the paired-row system improved water-use efficiency.

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Cereal-Pigeonpea Intercropping Systems: the Ugandan Experience

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Introduction

Pigeonpea is an important grain legume in Uganda. It is consumed mostly as dry grain, but fresh green peas are also eaten as vegetables. The grain and fodder are excellent livestock feed, especially during the dry season. Stems are used for fencing, baskets, and construction materials for huts, and in the more arid regions, as fuelwood. Pigeonpea usually improves soil fertility through nitrogen fixation and its ability to recycle nutrients through its deep rooting system.

The total area under pigeonpea cultivation in Uganda is estimated at 72,000 ha (Saxena 1999). Production is concentrated mostly in the drier northeastern and northern areas (Apac, Lira, Gulu, Kitgum, Soroti, Kumi, Arua, Moroto). Production in the wetter parts of the country is probably limited by the prevalence of cercospora leafspot disease and competition from other grain legumes.

Pigeonpea is largely grown in association with other crops, usually cereals. In north and northeastern Uganda it is intercropped with finger millet, which is considered as the main crop – the pigeonpea yield is regarded as a bonus (Silim et al. 1991). Medium- and long-duration landraces or cultivars, especially Apio Elena and Adong, are the most favored because they mature much after the other component crops, ensuring that the peak growth demands of the component crops occur at different times, giving the intercrop a yield advantage. However, yields of these landraces are low, on average 300-600 kg ha^{-1} (Musaana and Silim 1998, Silim et al. 1991), and, therefore, there is need to promote adoption of new high-yielding cultivars. One problem is that short-duration cultivars, e.g. Kat 60/8 and ICPL 87091 which were recently introduced, mature in 90-130 days, which more or less coincides with the maturity period of finger millet. Similarly, the introduced medium-duration varieties such as ICP 6927 tend to mature early in Uganda and could potentially compete with the main crop. The potential reduction in millet yield due to competition between the two crops highlights the importance of testing these materials in intercrop situations before making recommendations to farmers.

The main aim of the work reported in this paper, therefore, was to develop new production technologies involving the new cultivars and determine the most appropriate sowing patterns and plant populations of the component crops in order to minimize competition effects and ensure high yields of both crops.

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Experimental Work in Uganda

Research involving cereal/pigeonpea intercropping in Uganda has been conducted intermittently. Some work was carried out during the mid-seventies (1975-77) with funding from the International Development Research Centre (IDRC); but was discontinued because of lack of funding. More recently (1998/99), research on cereal/pigeonpea intercropping was initiated with funding from the European Union. This work focused largely on identifying optimal plant population and row arrangements for short-duration pigeonpea cultivars, thus minimizing competition at critical growth periods and maximizing complementary effects in the intercrop.

The earlier experiments (1975-77) examined combinations of finger millet/pigeonpea and sorghum/pigeonpea. The finger millet variety was Serere 1, which usually grows to a height of 70-80 cm and matures in about 110 days. The sorghum variety used was Dobbs, an improved local variety that was widely grown around the Lake Victoria crescent at that time. It matures in about 120 days. Two pigeonpea varieties were used – UC 11 for the millet/pigeonpea intercrop and Determinate Short for sorghum/pigeonpea. UC 11 is a dwarf Ugandan collection, shorter than Serere 1. Determinate Short is a high-yielding variety, slightly shorter than Dobbs, maturing in 124-130 days.

In the later experiments (1998/99), both finger millet/pigeonpea and sorghum/pigeonpea combinations were examined. The objective was to determine the appropriate row pattern, plant population, and cultivar suitability for these intercrop systems. As with the earlier experiments, a wide range of plant populations were used to ensure that the maximum productivity of intercrops could be compared with the maximum productivity of pure stands. The finger millet variety was Pese 1, short-statured, maturing in about 120 days. The sorghum varieties were Sekedo and Seredo.

Three pigeonpea varieties were used: ICP 6927 (medium duration), Kat 60/8 (early to medium duration), and ICPL 87091 (short duration). The experiments were carried out at Makerere University Agricultural Institute Kabanyolo (MUARIK) and Ngetta Experimental Station in Lira district. In the work involving finger millet, two sets of experiments were carried out. One examined the effects of plant population on pigeonpea intercropped with finger millet at different row patterns, while the other studied the effects of row patterns on three pigeonpea cultivars intercropped with finger millet.

Results, 1975-77

The results have generally shown that intercropping can provide yield benefits. Large yield benefits were achieved, with LERs of up to 1.30 and 1.29 in millet/pigeonpea and sorghum/pigeonpea mixtures respectively. Pigeonpea yields were low in all treatments, due to heavy disease infection and pest attack. When planted as sole crops, both finger millet and pigeonpea gave their highest yields at the highest plant populations – indicating that the plant populations used in the experiments were less than optimum.

The experiment also studied the effect (at each plant population) of replacing part of one crop by the other crop. For instance, when one-quarter of cereal was replaced by pigeonpea, the decrease in cereal yield could not be compensated by increased pigeonpea yield – total grain yield from the mixture was lower than from sole cereal. As more and more cereal was replaced with pigeonpea, there was a progressively significant decrease in cereal yield and the total yield of the mixture. However, at the highest plant population, and the lowest degree of substitution (25% of cereal replaced by pigeonpea), loss of cereal yield was largely compensated by increased pigeonpea yield.

Results, 1998/99

Results of experiments conducted in 1998/99 are summarized in Tables 1 to 4. Increasing plant population significantly ($p<0.05$) reduced the number of branches per plant, pods per plant, 100-seed mass, and dry matter per plant of pigeonpea in all row patterns. Plant height, however, significantly increased with increase in plant population, but the number of seeds per pod was not affected by either plant population or row pattern. The increase in dry matter per plant and pods per plant was due to increased branching at low plant populations and in intercrops. Increased branching in turn was due to increased space per plant, which reduced shading and therefore reduced intra-specific competition (Lawn and Troedson 1990, Ali 1990). This resulted in increased interception of radiation and consequently more pod formation. At very high plant populations, the reduction in the number of pods per plant could not be compensated for by the high number of plants per unit area, resulting in lower total yield. Intercropping significantly ($p<0.05$) increased the number of pods per plant at Ngetta compared to MUARIK.

Land equivalence ratios. LERs in all intercropping systems were higher than 1.0 (1.06-1.34 at MUARIK and 1.13-1.46 at Ngetta), indicating that intercropping pigeonpea with finger millet resulted in a yield advantage, and that Kat 60/8, a tall indeterminate variety, was suitable for such an intercrop (Table 1). Yields of the intercrop depended on both row pattern and intra-row spacing. The highest LERs were achieved from a 2:2 row pattern at pigeonpea intra-row spacings of 30 cm and 20 cm at MUARIK and Ngetta respectively.

When millet was sown in rows, LERs were above 1.0 for all row patterns. For intercrops where millet was broadcast, LERs were less than 1.0 (Table 2). Kat 60/8 and ICPL 87091 gave their highest LERs at 2:2 row patterns and ICP 6927 in 1:2 row pattern. These results indicated that for a given row arrangement, optimal planting pattern depended on the pigeonpea cultivar used.

Conclusions

The results of the experiments clearly indicated that the highest yield advantages were obtained at row patterns of 2:2 for Kat 60/8 and ICPL 87091; and at a 1:2 row pattern with ICP 6927. The advantages seem to be due to increased branching and podding of pigeonpea in intercrops, which more than compensated for the reduction in cereal population in the intercrop.

Table 1. Yield and LERs of Kat 60/8 intercropped with finger millet at various plant populations and row patterns, MUARIK and Ngetta, 1999 second season.

Row pattern	MUARIK					Ngetta				
	Yield (kg ha^{-1})		LER			Yield (kg ha^{-1})		LER		
	Pigeonpea	Millet	Pigeonpea	Millet	Total	Pigeonpea	Millet	Pigeonpea	Millet	Total
S, A	983	ó	1.00	ó	1.00	636	ó	1.00	ó	1.00
S, B	1070	ó	1.00	ó	1.00	726	ó	1.00	ó	1.00
S, C	1200	ó	1.00	ó	1.00	758	ó	1.00	ó	1.00
S, D	1043	ó	1.00	ó	1.00	680	ó	1.00	ó	1.00
1, A	835	354	0.85	0.27	1.12	489	200	0.79	0.30	1.09
1, B	933	515	0.87	0.30	1.17	584	245	0.80	0.30	1.10
1, C	1070	530	0.89	0.31	1.20	631	214	0.83	0.30	1.13
1, D	843	516	0.81	0.30	1.11	522	144	0.77	0.32	1.09
2, A	347	931	0.35	0.70	1.05	299	457	0.47	0.68	1.15
2, B	453	961	0.42	0.55	0.97	378	503	0.52	0.61	1.13
2, C	598	1046	0.50	0.60	1.10	436	461	0.58	0.64	1.22
2, D	433	976	0.42	0.56	0.98	324	273	0.48	0.61	1.09
M, A	ó	1333	ó	1.00	1.00	ó	668	ó	1.00	1.00
M, B	ó	1737	ó	1.00	1.00	ó	823	ó	1.00	1.00
M, C	ó	1754	ó	1.00	1.00	ó	726	ó	1.00	1.00
M, D	ó	1740	ó	1.00	1.00	ó	446	ó	1.00	1.00

S = sole pigeonpea, M= sole millet

1 = 2:2 row pattern, 2 = 1:4 row pattern

A= 40/20 cm, B = 30/15 cm, C= 20/10 cm, D = 10/5 cm pigeonpea/millet within-row distance

Table 2. Yield and LERs of Kat 60/8, ICP 6927, and ICPL 87091 intercropped with finger millet variety Pese at various row patterns, MUARIK and Ngetta, 1999 first season.

Treatment	MUARIK					Ngetta				
	Yield (kg ha^{-1})		LER			Yield (kg ha^{-1})		LER		
	Pigeonpea	Millet	Pigeonpea	Millet	Total	Pigeonpea	Millet	Pigeonpea	Millet	Total
ICPL 87091, 2:2	1177	1044	0.95	0.36	1.31	423	1183	0.66	0.64	1.30
ICPL 87091, 1:2	690	1382	0.56	0.48	1.04	188	1450	0.29	0.79	1.08
ICPL 87091, 1:4	428	1850	0.35	0.64	0.99	148	1717	0.23	0.96	1.17
ICPL 87091, 1:B	699	1137	0.56	0.40	0.96	138	1375	0.21	0.75	0.96
Sole ICPL 87091	1240	ñ	1.00	ñ	1.00	646	ñ	1.00	ñ	1.00
Kat 60/8, 2:2	1358	712	1.00	0.25	1.25	725	1217	0.67	0.66	1.33
Kat 60/8, 1:2	812	1308	0.60	0.46	1.06	300	1415	0.28	0.77	1.05
Kat 60/8, 1:4	692	1993	0.51	0.69	1.20	153	1803	0.14	0.98	1.12
Kat 60/8, 1:B	752	865	0.55	0.30	0.85	169	1233	0.16	0.67	0.83
Sole Kat 60/8	1357	ñ	1.00	ñ	1.00	1090	ñ	1.00	ñ	1.00
ICP 6927, 2:2	784	850	0.73	0.30	1.03	623	792	0.71	0.43	1.14
ICP 6927, 1:2	729	1217	0.68	0.42	1.10	525	1250	0.60	0.68	1.28
ICP 6927, 1:4	377	1907	0.35	0.66	1.01	250	1454	0.28	0.79	1.07
ICP 6927, 1:B	749	998	0.69	0.35	1.05	282	958	0.32	0.52	0.84
Sole ICP 6927	1079	ñ	1.00	ñ	1.00	883	ñ	1.00	ñ	1.00
Sole millet	ñ	2875	ñ	1.00	1.00	ñ	1838	ñ	1.00	1.00

Table 3. Yields and total LERs for pigeonpea intercropped with finger millet and sorghum, MUARIK, first season 1998.

Treatment	Yield (kg ha^{-1})				Total LER
	Pigeonpea	Finger millet	Sorghum	Combined	
PP1+FM (1:1)	864	640	–	1504	1.30
PP1+FM (1:2)	669	636	–	1305	1.16
PP1+FM (2:2)	907	839	–	1746	1.54
PP2+FM (1:1)	558	722	–	1310	1.37
PP2+FM (1:2)	391	928	–	1319	1.38
PP2+FM (2:2)	1010	701	–	1711	1.79
PP1+S (1:1)	433	–	1807	2240	0.95
PP1+S (1:2)	404	–	2594	2998	1.21
PP1+S (2:2)	777	–	2220	2997	1.35
PP2+S (1:1)	349	–	1547	1896	0.91
PP2+S (1:2)	334	–	1865	2199	1.00
PP2+S (2:2)	632	–	2247	2879	1.45
Sole PP1	1359	–	–	1359	1.00
Sole PP2	956	–	–	956	1.00
Sole FM	–	958	–	958	1.00
Sole S	–	–	2848	2848	1.00
LSD (0.05)	96.1	113.6	121.9	122.5	–
CV (%)	9.05	5.04	5.04	3.52	–

PP1 = Kat 60/8, PP2 = ICPL 87091, FM = Pese 1, S = Seredo (sorghum)

Table 4. Mean yields and LERs in pigeonpea/finger millet intercrops, Ngetta, 1998.

Intercrop and population (plants/m^2)	Yield (kg ha^{-1})			Total LER
	Pigeonpea	Finger millet	Combined	
PP1+FM (8.3:8.3)	1378	1472	2850	1.01
PP1+FM (5.6:11.1)	1098	1830	2928	0.99
PP1+FM (4.8:16.7)	798	2861	3650	1.14
PP1+FM (4.2:33.3)	709	3944	4655	1.40
PP2+FM (16.7:8.3	2345	1325	3670	1.19
PP2+FM (11.1:11.1)	1645	1428	3073	0.97
PP2+FM (8.8:16.7)	926	2200	3126	0.93
PP2+FM (5.6:33.3)	850	3156	4006	1.17
Sole PP1 (5.6)	2272	–	2272	1.00
Sole PP2 (8.3)	2844	–	2844	1.00
Sole FM (33.3)	–	3622	3622	1.00
LSD (0.05)	235.0	238.9	159.3	–
CV (%)	10.8	5.90	5.48	–

PP1 = Kat 60/8, PP2 = ICPL 87091, FM = Pese 1 (finger millet)

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The Potential of Pigeonpea-Cotton Intercropping in Uganda

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Introduction

Intercropping studies involving cotton with beans, maize, and cowpea have been conducted earlier (e.g. Elobo 1996). However, no experimental work has been documented for cotton-pigeonpea intercropping. Development of a cotton-pigeonpea system would allow the legume to benefit from cotton pest management, while cotton could benefit from the synergetic effects of the intercrop. A series of experiments were therefore conducted at Serere Agricultural and Animal Research Institute (SAARI) in Soroti district, Uganda during the two rainy seasons of 1999. The objective was to compare different spatial arrangements, varieties, pest control treatments, and plant densities.

Materials and Methods

The following factors were tested; treatments are listed in Table 1.

Table 1. Treatments used in cotton-pigeonpea intercopping studies, Serere, 1999.

	C-P*	C-C-P	C-C-C-P	C-C-P-P	C-P-P-P	P-sole	C-sole
First rainy season, planted 12 May							
ICPL 87091 (60 x 20 cm)	✔				✔	✔	
ICPL 87091 (75 x 20 cm)	✔	✔	✔	✔	✔	✔	✔
Kat 60/8 (75 x 30 cm)	✔	✔	✔	✔	✔	✔	✔
Adong (75 x 45 cm)		✔	✔			✔	✔
Second rainy season, planted 12 Aug							
ICPL 87091 (60 x 20 cm)	✔	✔	✔	✔	✔	✔	✔
ICPL 87091 (75 x 20 cm)	✔	✔	✔	✔	✔	✔	✔
Kat 60/8 (75 x 30 cm)	✔	✔	✔	✔	✔	✔	✔

*C-P: 1 row cotton, 1 row pigeonpea. C-C-P: 2 rows cotton, 1 row pigeonpea, etc

ï *Spatial arrangement.* Various combinations such as 1 row cotton and 2 rows pigeonpea, etc were compared with sole cotton and sole pigeonpea.

ï *Variety.* Three pigeonpea varieties were used: ICPL 87091 (short-duration determinate), Kat 60/8 (medium-duration indeterminate), and Adong (long-duration). The cotton variety used was BPA 97.

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- ï *Pest control.* Chemical pest control was applied on three blocks. Cypermethrin was applied on cotton only, starting 35 days after germination and repeated fortnightly to end of flowering. Two control blocks had no pest control.
- ï *Plant density.* Pigeonpea variety Kat 60/8 was sown at 75 x 30 cm, Adong at 75 x 45cm. ICPL 87091 was sown at two densities, 75 x 20 cm and 60 x 20 cm. The cotton variety BPA 97 was also sown at two densities, 75 x 45 cm and 60 x 45 cm.

The experiments were conducted during the two rainy seasons of 1999, planted in May and Aug. Plot size was 6 x 5 m. The experiment was laid out in two unsprayed replications and three replications with pest control applied on cotton plants only. Treated and untreated treatments were separated by a 25 m strip planted with sorghum variety Secedo, sown at the same time. Adong was planted only during the first rainy season. ICPL 87091 and Kat 60/8 were ratooned to obtain a second harvest (not reported here).

In addition, 8 random plant samples were taken for each crop and for each treatment in five replicates, in order to determine the major biomass components. Finally, leaf fall was recorded in one treated and one untreated block.

Results and Discussion

Spatial arrangement

Land Equivalent Ratio (LER) was higher than one in all intercropping treatments (Table 2, Fig 1). This was due to the fact that per-area cotton yields were higher in intercrop treatments than in sole cotton. Further, as the share of the cotton component increased, total LER for the intercrop also increased. The highest LER during the first rainy season was obtained from treatment C-C-C-P, i.e. three rows of cotton with one row of pigeonpea. Cotton seed yield per unit area from this arrangement was about 30% higher than the monocrop treatment. Yields of pigeonpea, which occupied only 25% of the intercrop, were as high as 42% of the corresponding monocrop yield. In the second rainy season, yields of both crops were low as a result of drought and insect pests. However, as in the first season, LERs were high in all intercrops, underlining the benefits of this intercropping system.

Table 2. Yield performance of pigeonpea-cotton intercropped with different spatial arrangements.

Treatment	1st rainy season (planting date 12 May)			2nd rainy season (planting date 12 Aug)		
	Pigeonpea yield (kg ha^{-1})	Cotton yield (kg ha^{-1})	Total LER	Pigeonpea yield (kg ha^{-1})	Cotton yield (kg ha^{-1})	Total LER
C-P	318	1101	1.51	127	339	1.59
C-C-P	300	1148	1.51	75	378	1.23
C-C-C-P	194	1745	1.73	78	444	1.37
C-C-P-P	247	1050	1.32	105	351	1.43
C-P-P-P	490	519	1.45	151	117	1.41
C sole	0	1329	1.00		601	1.00
P sole	464	0	1.00	124	0	1.00

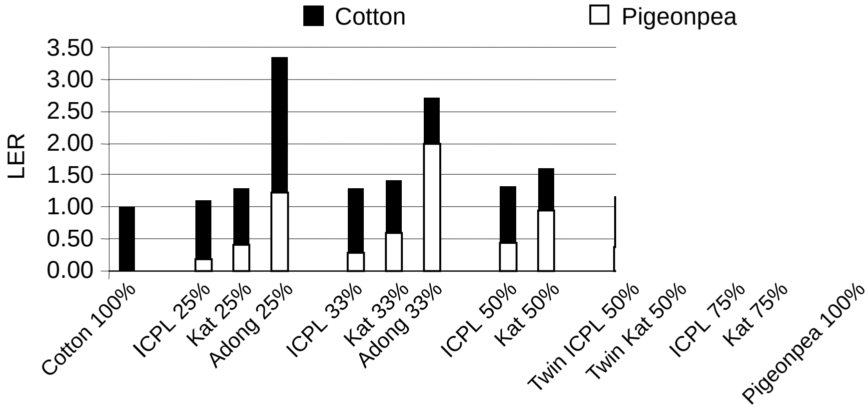

Figure 1. LERs from various cotton-pigeonpea intercrops, Serere, first rainy season 1999.

Effect of variety

Intercrop performance depended on the pigeonpea variety being used. In terms of yield of both crops and total LER, the local variety Adong was the best among the three pigeonpea cultivars used, followed by Kat 60/8 and ICPL 87091. Kat 60/8 gave a much higher LER than ICPL 87091, while competition effects were lower with Kat 60/8 than with ICPL 87091. These results can be explained by the different growth stages and hence the reduction of intercrop competition (Steiner 1982). Adong started flowering about 10 weeks later than cotton and harvest was even further delayed.

Pest control

In all treatments, pest control increased cotton yields (Table 3). Similar results were observed for pigeonpea, especially Kat 60/8 and ICPL 87091. Pest control was relatively more effective in Kat 60/8, because the flowering stage roughly coincided with that of cotton. The difference between treated and untreated plots was smallest in Adong, indicating some degree of pest tolerance.

Plant density

ICPL 87091 was planted at two densities, i.e. 75 x 20 cm and 60 x 20 cm. Increase in plant density increased pigeonpea yield in the intercropped treatments but reduced cotton yield (Table 3). High plant density also increased total LER: by 65% for the 75 x 20 cm spacing, and by 21% for 60 x 20 cm, when pest control measures were taken. Performance was poor when no pest control was applied (e.g. LER < 1.0 at 60 x 20 cm spacing). This suggests that intercropping without pest control gave no yield advantages over a monocrop.

Biomass and nutrient transfer in pigeonpea-cotton intercrops

The importance of biomass and its components, including leaf fall, was measured in each of the intercropping systems. Fig. 2 shows the results of the experiment planted during the second rainy season. The collection of fallen leaves started 102 days after planting and was completed together with the last picking of cotton. Cotton produced the highest total biomass amount (leaf fall and plant weight). Hence, it follows that treatments with a high share of cotton (e.g. 75% or 3 rows of cotton with 1 pigeonpea row) produce the highest biomass. Plant density is another factor ñ cotton at lower plant density (row spacing 75 cm) produced more biomass than at higher density (60 cm). The medium-duration pigeonpea variety Kat 60/8 was taller and produced more biomass than the short-duration ICPL 87091. Similar results were reported by Nene et al. (1990).

Gross economic returns

Table 4 shows the estimated gross economic returns from different intercropping treatments. In 1999, the market price (Ugandan shillings) for cleaned seed cotton was 250 USh/kg and for shelled pigeonpea 500 USh/kg. The returns were highest when cotton was intercropped with pigeonpea variety Adong, particularly with 25% Adong (863 USh/ha). However, note that these are gross returns, and do not include input costs (labor, pesticides etc), which are considerable for cotton.

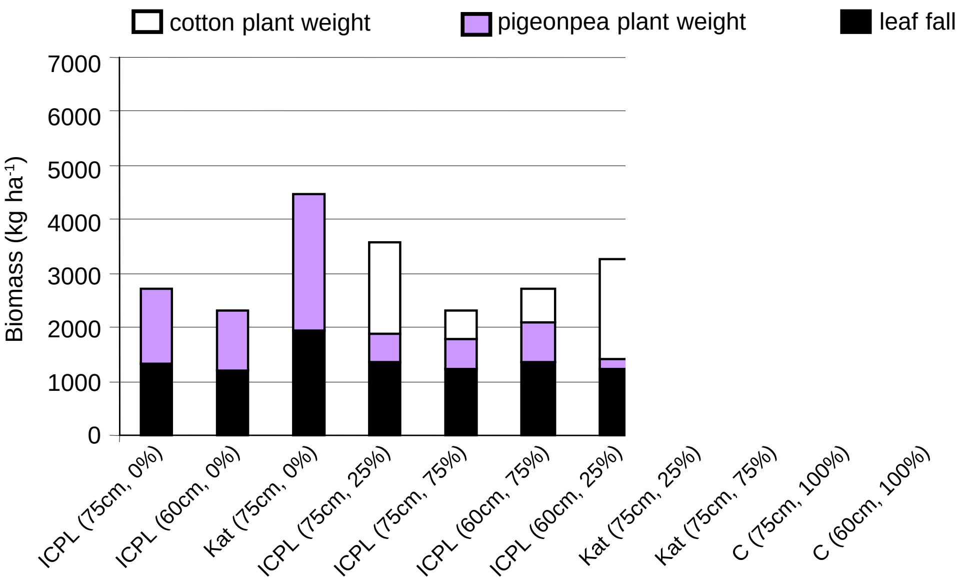

Figure 2. Biomass production in various cotton/pigeonpea intercrop combinations, Serere, second rainy season 1999.

Table 3. Cotton performance in various pigeonpea-cotton intercrop treatments, Serere, 1999.

Treatment	1st rainy season (planting date 12 May)				2nd rainy season (planting date 12 Aug)			
	Height (cm)	No. of branches	Ball weight (g)	No. of balls	Height (cm)	No. of branches	Ball weight (g)	No. of balls
ICPL 87091 (75 cm) with pest control	110	8	128.56	25.27	91	7	32.94	10.35
ICPL 87091 (75 cm) without pest control	104	10	51.80	13.14	104	7	11.48	4.78
ICPL 87091 (60 cm) with pest control	115	10	108.95	22.79	98	7	31.10	9.92
ICPL 87091 (60 cm) without pest control	116	10	45.39	10.50	104	8	9.69	4.33
Kat 60/8 (75 cm) with pest control	105	8	110.12	21.85	108	9	37.10	11.92
Kat 60/8 (75 cm) without pest control	138	13	58.76	14.23	114	8	11.29	4.73
Adong (75 cm) with pest control	106	8	85.06	17.04	-	-	-	-
Adong (75 cm) without pest control	138	12	65.42	14.06	-	-	-	-
Cotton (75 cm) with pest control	105	8	80.39	16.44	98	6	35.63	10.33
Cotton (75 cm) without pest control	114	11	48.50	11.38	89	6	31.55	9.50
Cotton (60 cm) with pest control	-	-	-	-	107	6	11.19	5.00
Cotton (60 cm) without pest control	-	-	-	-	94	4	12.96	5.00

Table 4. Gross economic returns from various pigeonpea-cotton intercrop treatments, Serere, first rainy season 1999.

Row arrangement	Variety, row spacing	Yield (kg ha^{-1})		LER			Gross returns (USh ha^{-1})		
		P	C	P	C	Total	P	C	Total
C-P	ICPL 87091, 75 cm	289	1175	0.45	0.88	1.34	144.5	293.7	438.1
C-C-P	"	177	1360	0.28	1.02	1.30	88.5	339.9	428.4
C-C-C-P	"	122	1232	0.19	0.93	1.12	60.8	308.1	368.9
C-C-P-P	"	248	1031	0.39	0.78	1.16	123.9	257.9	381.8
P-P-P-C	"	351	579	0.55	0.44	0.99	175.7	144.7	320.4
C-P	ICPL 87091, 60 cm	354	1223	0.57	0.92	1.49	176.9	305.7	482.6
C-P-P-P	"	416	454	0.67	0.34	1.01	207.9	113.4	321.3
C-C-P	Adong, 75 cm	527	983	1.97	0.74	2.71	263.7	245.8	509.6
C-C-C-P	"	327	2798	1.22	2.11	3.33	163.6	699.6	863.2
C-P	Kat 60/8, 75 cm	312	905	0.93	0.68	1.62	155.9	226.3	382.2
C-C-P	"	196	1102	0.59	0.83	1.42	98.1	275.5	373.6
C-C-C-P	"	133	1203	0.40	0.91	1.30	66.4	300.8	367.2
C-C-P-P	"	246	1069	0.74	0.80	1.54	122.9	267.2	390.1
P-P-P-C	"	701	524	2.10	0.39	2.50	350.7	131.1	481.8
Sole P	Adong	267	0	1.00		1.00	133.7	0	133.7
Sole P	ICPL 87091, 75 cm	638		1.00		1.00	318.9	0	318.9
Sole P	ICPL 87091, 60 cm	617		1.00		1.00	308.7	0	308.7
Sole P	Kat 60/8, 75 cm	333	0	1.00		1.00	166.7	0	166.7
Sole C	75 cm		1329		1.00	1.00	0	332.2	332.2

1 USD = 1500 USh

Single plant samples

Analysis of single plant samples of cotton and pigeonpea allows some preliminary conclusions to be drawn. In cotton, yields were higher during the first rainy season. Yield per single plant and number of balls were highest in the C-P-P-P treatment. For pigeonpea, the highest yield per single plant, and largest number of pods and seeds were obtained from the C-C-P and C-C-C-P treatments in both seasons. The higher the share of cotton, the higher the yield of pigeonpea. Plants in the C-C-C-P treatment were taller and more branched. Among the three varieties tested, the local variety Adong showed the highest seed weight and largest number of seeds and pods per plant. Adong also had fewer damaged seeds (24-31%) and failed pods, indicating a high degree of pest tolerance. The seeds are small and hard. The plants are much more branched and more than twice as tall as the the two improved varieties.

Conclusions

ï All intercrop treatments gave yields higher than the corresponding monocrop, as measured by LER

ï Crops planted during the first rainy season gave higher yields than crops planted during the second rains

ï A high share of the cotton component increased total yield (LER) of the intercrop

ï Yields and gross returns were highest in intercrops with the pigeonpea variety Adong

ï Increasing plant density increased pigeonpea yield but reduced cotton yield

ï Treatments with a high share of cotton produced the largest amount of biomass.

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Potential of Short- and Medium-Duration Pigeonpea as Components of a Cereal Intercrop

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Introduction

Pigeonpea is one of the most important grain legumes in Africa. The crop is commonly grown as a multi-purpose legume species intercropped or strip cropped with maize, sorghum, cowpea, greengram, and cucurbits (Le Roi 1997). Maize/pigeonpea is the dominant intercropping system, maize being the principal crop (Silim et al. 1991). The crop is grown under conditions characterized by poor soils and frequent drought. Farmers traditionally intercrop maize with pigeonpea landraces with little regard for spacing and population (Silim et al. 1995). Studies have earlier been carried out on spatial arrangement and plant population in cereal-pigeonpea intercrops, e.g. Silim et al. (1995). Information on the effect of plant population in intercropping mostly focuses on spacing between rows. However, during planting most farmers drill seeds in the furrow behind the plow, which does not allow much flexibility in inter-row spacings. Another way of studying the effect of densities in an intercrop is to alter the intra-row spacings while inter-row spacings remain constant. Rao and Willey (1983) showed that long-duration pigeonpea genotypes were ideal for intercropping with cereals. However, in Kenya, where severe terminal drought is frequent, long-duration pigeonpea varieties often fail to produce yield and researchers are looking at short- and medium-duration varieties as alternatives. As these duration groups are new in the region, there is need to determine appropriate production practices. The study reported here aimed at determining the effect of varying plant density in intercrops of maize with short- and medium-duration pigeonpea, so as to come up with a recommendation for farmer use.

Materials and Methods

Crop cultivation and management

The trial was conducted during the 1999 long rainy season under irrigation at Kenya Agricultural Research Institute (KARI) Thika Centre in Kenya, located at 1545 m altitude. The average minimum temperature recorded during the cropping season (Apr-Nov 1999) was 13.4∞C. Information on the average maximum temperature was not available due to thermometer failure at the station. The experiment was a 2x2x4 set out in a split-plot design with four replicates. The densities used were 4.2, 5.5, 8.3, and 11.1 plants/m^2 representing 40, 30, 20, and 15 cm intra-row spacings. The main treatments were (i) sole pigeonpea,

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(ii) intercrop maize/pigeonpea. Sub-plot treatments were four plant spacings within rows: (i) pigeonpea 11.1 plants/m^2, maize 4.2 plants/m^2, (ii) pigeonpea 8.3 plants/m^2, maize 5.5 plants/m^2, (iii) pigeonpea 5.5 plants/m^2, maize 8.3 plants/m^2, (iv) pigeonpea 4.2 plants/m^2, maize 11.1 plants/m^2 and two pigeonpea varieties, i.e. Kat 60/8 (medium indeterminate) and ICPL 87091 (short-duration determinate). The variety of maize used was Pioneer hybrid which is a locally improved variety adapted to highlands. In order to assess the advantages or disadvantages of growing intercropped maize versus sole maize at the four densities, four sole crops of maize were added.

The experiment was sown on 21-22 April. Diammonium phosphate (DAP 18-46-0) was applied only to maize rows at sowing time at the rate of 150 kg ha^{-1}. The inter-row spacing was 60 cm and the row proportion was 2:2 in intercrop, leaving crops at 50% of their equivalent sole-crop plant population. Paired-row spatial arrangement was selected because it allows more radiation to reach the crop grown between the cereal rows (Ali 1990). Each plot measured 5.5 x 7.8 m. Two seeds of maize and five seeds of pigeonpea were sown at the required distance. Maize was thinned to one plant per hill and pigeonpea to two plants per hill. Maize was harvested in Oct 1999 and both pigeonpea varieties in Nov 1999.

Observations and data analysis

Pigeonpea: Observations were made on phenology (days to flowering, pod set and maturity), on morphology (plant height, stem thickness, and number of primary branches at maturity), yield parameters (pods per plant and seeds per pod), and the main insect pests causing pod damage. *Maize:* Observations were made on stalk thickness and number of cobs per plant.

At maturity an area of 2.4 x 4.5 m (10.8 m^2) was harvested per plot to estimate total grain yield for both maize and the two pigeonpea varieties. The productivity of the system was assessed by calculating the land equivalent ratios (LERs) based on the method of Mead and Willey (1980):

LER = LP + LM = (Ypm/Ypp) + (Ymp/Ymm)

where Y is the yield per unit area, Ymm and Ypp the sole-crop yields of maize and pigeonpea, Ypm and Ymp the respective yields of pigeonpea and maize in intercrops.

Data were analyzed using Genstat 5. The assumptions that validate the analysis of variance were checked by plotting the residuals against the fitted values.

Results

Plant growth

The effect of plant spacing within rows on pigeonpea growth is shown in Table 1. There was no difference in phenology, height, and number of branches at maturity under sole and intercropping. Though the difference was not significant, the stems were thicker in the sole crop (5.8 mm) than in the intercrop (5.0 mm). There were significant differences among the four spacings, with increasing plant density tending to reduce the stem diameter.

Table 1. Plant growth of two pigeonpea cultivars at four plant densities, Thika KARI Station, Kenya, long rains 1999.

Density (plants/m^2)	Cultivar	Days to 50% flowering	Days to 75% maturity	Plant height (cm)	No. of branches
11.1	ICPL 87091	106	177.62	46.55	13.03
	Kat 60/8	119.37	186.62	81.80	16.25
8.3	ICPL 87091	105.62	179.75	48.57	12.92
	Kat 60/8	117.25	193.12	86.65	18.92
5.5	ICPL 87091	106	179.12	48.97	13.17
	Kat 60/8	117.87	190.12	87.95	17.10
4.2	ICPL 87091	105.62	179.12	48.37	13.60
	Kat 60/8	123.75	194.37	83.07	15.45
Intra-row spacing (IS)		ns	ns	ns	ns
Pigeonpea cultivar (PC)		***	***	***	***
IS x PC		ns	ns	ns	ns
SED (%)	IS	1.945	2.454	2.752	0.834
	PC	1.375	1.735	1.946	0.590

*significant at 5% probability level, ***significant at 0.1% probability level

Pest damage

Pod and seed damage by all pests differed significantly among cultivars, with ICPL 87091 being the most affected. Neither cropping system nor plant population had any effect on pest incidence.

Crop yield

Grain yields for maize and pigeonpea are shown in Table 2. After plotting the residuals against the fitted values, a systemic pattern was observed for pigeonpea yield values, showing violation of the assumptions validating the ANOVA. A log transformation of the data best gave rise to a random scatter graph of residuals and was then used for the analysis of variance.

Maize grain yields (per hectare) in intercrops were 72% of sole-crop yields, showing a decline due to intercropping. No differences were found in maize grain yields between the four densities. Pigeonpea grain yields in intercrops were reduced to 34% of the sole-crop values, showing a negative effect of intercropping. There was significant interaction between the two cropping systems and the plant density. Regression lines ($P<0.001$) were fitted to the pigeonpea yield means for each cropping system separately. Though decreasing pigeonpea plant density consistently reduced yields in both cropping systems, the response was higher in intercropping. The yields of Kat 60/8 and ICPL 87091 differed significantly ($P<0.001$) in both sole crop and intercrop, with ICPL 87091 producing the lowest yield.

The grain yield components of pigeonpea and maize are shown in Tables 3 and 4. In maize the intercrops had more cobs per plant and larger grain size. Increasing maize plant density reduced progressively the average grain size. In pigeonpea, intercrops had fewer pods per plant than the respective sole crops. An interaction was also found between the cropping system and the intra-row spacing. The relationship between number of pods and increasing pigeonpea plant density was positive in the intercrop and negative in the sole crop. The number of seeds per pod was not affected by any of the factors. Average seed size in both cultivars differed significantly between the two cropping systems.

Absolute pigeonpea yields were positively correlated to the number of pods ($P<0.01$) and the number of seeds (non significant) and negatively correlated to seed size ($P<0.01$). Maize grain yield was negatively correlated to both number of cobs ($P<0.05$) and seed size ($P<0.01$).

Land equivalent ratios

Most LERs were lower than 1 because of the poor pigeonpea yields in intercrops (Table 5). The highest yielding combination overall was Kat 60/8 at 5.5 plants/m^2 intercropped with maize at 8.3 plants/m^2. However, the yield advantage was very small (1%). The relative biological efficiency of the intercrops for each pigeonpea cultivar is shown in Table 5. In ICPL 87091, maximum LER was achieved when pigeonpea at 5.5 plants/m^2 was intercropped with maize at 8.3 plants/m^2, with a yield advantage of 3%. The yield proportion of maize [LERm/(LERm+LERp)] within the most efficient combination was 0.75 for each

Table 2. Grain yield (kg ha^{-1}) of two pigeonpea cultivars at four plant densities in sole crop and intercrop, Thika KARI Station, long rains 1999.

Plants/m^2	Cultivar	Sole maize	Intercrop maize	Sole pigeonpea		Intercrop pigeonpea	
				Original value	Transformed value	Original value	Transformed value
11.1	ICPL 87091	-	5068	558	6.26	215	5.35
	Kat 60/8	-	4270	1620	7.36	734	6.54
	Maize	5549	-				
8.3	ICPL 87091	-	4608	493	6.15	154	5.03
	Kat 60/8	-	4487	1592	7.27	510	6.21
	Maize	5910	-				
5.5	ICPL 87091	-	4354	368	5.89	143	4.92
	Kat 60/8	-	3602	1262	7.03	411	5.99
	Maize	5565	-				
4.2	ICPL 87091	-	2856	450	6.04	82	4.32
	Kat 60/8	-	2988	872	6.72	188	5.18
	Maize	5125	-				
Cropping system (CS)			*			***	
Intra-row spacing (IS)			ns			***	
Pigeonpea cultivar (PC)			-			***	
CS x IS			ns			*	
CS x PC, IS x PC, CSxPCxIS			ns			ns	
SED (%)	CS		266.8			0.072b	
	IS		551.6			0.131b	
	PC		-			0.092b	
	CS x IS		764.6			0.175b	

*significant at 5% probability level, ***significant at 0.1% probability level

Table 3. Grain yield components of maize at four plant densities in sole crop and intercrop, Thika KARI Station, long rains 1999.

Cropping system		Density (plants/m^2)	Cobs/plant	100-seed mass (g)
Sole crop		11.1	1.00	36.20
		8.3	1.00	35.35
		5.5	1.00	35.80
		4.2	1.00	38.45
Intercrop		11.1	1.00	37.48
		8.3	1.02	37.88
		5.5	1.05	40.55
		4.2	1.10	40.01
Cropping system (CS)			*	**
Intra-row spacing (IS)			ns	*
CS x IS			ns	ns
SED (%)	CS		0.012	0.332
	IS		0.027	1.033

*significant at 5% probability level, ***significant at 0.1% probability level

pigeonpea cultivar. Individual LERs of maize indicate a general yield advantage of intercrops over sole maize, increasing consistently with maize plant density. In pigeonpea, all individual LERs were below 0.5, showing no benefit of intercropping. Although a general decline of individual LER with decreasing plant density can be observed, total LER did not show a similar trend.

Discussion

Intercropping effect on grain yield differed between crops. Maize was positively affected; the yield advantage in the intercrops was due to bigger grain and more cobs per plant than in the respective sole crops. Both pigeonpea varieties showed no yield advantage in intercrops due to a reduction in the number of pods per plant. Willey et al. (1981) reported that in the traditional sorghum/pigeonpea cropping system, high sorghum yields were maintained but pigeonpea yield was adversely affected; however if both species were grown using improved genotypes sown at full sole-crop population, the pigeonpea yield could be considerably increased without greatly lowering the contribution of the cereal (Reddy and Willey 1985). In this study, maize seems to have competed vigorously with pigeonpea.

The low temperatures experienced during the cropping season may explain the generally poor performance of the normally high-yielding ICPL 87091 and Kat 60/8. The negative influence of cool weather on performances of short- and medium-duration pigeonpea varieties has been reported by Silim et al. (1995) in a study of the Kenyan transect, which is located near the Equator (1∝d 5í to 4∝25í S) with altitudes varying from to 0 to over 1800 m. The lack of vigor in pigeonpea would have then favoured maize competitiveness in the intercrops. Short-duration varieties are also known to respond poorly to intercropping with cereals compared to medium- and long-duration ones (Omanga et al. 1992). However, in this

Table 4. Grain yield components of two pigeonpea cultivars at four plant densities in sole crop and intercrop, Thika KARI Station, long rains 1999.

Density (plants/m²)	Cultivar	Pods/plant		Seeds/pod		100-seed mass (g)	
		Sole crop	Intercrop	Sole crop	Intercrop	Sole crop	Intercrop
11.1	ICPL 87091	35.6	21.7	5.3	5.3	13.78	13.5
	Kat 60/8	44.3	44.9	5	5.6	11.62	12.35
8.3	ICPL 87091	39.5	20.6	5	5.4	13.12	13.4
	Kat 60/8	56.6	45.6	5.3	5.3	11.7	12.8
5.5	ICPL 87091	31.6	23.6	5.05	5	13.25	13.37
	Kat 60/8	70.4	42.8	5.6	5.25	12.35	12.67
4.2	ICPL 87091	45.4	18.6	5.25	5.05	13.45	13.47
	Kat 60/8	83.4	33.3	4.95	5	12.1	12.85
Cropping system (CS)		*		ns		ns	
Intra-row spacing (IS)		ns		ns		ns	
Pigeonpea cultivar (PC)		***		ns		***	
CS x IS		**		ns		ns	
CS x PC		ns		ns		**	
ISxPC, CSxPCxIS		ns		ns		ns	
SED (%)	CS	5.46		0.054		0.135	
	IS	4.20		0.169		0.163	
	PC	2.97		0.120		0.115	
	CS x IS	7.50		0.215		0.241	
	CS x PC	6.21		0.132		0.178	

*significant at 5% probability level, **significant at 1% probability level, ***significant at 0.1% probability level

Table 5. LER of two pigeonpea cultivars in intercrop with maize, Thika KARI Station, long rains 1999.

Pigeonpea cultivar	Density (plants/m^2)		LER using specific best sole genotype				LER using best sole genotype		
	Pigeonpea	Maize	Pigeonpea[1]	Maize[3]	Total	Yield proportion of maize[4]	Pigeonpea[2]	Maize[3]	Total
ICPL 87091	11.1	4.2	0.39	0.48	0.87	0.55	0.13	0.48	0.61
	8.3	5.5	0.28	0.74	1.01	0.73	0.09	0.74	0.83
	5.5	8.3	0.26	0.78	1.03	0.75	0.09	0.78	0.87
	4.2	11.1	0.15	0.85	1.00	0.85	0.05	0.86	0.91
Kat 60/8	11.1	4.2	0.45	0.51	0.96	0.53	0.45	0.51	0.96
	8.3	5.5	0.32	0.61	0.92	0.66	0.32	0.61	0.92
	5.5	8.3	0.25	0.76	1.01	0.75	0.25	0.76	1.01
	4.2	11.1	0.12	0.72	0.84	0.86	0.12	0.72	0.84

1. Sole ICPL 87091 at 11.1 plants/m^2 (558 kg ha^{-1}). Sole Kat 60/8 at 11.1 plants/m^2 (1620 kg ha^{-1})
2. Sole Kat 60/8 at 11.1 plants/m^2 (1620 kg ha^{-1})
3. Sole maize at 8.3 plants/m^2 (5910 kg ha^{-1})
4. Yield proportion of maize = LERmaize/(LERmaize+LERpigeonpea)

trial no interaction was observed between the cropping system and the cultivars used; despite differences in phenology (20 days), both pigeonpea cultivars started flowering when maize had not completed its growth cycle so that at a period of high nutrient demand, the two varieties were subjected to similar competition from maize. Yield loss was greater in ICPL 87091 than in Kat 60/8 probably because of higher pest infestation.

The positive relationship between pigeonpea yields and increasing plant density suggests a better use of resources at narrower spacings. Natarajan and Willey (1980) observed that in sorghum/pigeonpea intercropping, an increase in pigeonpea population improved light interception and productivity. However, high plant density might not be as suitable in environments subject to higher water deficit, due to increased competition for soil moisture. Rees (1986) found that sorghum/cowpea intercrops were disadvantageous at medium densities in dry conditions but beneficial in moist conditions.

The results also show that decreasing pigeonpea plant density reduced pigeonpea yields more rapidly in intercrops than in sole crops, probably as a result of increasing competition from maize. In maize the negative relationship between yield and seed size indicates that though maize plants set bigger grain at wide spacings, this does not compensate for the low plant population.

LER tended to be lowest when there was an imbalance in the densities of the two crops, suggesting that intercropping should be beneficial when the two species are sown at equivalent densities. However, the total LERs were generally low, either less than or slightly greater than 1, suggesting that the different systems studied show little potential.

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Discussions ñ Crop Management

Short-duration pigeonpea is not suitable for intercropping. It is best sole-cropped, but requires attention to insect pest management. Medium- and long-duration varieties are suitable for intercrops (and have traditionally been intercropped with cereals) because the initial growth is slow, minimizing competition with maize.

Spacing and plant population

A number of studies have been conducted on optimal cropping systems and intercrop combinations. The advantages of cereal-pigeonpea intercropping are unquestionable, but experiments on spacing, row patterns, plant densities etc have yet to yield precise recommendations. These recommendations are likely to be highly location-specific, particularly since pigeonpea is sensitive to changes in temperature and photoperiod.

In general, smallholders tend to use lower-than-desirable plant populations. Spacing as low as 30 cm between rows has been successfully tried under irrigation, but farmers continue to use spacings of 70-80 cm or more, which is wasteful of resources. Optimal spacing also depends on availability of soil moisture. Under dry conditions pigeonpea plants do not grow large and therefore higher densities are more efficient. In wet environments, when plant growth is more luxuriant, low density is more suitable.