BEYOND DROUGHT TOLERANT MAIZE: STUDY OF ADDITIONAL PRIORITIES IN MAIZE

Report to Generation Challenge Program

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SUMMARY

In recognition of the complexity of factors which affect the improvement of maize yields and productivity in different farming systems throughout the developing world, panels of crop research and extension experts assessed the relative importance of abiotic, biotic, crop management and socioeconomic constraints in a dozen major maize production systems in developing regions which are characterized by severe poverty, as indicated by child stunting. Maize plays an important role in household nutrition and poverty reduction in each of these farming systems.

Drought has been identified as a major priority for maize improvement programs in international agricultural research, and especially in Africa and Asia. However, it is generally accepted that a variety of other "secondary" constraints limit maize productivity in good seasons, as well as in drought years. The well known CABI data base contains comprehensive but rather general information on losses and distribution. CIMMYT has conducted a number of studies with valuable information on constraints, and CIMMYT scientists have scored the severity of maize production constraints. However, few of these studies provide sufficient contextual information to extrapolate the results across zones, seasons and years.

In these circumstances, this study organized the systematic tapping of the tacit knowledge of experienced research and development practitioners to provide valuable information on the relative importance of different production constraints and traits. The results of this study can be a checklist and guide to those involved in maize breeding and crop systems research and development by prioritizing key traits for the improvement in each of the systems.

INTRODUCTION

From humble origins in Mexico, maize has colonized most tropical, sub-tropical and temperate agricultural regions of the world, and produces more than 700 million tons of grain from about 143 million ha (FAO 2007). Of this about 325 million tons (with an annual growth rate of more then 2 %) is produced in developing regions from about 98 million ha of irrigated and rainfed crop land. Even though a large and growing proportion is used for livestock feed, maize underpins the household and national food security in many areas – for example maize provides an average of 1105 kcal/cap/day in Malawi. While average maize yield in the US, Spain, Italy and Chile exceeds 9 t/ha, more than one quarter of countries in continental Africa average less than 1 t/ha and many substantial maize producing countries in the developing world average less than 2 t/ha, e.g., India, Kenya, Tanzania and Zambia. Even within developing countries, there are large gaps between potential yields, whether defined from a biophysical or a socioeconomic perspective, and farmers' yields (Pingali and Pandey 2001). The gaps are caused by a variety of constraints: abiotic, e.g., drought; biotic, e.g., stem borer; management, e.g., tillage; and socioeconomic, e.g., market access. Notwithstanding the diversity of production constraints, low maize yields of smallholders can be substantially increased by the availability of the improved maize germplasm with traits which address specific causes of yield loss.

Globally, the level of public resources allocated to agricultural research is diminishing, while private sector research which produces appropriable products and services is increasing: however, in both cases major research efforts are concentrated in relatively few countries (Pardey et al 2006). Whilst returns to cereal research in the past four decades have been exceptionally high (Anderson et al 1988; Alston et al 2000; Evenson and Gollin 2003), the decline of public resources for agricultural research underlines the importance of systematical prioritization of research objectives and maize improvement traits.

There are limitations associated with currently available published crop loss assessment studies. The assessments are often highly season and location specific, and frequently lack contextual detail. On another level, the CABI data base covers a large number of pests and diseases yet the information on distribution and losses is relatively general. Nevertheless, there are generally implicit priorities and assumptions among scientists working with the genetic improvement of a particular crop, and priorities can be deduced from breeding objectives and resource allocations to the identification of traits and the development of advanced lines and cultivars with specific traits. Notwithstanding the scarcity of authoritative studies, there are, however, a very large number of production constraints which potentially cause significant losses that could be reduced or eliminated through improved maize germplasm. Systematic priority setting among these constraints has been frustrated by the scarcity of systematic crop loss assessments.

The frame of reference for this study is the FAO/World Bank farming systems classification of 72 farming systems across six regions of the world (see Dixon et al., 2001; see www.fao.org/farmingsystems/). In this study the farming systems were characterized using broad natural resource and institutional characteristics, with a particular emphasis on examining the potential of various development pathways for the achievement of the first Millennium Development Goal of the halving of poverty by 2015. Of these 72 systems, the Generation Challenge Program (GCP) identified 15 key systems which are characterized by extensive poverty, indicated by the prevalence of child stunting, and in which key GCP crops are widely grown (Hyman et al unpub). Anecdotal information suggests substantial crop losses from various stresses which reduces the availability of food to the poor. Brief descriptions of the twelve selected maize growing farming systems are given in Annex 2 together with maps of their distribution.

METHODOLOGY

The essence of the study methodology was the selection of relevant farming systems, the construction of a comprehensive list of production constraints, the identification of expert panels for each farming system, the identification of the ten most critical production constraints, and the assessment of the average crop losses associated with these constraints (see TOR in Annex 1).

As noted above, an earlier study for GCP had identified fifteen farming systems with GCP mandate crops and extensive child stunting. In a few of these systems maize was of relatively lower importance, e.g., Rainfed Mixed Farming System in India, thereby focusing on 12 farming systems characterized by substantial poverty and significant areas of maize. The descriptions and distribution of these systems appear in Annex 2. These farming systems were:

Sub-Saharan Africa Farming Systems:
- Maize Mixed,
- Cereal Root Crop Mixed,
- Root Crop,
- Agropastoral Millet Sorghum, and
- Highland Temperate Mixed;

South and East Asian Farming Systems:
- Rice (South Asia),
- Lowland Rice (East Asia),
- Rice Wheat,
- Highland Mixed,
- Upland Intensive Mixed, and
- Temperate Mixed;

Latin American Farming System:
- Maize-Beans.

Second, one comprehensive, initial, list of possible production constraints which could apply to any of the farming systems was drawn up through consultations with CIMMYT maize researchers. The production constraints included abiotic (e.g., drought, soil fertility), biotic (e.g., stem borer, wild animals), crop management (e.g., tillage, plant population) and socioeconomic (e.g., market access, labour availability). The methodology included the presentation of this list to the expert panels for the addition of any additional relevant constraints.

Third, CIMMYT maize researchers assisted with the identification of potential panelists who were presumed to have personal experience with maize research, extension or development in one or more of the above farming systems (see also below). Panelists were drawn from a range of disciplines recognizing that researchers, extension workers and NGOs may well have different experience and views on production constraints even in the same system... In practice the initial list of panelists had to be supplemented through further contacts in the regions and with public sector, NGO and private sector maize breeders, agronomists, social scientists and extension specialists.

Fourth, a rapid, interactive, procedure was employed for capturing the knowledge and experience of expert panels for the assessment and prioritization of recognizable constraints to maize production within each farming system. The method of interaction adopted was a modified version of the Delphi technique (see Annex 3 for a full description and relevant references) originally developed by the Rand Corporation to support decision making on subjects characterized by a high degree of uncertainty. In this modified version of the Delphi technique, expert panels were polled in four rounds. In the second, third and fourth rounds experts received the panel results of the previous round for revision and adjustment, as well as some additional questions. The explanations and questionnaires were drafted in English and translated to Spanish for Latin America, after ascertaining that a majority of potential panelists for the selected systems in Asia and Africa understood English.

In the initial round the potential panelists (initially 227 who responded to the initial round, but ultimately more than 390 were contacted in Asia, Africa and Latin America) were provided with descriptions and distribution maps of 14 major farming systems (see Annex 2 for maps and descriptions) and were asked to assess their level of familiarity, i.e., their knowledge and experience, of each of the selected farming systems. For one or more systems with which they were most familiar, they were asked to indicate the key maize production constraints for the system, augmenting the initial constraints list as appropriate. In this way a master list of constraints was established. This round also ensured that experts retained on panels had knowledge and experience related to one or more of the systems under investigation; and ensured that each panel comprised a mix of breeders, agronomists, social scientists and extension specialists drawn from a variety of international, regional and national stakeholders. A considerable number of the initial experts contacted did not have personal knowledge of the particular 14 maize farming systems under investigation or were too busy to complete the questionnaires, with the result that quite a number of additional, substitute, panel members were identified, with some delay, targeting 15 members for each system panel. Average panel size was 17: some had more than 20 members; one (for Highland Mixed Farming Systems in South Asia) had only 12 panelists.

In a second round, panelists were asked to identify and rank the top ten constraints, across all the four categories of constraints, for each system with which they were familiar. To clarify the relative importance of constraint groups, panelists were asked to estimate the relative importance of abiotic, biotic, crop management and socioeconomic constraints. They were also asked to estimate the reduction of yield (in kg/ha) due to each of the top ten constraint. These results were summarized for each farming system.

In the third round, these summaries were shared with the panelists who were asked to review, reconsider and revise as appropriate the ranking of the top ten constraints and the estimated yield loss. As an additional theme, panelists were asked to speculate on the potential impact of current dynamics and future trends in the farming system.

In the fourth round, panelists were asked to consider the summarized results from earlier rounds, notably: the relative importance of abiotic, biotic, socioeconomic and crop management constraints on maize productivity; and the rankings and the estimated reductions in yield due to these constraints under small farm conditions. In this process the responses had converged to a substantial degree. Finally, panelists were asked to estimate the proportion of fields and the proportion of years with serious yield losses from each of the top ten constraints.

RESULTS

Existing evidence

Production constraints can be considered from the viewpoint of yield gaps, with an analysis of the differences in yields as constraints are progressively relaxed. Many types of yields can be considered, ranging from the biophysical yield potential, calculated theoretically from solar radiation and temperature for a particular germplasm, to drought- and pest-afflicted yields of small holders. Four examples of useful intermediate yields in any given farming systems are: economic yield potential with all inputs and management provided at optimal levels in a risk free environment; yields obtainable under best management on research stations; yields achieved by best farmers in a given farming system; and yields of resource-poor smallholders. Constraints to increasing crop production can be grouped into four broad categories: abiotic (e.g., soil and climatic), biotic (e.g., pests, weeds and diseases), crop management (e.g., low plant population, late planting) or socio-economic (e.g., shortage of labour, lack of market access, pricing policies, terms of trade). Some of these constraints are periodic, e.g., drought and many biotic stresses, whereas others tend to be relatively constant in the short term, e.g., low soil nitrogen. Some proportion of constraints may be avoidable through management action, e.g., weed pressure. The relative importance of these constraints varies widely across different farming systems. Some constraints vary in intensity between fields and farms; and others vary in severity between seasons, e.g., drought. The resistance or tolerance to these constraints may be regarded as potentially important for the focus of future breeding and management strategies in marginal or drought prone areas where poverty is currently widespread.

A summary of the identified maize production constraints (abiotic, biotic, socioeconomic and crop management), approximate maize areas and estimated percentage yield depression due to these constraints under small farm conditions for each farming system are presented in Annex 4, Table A 4.1. Note that the collections of constraints in this table are not placed in any priority order.

It is important to distinguish the relationship of different types of constraints to observed farmers yields. Those constraints which are more-or-less permanent in nature and for which no practical feasible mitigation actions exist, e.g. low soil N in Africa where inorganic fertilizers are not available, tend to depress yields to the actual observed levels. In some cases the yield depression may be large even several times existing farmer yields. A second type of constraint, e.g. weeds, may be more-or-less permanent but feasible management options exist for the alleviation of the constraint, but the options may not be economic. These also depress yields. The third category, periodic constraints, e.g. drought, stem borer, reduce yields in some years.

The magnitude of the impact of the constraint accounts for the difference in yields between stress, e.g. drought, years and non-stress years, i.e., good seasons. Many of the constraints have an associated frequency of impacts, by proportion of years, e.g., drought, or by proportion of fields affected, e.g. low soil N, or both, e.g., army worms. It is important to take the relative frequency into account when calculating average yield reduction associated with a constraint.

The CABI data base is one of the most comprehensive source of information: yet, the distribution of pests and diseases and systematically updated and yield losses are often reported in general terms. The incidence of abiotic constraints can be estimated from climatic data or from environmental constraints data bases, e.g., from FAO. However, data on yield losses are sparse and often contentious. The Harvest Choice Project (BMGF, IFPRI, University of Minnesota) has assembled more than 2000 papers on food crop yield losses: however, only a small proportion has sufficient contextual detail to extrapolate the yield losses to wider regions or systems (Beddow *pers comm*.). There have been a number of CIMMYT studies and papers on the relative importance of secondary traits for maize (see, for example, Bänziger and Lafitte 1997; Bolaños and Edmeades1996). These are of particular interest in relation to selection for drought tolerance, but also in relation to other important abiotic and biotic constraints. A series of Asian maize production systems, constraints and research priority studies ranked production constraints in terms of efficiency and poverty reduction. These studies covered Nepal (Paudyal 2001), Indonesia (Swastika et al 2004), Vietnam (Ha et al 2004), Thailand (Ekasingh et al 2004), Philippines (Gerpacio et al 2004), India (Joshi et al 2005) and China (Meng et al 2006). Other CIMMYT studies have examined the impacts of Striga and stemborer in Africa. The tacit knowledge of scientists working with crop improvement and management should not be underestimated. Moreover, priorities can be deduced from breeding objectives and resource allocations to trait identification or the development of advanced lines and cultivars with specific traits. In the case of maize, CIMMYT pathologists and breeders have scored the severity of major pests and diseases and abiotic stresses (CIMMYT unpub) in different mega-environments but these have not been translated into yield, food or livelihood losses. There are, nevertheless, a very large number of production constraints which potentially cause significant losses that could be reduced or eliminated through improved maize germplasm. Overall, however, systematic priority setting has been frustrated by the scarcity of objective crop loss assessments and the spatial, system and seasonal specificity of losses.

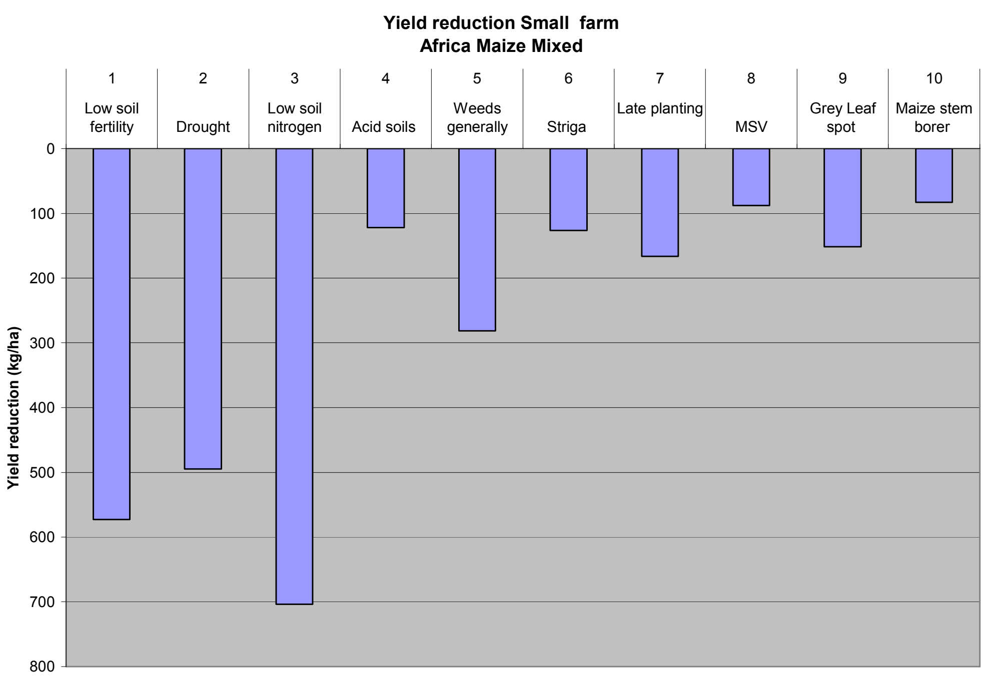
It is important to bear in mind that the information is primarily qualitative, based on the practical knowledge of an experienced group of panelists. The results may be seen as complementary to existing databases and empirical data. They provide indications of potentials avoidance of losses and in this way are useful inputs to decisions on key future breeding and improvement strategies. This kind of information and data are highly unusual as it relies, not on empirical data from field trials and observations, but the years of experience and judgments of a range of scientists, extensionists and professional field staff.

Some discussion of the responses on the systems follows:

African systems.

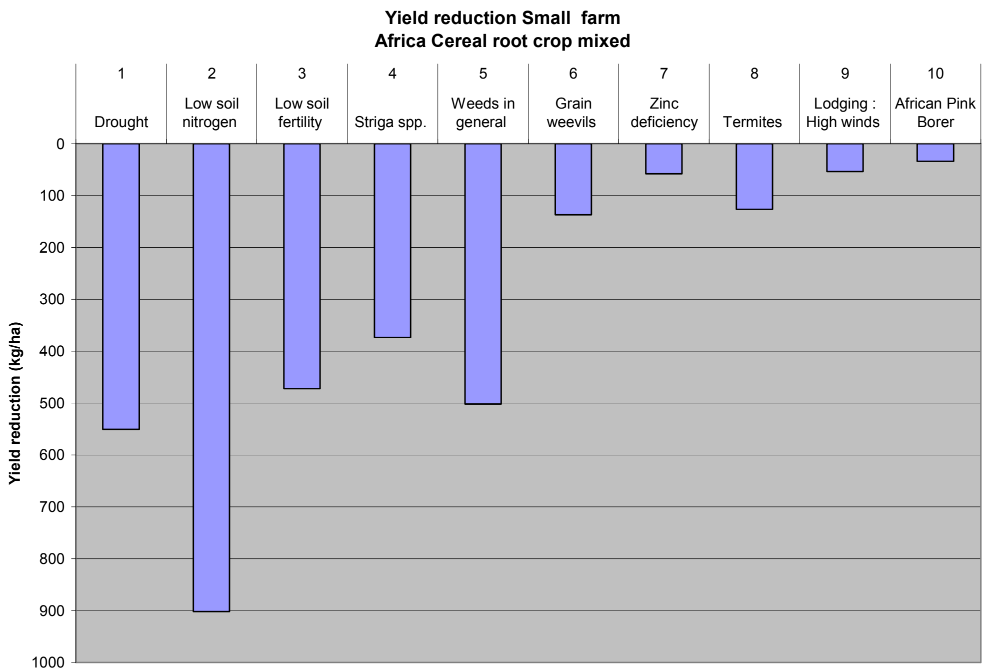
Maize mixed farming system (MM). The most significant system area (approximately 6.3 M ha of maize, estimated on the basis of recent IFPRI crop area surfaces) is found here. Potential yields are highly variable between 5 and 10 t/ha, and typical farm yields are in the range 1-3 t/ha. Low soil fertility, acid soils, heat stress and low nitrogen are common. The biotic pest complex is substantial, markets for maize are poorly developed and prices of maize are severe constraints. Seed supply problems are frequent. Common crop management constraints include late planting, low plant populations, poor weed management and large post harvest losses.

Low soil fertility, drought and low soil nitrogen are the top constraints. We can assume, of course, that low soil fertility and low soil nitrogen are usually strongly associated. Abiotic factors appear to have a key role in this system in contributing to potential crop losses, but both pests and diseases have significant, but lower, effects. In this system, late planting is prevalent. The possible solutions to this problem are connected with crop management, and could involve even shorter term maturing varieties of maize.



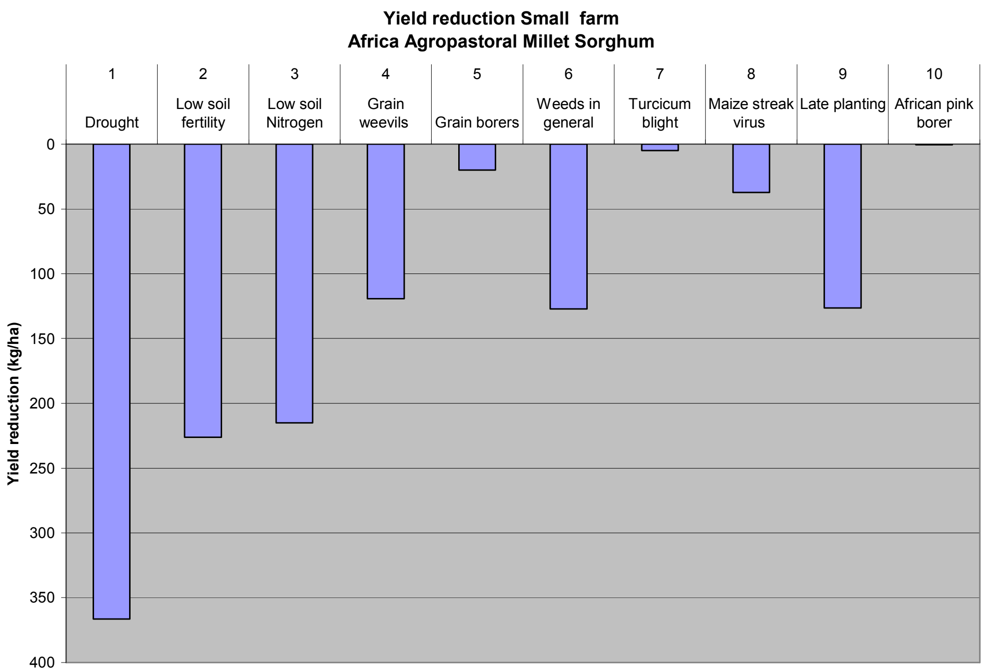
Cereal root crop mixed farming system (CRCM). This system's characteristic constraints are low soil fertility, leaf rusts, grey leaf spot, poor prices of grain and a weak market structure for maize. Both early and late planting are named as constraints in relation to crop management and harvesting difficulties also affect maize productivity.

Poor soil fertility and nitrogen are prominent constraints, but weeds and *Striga spp.* also appear as important. Abiotic constraints are again the principal factors affecting yields of the crop on small farms. Zinc deficiency appears here, as well as storms and high winds.



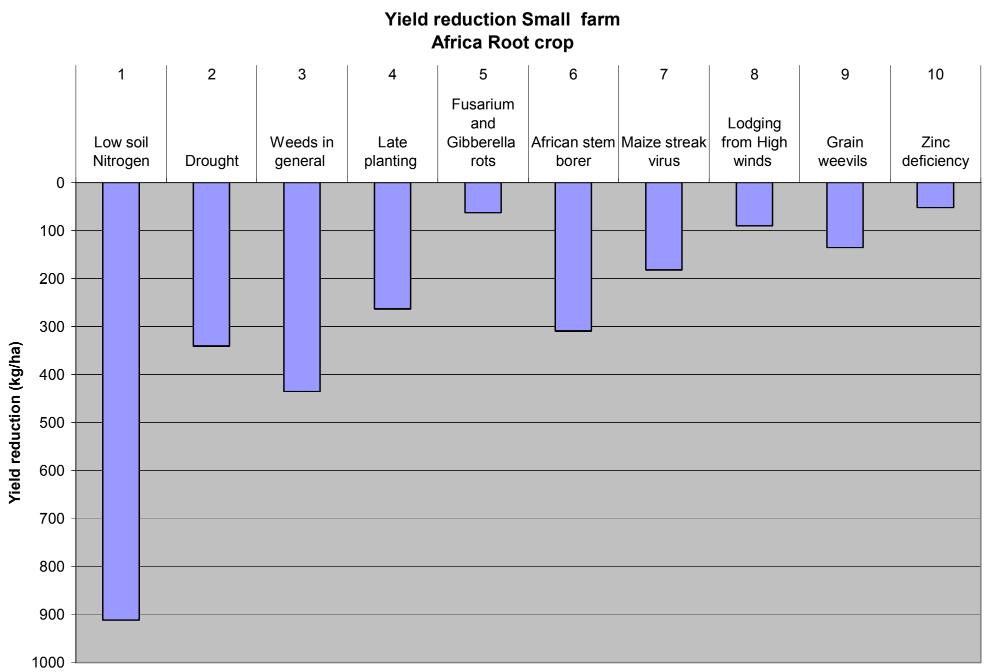
Agropastoral millet sorghum farming system (APMS). This is the driest of all the African systems and as might be expected, drought, soil acidity, low soil fertility and low N are serious constraints. There are fewer identified pests than in several other systems, but stem borer and *Chilo partellus* are frequently cited. Maize streak virus is also a common problem. Of the socioeconomic problems, poor access both inputs and to markets are considered important. Late planting, low fertilizer use and late weeding are common problems. In this system, competition with livestock is cited as a problem. This system has the lowest average on farm yields of any African system.

Biotic constraints play a more prominent role, although abiotic stresses are still the most important. The storage of grain is an important issue within these systems. In many years, grain crops may fail due to drought so older systems had developed long term grain storage facilities at local level and millets and sorghums were selected for their ability to survive in store for many years. Grain pests are a major constraint for maize and this is still an area where further progress can be made.



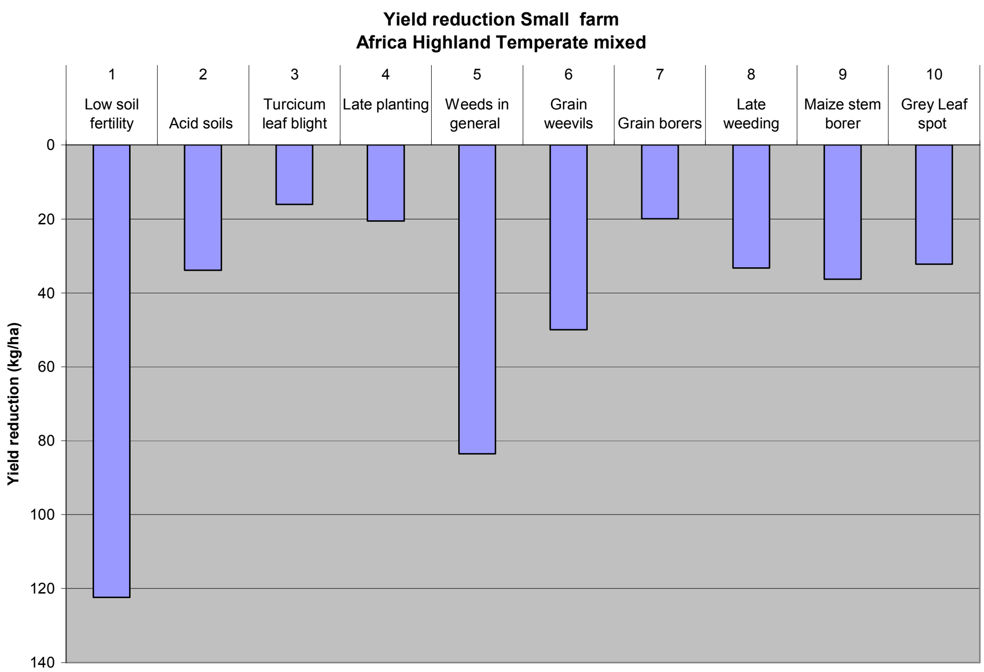
Root crop farming system (RC). The same top set of abiotic constraints is present here, but in addition, heat stress can be problematic. An even greater range of biotic constraints are present, including *Striga spp.*, blights, cob rots and weevils in storage. Market constraints of many kinds are cited as important here. Low plant populations and poor weed management are regarded as important constraints. Zinc deficiency is cited as commonly found in this system.

A few abiotic constraints, notably drought, nitrogen, zinc deficiency and high winds play important roles in depressing yields here, but there is also a complex of pests that affect the growing plant and grain in store. Weeds are also cited as having a key negative effect. Weeds are an example of a constraint which is connected to cultural and management issues, notably labour availability at critical periods in the growth cycle.



Highland temperate mixed farming system (HTM). This has the lowest area of maize in the set of African systems (1.0M ha.) Among abiotic constraints found here, low soil fertility stands out. Leaf rust, *Fusarium spp*. and *Turcicum* are some of the important diseases. The absence of a market for grain is considered important and high input prices mean that poverty is common. Late planting and late harvesting is a feature of this system as the crop is in the ground for many months due to low temperatures and a long growing season. Despite these constraints, this system has the highest potential on farm yields (1.0-3.5 t/ha) of the African systems.

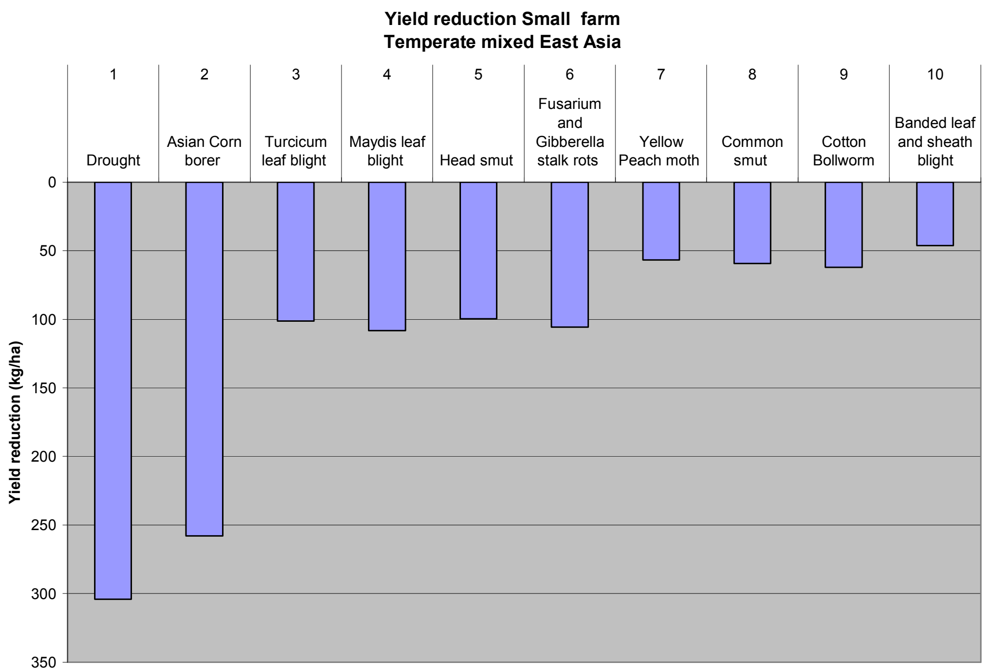
This is the only system (of the 13) in which drought does not feature in the top ten key constraints. After low soil fertility, acid soils are considered to be the second constraint, and late planting again appears as a major factor.



Asian systems. Given the range of environments within which maize is grown, it is not surprising that there is greater variability (than in the African context) in the range of key constraints in these systems. Drought is still named as important in all systems. Estimated yield levels on small farms are higher than in the African cases and sometimes similar to research station yields.

Temperate Mixed (TM) (EA)[1]. This system represents the most significant area of maize; estimated to be about 10.2 M ha. Apart from the common abiotic constraints, high winds and hail storms are found here. Corn borers, earworms, aphids, rusts, maydis, *Turcicum* and stalk rot are also important here. Price support policies, poor market infrastructure, late input availability and access to inputs are common socioeconomic constraints. Key crop management problems are the lack of minimum tillage techniques, late sowing, poor weed and nutrient management.

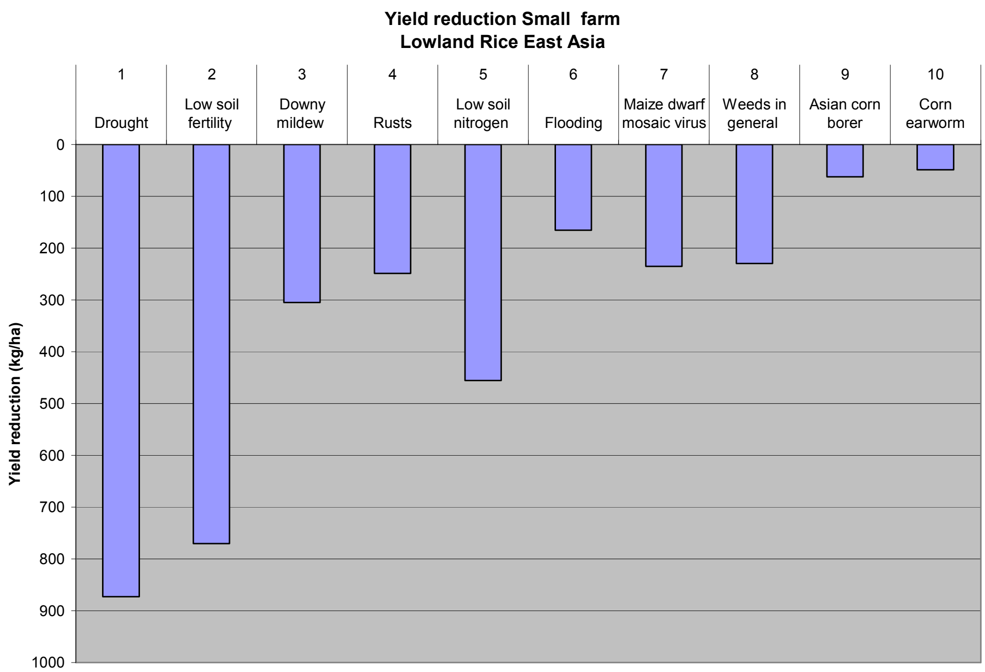
Apart from drought as the top constraint, this system seems to be affected by a few pests (borers, moths and bollworm) and a wide range of blights, smuts and rots that affect the stems, leaves and ears of the crop. Most prominent are Turcicum and Maydis leaf blights.



[1] EA is East Asia; SA is South Asia.

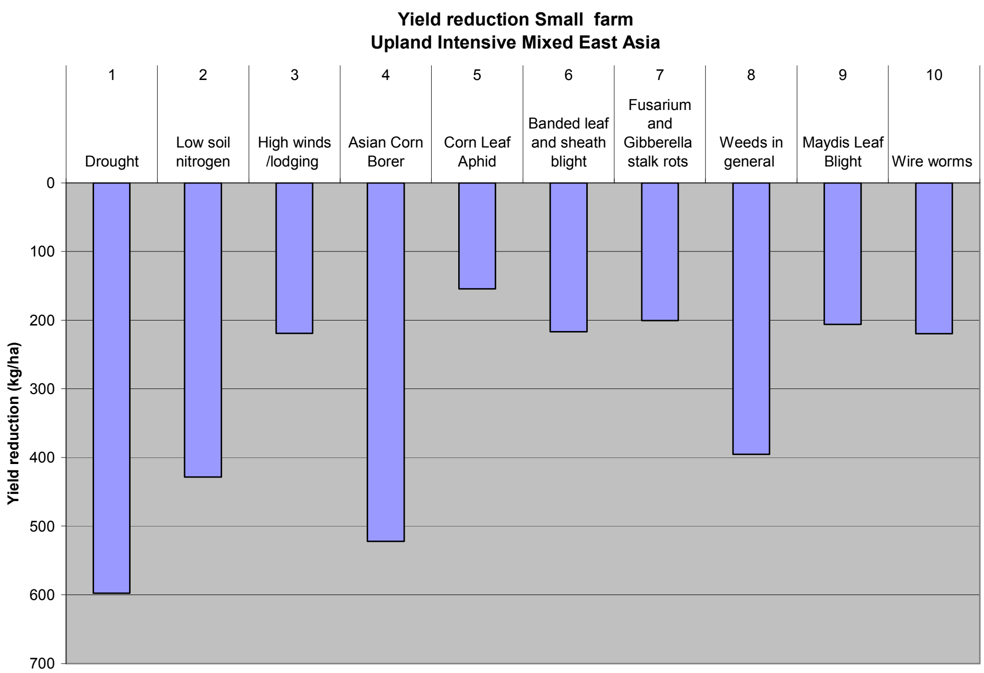
Lowland Rice (EA). Stem borers, cut worms, army worms and various rots, rusts, blast, blights and viruses are common problems. This system has 8.5 M ha of maize, the second largest area of the Asian systems.

Although drought and low fertility are cited as very significant constraints, a number of diseases (Mildew, rusts and mosaic virus) are also considered to be important here. In this system, flooding appears as a key constraint, as it does in the other two rice-based systems. Resistance to flooding, either temporary or seasonal, must be a major goal if maize is to have a future in any of these systems. Borers are also found to be within the top ten constraints here.



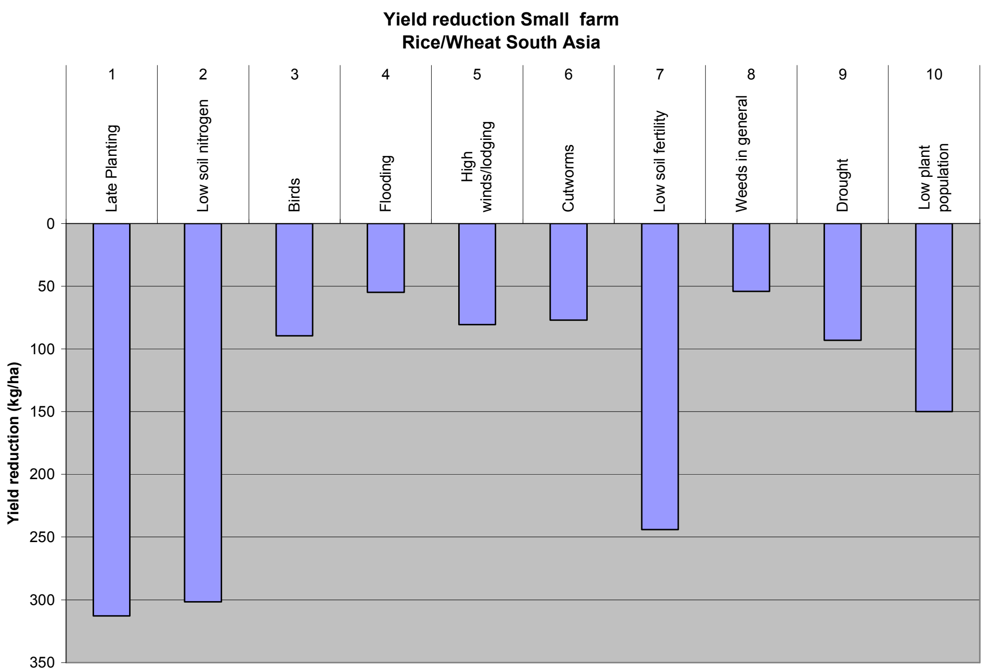
Upland Intensive Mixed (EA). Key constraints are low soil nitrogen and soil fertility and acidity. Many biotic constraints are important including, leaf rust, maize streak virus, grey leaf spot, mildews, blights, rots, aphids and white grubs are all important constraints here. Access to inputs and market failure is common as are seed shortages and high production costs. There appears to be a failure in the transfer of technical knowledge that is important and this results in many flaws in crop management techniques.

Although drought and low soil nitrogen are the top constraints, high winds and lodging are also important. The flexible stem maize varieties of Nepal (bred for hail resistance) might have a role in other systems where the same problem has been reported (e.g. R-W). Both pests (corn borer, leaf aphids, and wireworms) and diseases (Banded leaf and sheath blight, Fusarium and Gibberella stalk rots and Maydis Leaf blight) are featured here as constraints. The unique feature about the responses to questions about this system was that more pests and diseases were named by panelists as important constraints than with any other system.



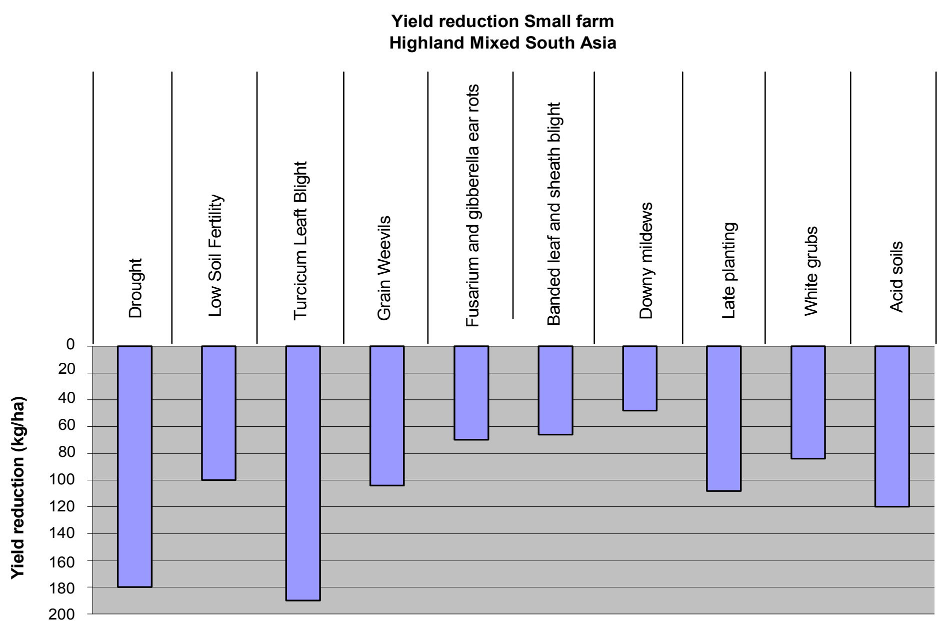
Rice-Wheat (SA). In this system, saline and acid soils and low fertility are important. Stem borers, birds and rodents, mildews, rusts and stem rots are typical constraints. Technical knowledge, seed availability and cost and high production costs are key constraints here. Poor water, weeds and crop management are also significant.

This is one of the two systems in which late planting is named as the top constraint. The timing of these operations is clearly problematic and this presents an opportunity to develop a maize variety that can occupy this niche. Once again, flooding is a prominent constraint, together with high winds, making this one of the most challenging environments in which to cultivate maize. In this system, together with other rice based systems and the Latin American system, birds feature as important constraints. Drought is still mentioned here, but as a lesser constraint.



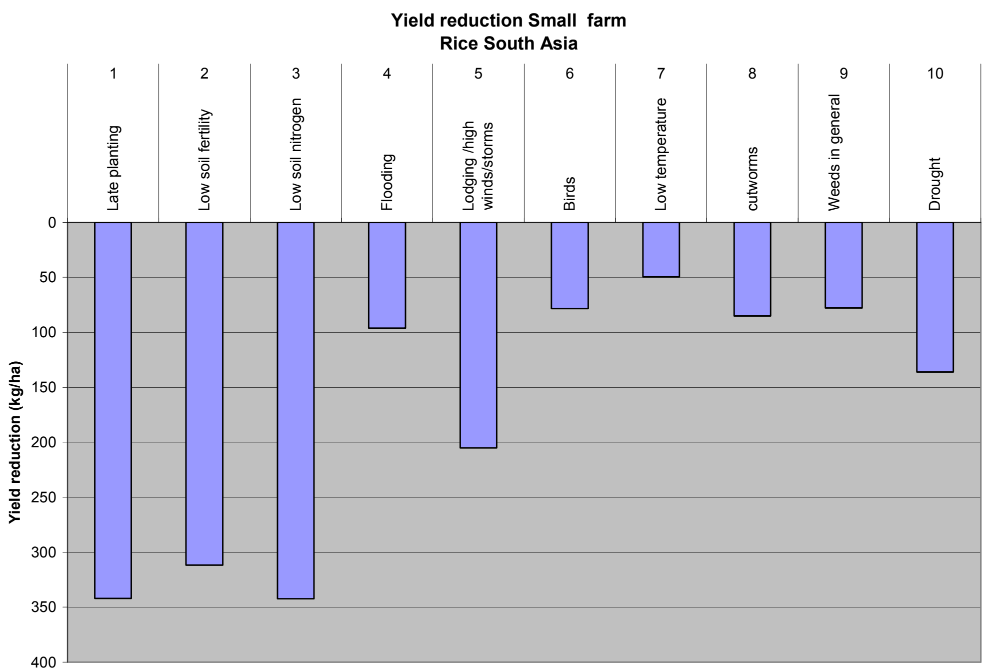
Highland Mixed (SA). For the highland systems, low soil fertility and low temperatures are significant. Stem borers, downy mildew, rusts and weed competition are all major constraints. There are many specific socioeconomic constraints that are recognized here, including, access to inputs (seed) and credit, market access, technological knowledge, high production costs and specific consumer preferences. Weed management is cited and the most important crop management constraint.

This system has a similar set of constraints to the rainfed mixed system of South Asia with drought and low soil fertility being the top ones. However, Turcicum Leaf blight, Fusarium and Gibberella ear rots, Banded leaf and sheath blights and Downy mildews feature strongly. Grain weevils, are significant constraints and white grubs are less important. Late planting again features in this set of top constraints.



Rice (SA). In this rice based system, maize generally plays a minor role and the area of maize is estimated to be 0.17M ha. Low soil fertility, waterlogging, acidity and low nitrogen are key abiotic constraints. Cut worms, stem borers, army worms, birds and rodents at planting, downy mildew, stem rots and rusts, blasts, blights and viruses are the major biotic constraints. Access to inputs and credit, market access and knowledge about technology, seed shortages and high production costs constitute the main socioeconomic constraints. Weeds, poor fertility management, low plant population and continuous cropping are the main crop management constraints. It was decided that as this system occupied a very low area, it would be dropped from the subsequent discussions in this study. The Dry Rainfed Asian system had also been dropped earlier.

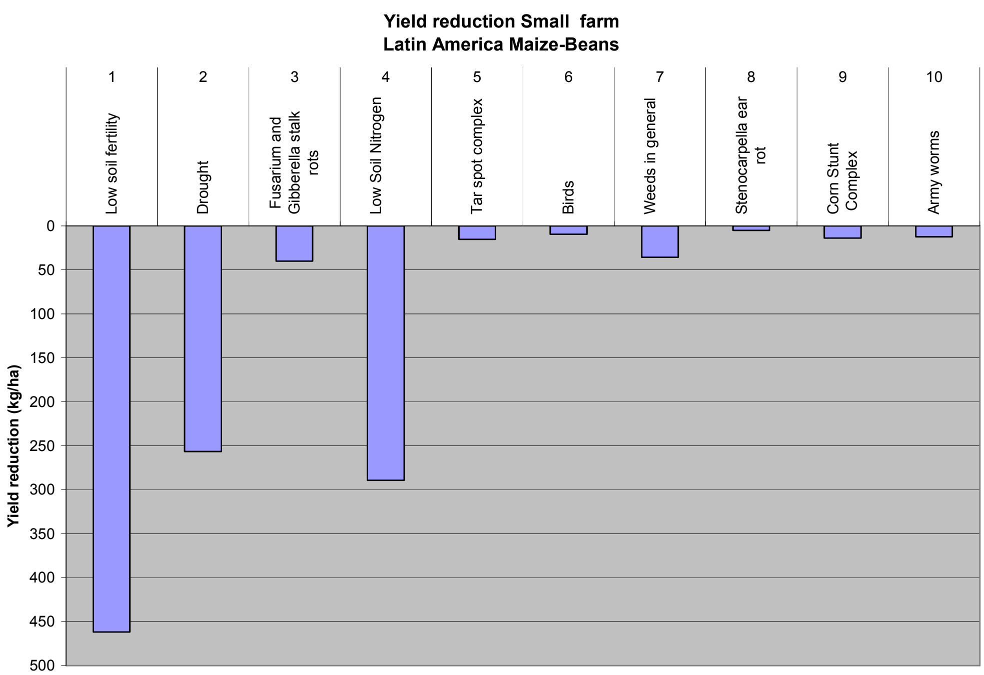
This is the other system in which late planting is named as the top constraint and is also followed by low soil nitrogen. Birds play an important role in reducing yields in this system, and storm damage is also critical. This is the only system where low temperatures are found one of the key constraints, Flooding is again important and weed problems are also found to affect yields negatively. Drought is the lowest of the top ten constraints.



Latin America

Maize–Beans (MB). In the widespread (4.4 M ha.) maize –bean system of Central America, Low soil fertility, acid soils and high winds and storms and a very wide range of biotic constraints are important in this system. These include many fungal diseases of the stem, leaf and ear and borers, armyworms and weevils in storage. Pricing policies, poor market infrastructure, late input availability and access to suitable new crop varieties are all considered key constraints. Lack of minimum tillage and poor standards of weed, crop and nutrient management are key management constraints.

Low soil nitrogen and fertility are the top constraints in this system. Weeds featured very high in the list of constraints and Stenocarpella ear rot appeared uniquely. Drought was a medium priority constraint, but many different rots were named as important (Fusarium and Gibberella stalk and ear rots and Tar spot complex).Grain weevils and bird were also named as important constraints.



There were many variations in the estimates of yield decrease due to specific constraints. This is perhaps inevitable as many people are making judgments based on their own experience, not necessarily on empirical evidence. As might be expected, drought appears within the top ten constraints in all but one system (Africa HTM) of the 13 systems. However, here we are trying to look beyond drought as the major constraint and consider the relative importance of other traits.

CONCLUDING POINTS OF INTEREST

There are a number of important points of interest that are prompted by this study.

1. *The relationship of these outputs to breeders' current prioritizations*

Given that there were many prominent and experienced plant breeders who participated in the study, we do have their thoughts and idea about priorities, some of which emerged in response to the formal questions, but more information has been collected from the informal comments during the second round.

The outputs do show that there is still general agreement on the need to focus on systems where poverty remains a major problem despite many years of crop improvement and the development of widely adapted plant materials. Many panelists feel that there is a continued link between crop productivity and poverty even though most feel that this cannot be seen in isolation from many other factors. The GCP studies point to the importance of recognizing that there are many systems in which maize is grown as a component, but in which (apart from a very few exceptions) there is little known about how to further develop the potential for maize production and directly address poverty issues.

There was some discussion on the very common problem of low and declining soil fertility, particularly with respect to low nitrogen and acidity. The strategy to combat this may be either to breed maize for even greater tolerance to low fertility, or to make greater efforts to combine with many development agencies to improve soil fertility through a more systemic approach (e.g. rotations, intercropping, integration of livestock) to environmental improvements. Some combination of strategies would also seem to be rational in order to realize some synergy.(see also below).

The summarized outputs from the first round of questions shows that there is some degree of convergence in relation to a few key constraints that affect yield of maize across many environments. However, there are also many specific constraints that apply only in specific systems (e.g. wind and hail in high altitude Asian systems or waterlogging in rice based systems in Asia). It may well be very productive to focus on these unusual constraints in order to produce specific plant materials for niche environments in where there might be many poor people living. A good example would be the maize with an exceptionally flexible stem that can survive heavy hailstorms in the Upland Integrated Maize system in Nepal.

Some panelists considered that there is much scope for improving the relevance and application of crop breeding research by moving it closer to the farm situation. This would require changes in the style and location of research (from stations to farmer's fields) and partnerships of researchers from national and international institutions working more with local and international NGOs . Such approaches are found in many places, but there is still much scope to develop this action learning process in many more places, particularly in systems in which there has been little focus so far.

2. ***Maize substitution for other cereals especially in marginal systems e.g. Africa systems***

Maize, in fact, has continued to spread into drier and higher altitude systems in Africa, and displace, or be grown alongside, other cereals, since it was first introduced over 300 years ago so there is no reason to suspect that this will not continue to happen.

3. ***Crop mixtures (pigeon peas, beans)***

The crops that dominate maize based small farming systems in Latin America almost always involves maize and beans or another legume in combination. Such systems are not found in many other areas where maize is currently grown, but as soil fertility continues to decline, maize is increasingly grown in combination with legumes such as pigeon peas or beans of various kinds. Several panelists consider that such systems will continue to develop. In some areas maize has been introduced into complex agroforestry systems and have continued to thrive. Perhaps breeders need to look at the requirements of such systems more closely.

4. Diversification.

Many panelists have placed emphasis on diversification, from several viewpoints. One was to recognize that there is much scope for the development of diverse products from maize, as fodder, fuel, popcorn, local food products, and that there is a need to see these as opportunities for breeding a wider range of materials. Another aspect of diversification was the need to look at more diverse systems of production which were more stable than those currently seen (see above). Yet another was to see maize production within a more diversified livelihood system. All these options have implications for the way in which farming families perceive maize and its value and this prompts the need for much more efficient means of communication both ways between researchers and farming families. Knowledge exchange is still very weak in many contexts.

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ANNEXES

ANNEX 1.
SOME RELEVANT ELEMENTS OF THE GCP STUDY ON POVERTY, DROUGHT AND FARMING SYSTEMS

The current study on secondary traits of maize poverty, drought and farming systems provided by an earlier Generation Challenge Program study. A detailed explanation of the methodology and results of the analysis, along with the full list of contributing researchers, can be found in the earlier study (Generation Challenge Program 2006). The methodology involved:

- Using an FAO worldwide classification of farming systems.
- Determining the absolute and proportional poverty in each system, as indicated by child stunting.
- Assessing the productivity and cultivated area of the major crops of the systems locate in areas where poverty was greatest.
- Assessing drought risk—the risk of failed seasons—by geographic area and examining the correspondence to farming systems where poverty was greatest.

The classification of farming systems was the spatial foundation for the overlay of the other data sets (on poverty, failed seasons, crops, and crop productivity). Farming systems were classified on the basis of (1) the natural resources available for agriculture (water, land, grazing, and forested area; climate; landscape; and farm size, tenure, and organization) as well as the institutional setting and (2) on the dominant pattern of farm activities and household livelihoods.

To determine the crops of importance in the target farming systems, the study used production and area data, and market value data will shortly be available as well. The original source of the data is the national governments that participate in FAO statistics programmes. Their data is acquired from censuses, surveys and other sources within the government and private sector. The impact targeting study authors have converted the country level data to sub-national data in grid cells of 100 km2 for the developing countries. The conversion uses a sub-national database of crop production based on censuses and surveys. You and Wood (2006) explain the conversion of the data. The production is expressed in metric tons.

Regarding limitations of the data in the context of the major crops of the developing countries: Three groups of crops are represented in aggregated categories. They are the lesser pulses, the major crops of the *Musa* genus, and several crops that are different types of millet. These crops are assigned to aggregated categories because as individual crops there are few consistent data sources across the broad range of countries throughout the developing world. These crops also tend to be confused within their broader reporting category. The pulses are an aggregation of cowpea, chickpea, pigeon pea, lentils and some other minor crops. Musa refers to plaintain and banana. Millet refers to pearl millet, finger millet and other lesser millets. One way to disentangle these data is by using documentary information.

Selecting the appropriate poverty indicator was a challenge. Traditional indicators of income or wealth are familiar alternatives but have marked drawbacks: they are difficult to elicit and verify, challenging to standardize in a way that permits comparison, and highly variable as a factor contributing to well-being. Instead, the team chose to use child stunting (poor growth in length or height for age) as the indicator of poverty. Stunting occurs when a child has been malnourished over a long period. Unlike underweight children, whose low weight for age may be a temporary phenomenon, stunted children rarely catch up to their peers. Stunted children come from households lacking sufficient food or income to purchase food for adequate nutrition.

To simulate drought stress, a 'failed seasons' model served as the most appropriate proxy. The failed seasons model highlights areas where fewer than 50 days were available for crop production or in which the number of drought stress days exceeded 15 percent. The potential for drought stress was assessed by simulating a hundred years of daily rainfall, temperature, and radiation data and calculating potential evapotranspiration and daily water balances. Crop-specific data were not included in the model.

A final challenge was to determine whether crop improvement research could be an appropriate response to poverty in a given farming system. The productivity of major crops in the poorest systems was assessed to verify that child stunting corresponded to areas of low agricultural yields, where genetic improvement could potentially help to alleviate poverty.

Table A.1.1. lists the 14 priority farming systems for GCP which emerged from the stunted children and drought rankings.

Table A.1.1. Priority farming systems for the Generation Challenge Programme

Region	System	Stunted Children (million)	Global Drought Rank	Regional Drought Rank
SA	**Asia rainfed mix**	**24.5**	2	1
EAP	**Asia lowland rice**	**13.4**	1	1
SA	**Asia rice wheat**	**28.3**	4	2
EAP	**Asia upland int mix**	**15.4**	3	2
SA	**Asia rice**	**11.7**	7	3
EAP	**Asia temperate mixed**	**2.6**	6	3
SA	**Asia dry rainfed**	**3.6**	19	4
SA	**Asia highland mixed**	**5.2**	23	5
SSA	**Africa cereal-root**	**6.3**	5	1
SSA	**Africa ag-past mil sorg**	**3.1**	10	2
SSA	**Africa maize mix**	**6.3**	13	3
SSA	**Africa root crop**	**5**	18	4
SSA	**Africa high temp mix**	**2.8**	29	8
LAC	**LA maize beans**	**2.8**	21	6

Bearing in mind the mandate crops of GCP, Table A.I.W displays the relative prevalence of the crops, expressed as the number of farming systems in which each crop appears at various proportions of cultivated area.

Table A.1. 2. Number of farming systems each crop appears in at various % of area cultivated

		HECTARES							
		50%	60%	70%	75%	80%	90%	95%	98%
	CROP	# app	# app	# app	# app	# app	# app	# app	# app
1	ha_MAIZE	5	6	8	8	10	12	12	12
2	ha_MILLE	4	4	4	4	4	9	11	11
3	ha_RICE	4	5	6	7	9	9	13	14
4	ha_CASSA	2	2	2	2	2	4	5	7
5	ha_SORGH	2	3	7	7	7	9	11	13
6	ha_WHEAT	2	2	4	6	6	8	10	11
7	ha_OPULS	1	2	3	4	6	8	9	11
8	ha_SOYBE	.	1	1	2	4	5	5	9
9	ha_BEAN	.	.	2	2	4	6	10	15
10	ha_GROUN	.	.	1	2	3	6	9	12
11	ha_BANPL	.	.	.	1	1	1	2	3
12	ha_SWEET	.	.	.	1	1	4	6	8
13	ha_POTAT	.	.	.	.	.	1	3	7
14	ha_BARLE	.	.	.	.	.	1	2	3
TOTAL CROPS		**20**	**25**	**38**	**46**	**57**	**83**	**108**	**136**

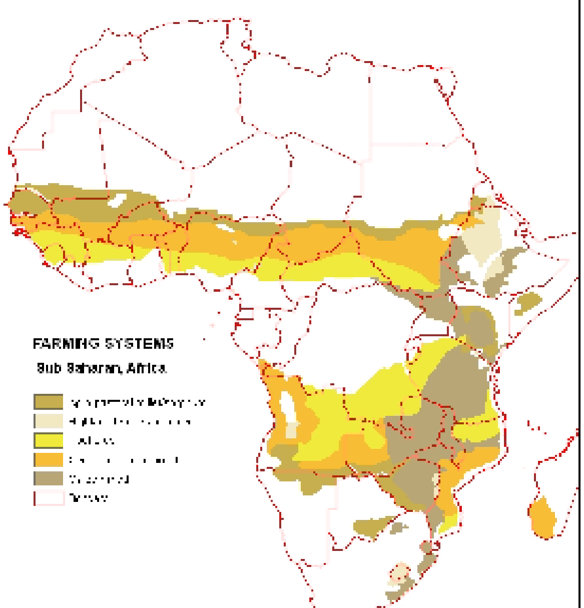
Notes: 50% column indicates those crops which appear in the top 50% of cultivated area in the 14 farming systems identified. The number under each column is the number of farming systems in which that crops appears in the top 50% of cultivated area. This is true also for the 60%, 70%, and so on.

ANNEX 2.
CHARACTERISTICS OF THE SELECTED FARMING SYSTEMS

This Annex draws heavily on Dixon et al (2001) – see references in main report. For each region the selected farming systems are summarized in a table and the distribution is indicated in a regional map.

African Farming Systems

Selected Farming Systems of Sub-Saharan Africa			
Farming Systems	**Agric. Popn. (% of region)**	**Principal Livelihoods**	**Prevalence of Poverty**
Highland Temperate Mixed	7	Wheat barley, tef, peas, lentils, broadbeans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work	Moderate-extensive
Root Crop	11	Yams, cassava, legumes, off-farm work	Limited-moderate
Cereal-Root Crop Mixed	15	Maize, sorghum, millet, cassava, yams, legumes, cattle	Limited
Maize Mixed	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work	Moderate
Agro-Pastoral Millet/Sorghum	8	Sorghum, pearl millet, pulses. sesame, cattle, sheep, goats, poultry, off-farm work	Extensive



Highland Temperate Mixed Farming System

This farming system occupies 44 million ha (only two percent) of the land area of Sub-Saharan Africa and accounts for six million ha (4 percent) of cultivated area, but supports an agricultural population of 28 million (7 percent of the total in the region). Most of the system is located at altitudes between 1800 and 3000 masl in the highlands and mountains of Ethiopia. Smaller areas are found in Eritrea, Lesotho, Angola, Cameroon and Nigeria, generally in subhumid or humid agro-ecological zones. Average population density is high and average farm size is small (1 to 2 ha). Cattle are numerous (estimated population of 17 million) and are kept for plowing, milk, manure, bridewealth, savings and emergency sale. Small grains such as wheat and barley are the main staples, complemented by peas, lentils, broad beans, rape, tef (in Ethiopia) and Irish potatoes. The main sources of cash are from the sale of sheep and goats, wool, local barley beer, Irish potatoes, pulses and oilseeds. Some households have access to soldiers' salaries (Ethiopia and Eritrea) or remittances (Lesotho), but these mountain areas offer few local opportunities for off-farm employment. Typically there is a single cropping season, although some parts of Ethiopia have a second, shorter season. There are major problems in the farming system: for instance, soil fertility is declining because of erosion and a shortage of biomass; and cereal production is suffering from a lack of inputs. There is, however, considerable potential for diversification into higher-value temperate crops.

Household vulnerability stems mainly from the risky climate: early and late frosts at high altitudes can severely reduce yields, and crop failures are not uncommon in cold and wet years. As with other food-crop based farming systems, a hungry season occurs from planting time until the main grain harvest. Poverty incidence is moderate to extensive - in comparison with other systems in Africa - except for the periodic droughts which afflict the Horn of Africa[12]. The potential for poverty reduction and for agricultural growth potential is only moderate.

Root Crop Farming System

This farming system is situated in, and extends from, Sierra Leone to Côte d'Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon, typically in the moist subhumid and humid agro-ecological zones. The area is bounded by the Tree Crop and Forest Based Farming Systems on the southern, wetter side and by the Cereal-Root Crop Mixed Farming System on the northern, drier side. There is a similar strip in Central and Southern Africa, on the south side of the forest zone - in Angola, Zambia, Southern Tanzania and Northern Mozambique - and a small area in Southern Madagascar. The system accounts for 282 million ha (around 11 percent) of the land area of Sub-Saharan Africa, 28 million ha (16 percent) of the cultivated area and 44 million (11 percent) of the agricultural population. Rainfall is either bimodal or nearly continuous and risk of crop failure is low. The system contains around 17 million cattle.

The prevalence of poverty is limited to moderate. Agricultural growth potential and poverty reduction potential are moderate; technologies for this system are not yet fully developed. Nonetheless, market prospects for export of oil palm products are attractive, urban demand for root crops is growing, and linkages between agriculture and off-farm activities are relatively better than elsewhere.

Cereal-Root Crop Mixed Farming System

This farming system extends from Guinea through Northern Côte d'Ivoire to Ghana, Togo, Benin and the mid-belt states of Nigeria to Northern Cameroon; and there is a similar zone in Central and Southern Africa. It accounts for 312 million ha (13 percent) of the land area of Sub-Saharan Africa - predominantly in the dry subhumid zone - 31 million ha (18 percent) of the cultivated area and supports an agricultural population of 59 million (15 percent of the region). Cattle are numerous - some 42 million head. Although the system shares a number of climatic characteristics with the Maize Mixed System, other characteristics set it apart, namely; lower altitude, higher temperatures, lower population density, abundant cultivated land, higher livestock numbers per household, and poorer transport and communications infrastructure. Although cereals such as maize, sorghum and millet are widespread, wherever animal traction is absent root crops such as yams and cassava are more important than cereals. Intercropping is common, and a wide range of crops is grown and marketed.

The main source of vulnerability is drought. Poverty incidence is limited, numbers of poor people are modest and the potential for poverty reduction is moderate. Agricultural growth prospects are excellent and, as described in the relevant section below, this system could become the bread basket of Africa and an important source of export earnings.

Maize Mixed Farming System

This farming system is the most important food production system in East and Southern Africa, extending across plateau and highland areas at altitudes of 800 to 1500 masl, from Kenya and Tanzania to Zambia, Malawi, Zimbabwe, South Africa, Swaziland and Lesotho[13]. It accounts for 246 million ha (10 percent) of the land area, 32 million ha (19 percent) of the cultivated area and an agricultural population of 60 million (15 percent of the Sub-Saharan African total). Climate varies from dry subhumid to moist subhumid. The most typical areas have monomodal rainfall, but some areas experience bimodal rainfall.

Population density is moderately high and average farm sizes are rather modest - often less than two ha. The farming system also contains scattered irrigation schemes, but these are mostly small-scale and amount to only six percent of the irrigated area in the region. Where a bimodal rainfall pattern occurs farmers have two cropping seasons, but in drier areas they usually harvest only once a year from a given field. The main staple is maize and the main cash sources are migrant remittances, cattle, small ruminants, tobacco, coffee and cotton, plus the sale of food crops such as maize and pulses. About 36 million cattle are kept for plowing, breeding, milk, farm manure, bridewealth, savings and emergency sale. In spite of scattered settlement patterns, community institutions and market linkages in the maize belt are relatively better developed than in other farming systems.

Socio-economic differentiation is considerable, due mainly to migration, and the whole system is currently in crisis as input use has fallen sharply due to the shortage of seed, fertiliser and agro-chemicals, plus the high price of fertiliser relative to the maize price. As a result, yields have fallen and soil fertility is declining, while smallholders are reverting to extensive production practices. The main sources of vulnerability are drought and market volatility. There is a moderate incidence of chronic poverty, linked to small farm size and absence of draught oxen and migrant remittances. Recently transitory poverty has sharply increased as a result of retrenchment of off-farm workers coupled with policy reforms affecting maize. In spite of the current crisis, long term agricultural growth prospects are relatively good and the potential for reduction of poverty is high.

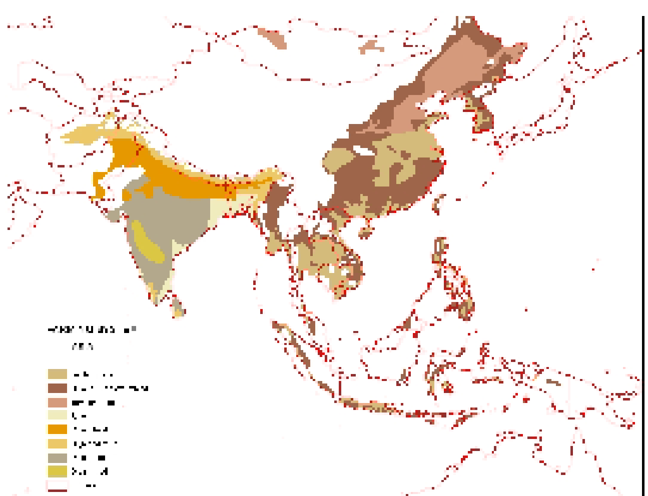
Agro-Pastoral Millet/Sorghum Farming System

This farming system occupies 198 million ha (8 percent) of the land of Sub-Saharan Africa, generally in the semiarid zone of West Africa from Senegal to Niger, and in substantial areas of East and Southern Africa from Somalia and Ethiopia to South Africa. It has an agricultural population of 33 million (8 percent) and their density is modest, but pressure on the limited amount of cultivated land is very high. Crops and livestock are of similar importance. Nearly 22 million ha are used for crops - 12 percent of the cultivated land in the region. Rainfed sorghum and pearl millet are the main sources of food and are rarely marketed, whereas sesame and pulses are sometimes sold. Land preparation is by oxen or camel, while hoe cultivation is common along riverbanks. The system contains nearly 25 million head of cattle as well as sheep and goats. Livestock are kept for subsistence (milk and milk products), offspring, transportation (camels, donkeys), land preparation (oxen, camels), sale or exchange, savings, bridewealth and insurance against crop failure. The population generally lives permanently in villages, although part of their herds may continue to migrate seasonally in the care of herdboys. The main source of vulnerability is drought, leading to crop failure, weak animals and the distress sale of assets. Poverty is extensive, and often severe. The potential for poverty reduction is only moderate. Agricultural growth potential is also modest and presents important challenges.

Asian (South and East/Southeast) Farming Systems

Selected Farming Systems in South Asia

Farming Systems	Agric. Popn.(% of region)	Principal Livelihoods	Prevalence of Poverty
Highland Mixed	7	Cereals, livestock, horticulture, seasonal migration	Moderate - extensive
Rice	17	Wetland rice (both seasons), vegetables, legumes, off-farm activities	Extensive
Rice-Wheat	33	Irrigated Rice, wheat, vegetables, livestock including dairy, off-farm activities	Moderate - extensive



Highland Mixed Farming System

This farming system, generally intermediate between the rice-wheat plains of the lowlands and the sparsely populated high mountain areas above, extends across the entire length of the Himalayan range, from Afghanistan to the extreme northeast of India, as well as in isolated areas of Kerala and Central Sri Lanka. Major products include cereals, legumes, tubers, vegetables, fodder, fodder trees, orchards and livestock. Total system area is 65 million ha with an estimated 19 million ha - about 29 percent - under cultivation. While most cultivated land is rainfed, an estimated 2.6 million ha, or 14 percent, is irrigated. There are about 45 million bovines and 66 million small ruminants. Of the total human population of 82 million, nearly 53 million are classified as agricultural. The prevalence of poverty, which is aggravated by remoteness and the lack of social services, is rated between moderate and extensive.

Rice Farming System

This farming system is dominated by intensive wetland rice cultivation12 by farmers and sharecroppers in fragmented fields with or without irrigation. Of the total system area of 36 million ha, an estimated 22 million ha - or more than 60 percent - is under cultivation. Some 10 million ha, or 43 percent of the cultivated area, is irrigated. Of the total system population of 263 million inhabitants, 130 million are classified as agricultural (17 percent of the South Asian total). The system is concentrated in Bangladesh and West Bengal, but smaller areas are found in Tamil Nadu and Kerala States of India, and Southern Sri Lanka. The system contains 50 million bovines, used for draft power, milk and manure, and considerable number of small ruminants. Poor farmers operate extremely small areas, and rely on off-farm income for survival. Poverty is extensive and also quite severe.

Rice-Wheat Farming System

Characterised by a summer paddy crop followed by an irrigated winter wheat crop (and sometimes also a short spring vegetable crop), the Rice-Wheat Farming System forms a broad swathe across Northern Pakistan and India, from the Indus irrigation area in Sindh and Punjab, across the Indo-Gangetic plain to the northeast of Bangladesh. Total system area is 97 million ha with an estimated 62 million ha - more than 60 percent of the land of the system - under cultivation. An estimated 48 million ha, or 78 percent of the cultivated area, is irrigated. The system has a significant level of crop-livestock integration, with an estimated 119 million bovines which produce draft power and milk, as well as manure for composting. Around 73 million small ruminants are kept, principally for meat. Of the total system population of 484 million people, 254 million are classified as agricultural. The Rice and Rice-Wheat Farming Systems together contain 40 percent of the cultivated land in South Asia and produce the bulk of the marketed foodgrains that feed the cities and urban areas of South Asia.

Selected Farming Systems in East/Southeast Asia			
Farming Systems	**Agric. Popn. (% of region)**	**Principal Livelihoods**	**Prevalence of Poverty**
Lowland Rice	42	Rice, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture, off-farm work	Moderate
Upland Intensive Mixed	27	Rice, pulses, maize, sugarcane, oil seeds, fruits, vegetables, livestock, off-farm work	Extensive
Temperate Mixed	14	Wheat, maize, pulses, oil crops, livestock, off-farm work	Moderate

Temperate Mixed Farming System

This farming system is found in moist and dry subhumid agro-ecological zones in Central-Northern China and restricted areas of Mongolia. Total system area is 99 million ha, with an agricultural population of 162 million. Cultivated area is 31 million ha, of which about one-third is irrigated. The transitional boundary between this system and the Lowland Rice Farming System in Central-Eastern China is not easily defined, and the system also blends into the Extensive Cereal-Livestock Farming System of Southern Siberia and parts of Central Asia (in the Eastern Europe and Central Asia region) Major crops are wheat and maize, with smaller areas of rice, cotton, soybeans, sweet potato and rape - depending on local temperature and water conditions - as well as citrus and some temperate fruits. Livestock are important, particularly cattle, pigs and poultry. The prevalence of poverty is moderate.

Upland Intensive Mixed Farming System

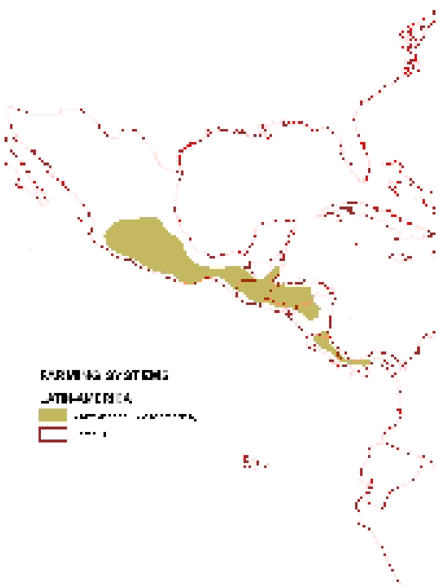
This farming system is found in upland and hill landscapes of moderate altitude and slope, in humid and subhumid agro-ecological zones. Total system area is 314 million ha, with an agricultural population of 310 million - the second most populous system, after Lowland Rice, in the region. Cultivated area is 75 million ha of which just under one quarter are irrigated. This is the most widespread and most heterogeneous farming system in the region (even including some remnant shifting cultivation), with major areas located in all countries of East and Southeast Asia. The system is characterised by the cultivation of a wide range of permanent crops, but the specific crops preferred depend on geographic area, agro-climatic conditions, slope, terracing and water regime. A significant crop area - mainly rice - is irrigated from local streams and rivers. Livestock production is an important component of most farm livelihoods (there are 52 million large ruminants and 49 million small ruminants in this system) and contributes draught power, meat, cash income and savings. Off-farm work is an important source of income for many poor households. Poverty is extensive, varying in severity from moderate to very severe

Lowland Rice Farming System

This farming system is found in both humid and moist subhumid agro-ecological zones in well-watered mainly flat landscapes. It covers an estimated 197 million ha and, with an agricultural population of 474 million, it is the most populous system in the region. Cultivated area is 71 million ha, of which about 45 percent are irrigated. Large areas of this system are found in Thailand, Vietnam, Myanmar, South and Central East China, Philippines and Indonesia. Smaller areas are located in Cambodia, Korea DPR, Republic of Korea, Laos DPR and Malaysia. The farming system is dominantly rice-based, with cropping intensity dependent on rainfall distribution, length of growing season and the availability of supplementary irrigation. Important subsidiary crops include oilseeds, maize, root crops, soybeans, sugarcane, cotton, vegetables and fruits in all areas, while wheat is significant in Central East China. Both livestock and off-farm income contribute to household livelihoods. Regional food security depends upon the production from this system. The prevalence of poverty is moderate overall, although it is extensive in Myanmar and Cambodia.

Latin American Farming System

Selected Farming Systems in Latin America and Caribbean				
Farming Systems		**Agric. Popn.(% of region)**	**Principal Livelihoods**	**Prevalence of Poverty**
Maize-Beans Mesoamerican)		10	Maize, beans, coffee, horticulture, off-farm work	Extensive, and severe



Stretching from Central Mexico to the Panama Canal and with an estimated agricultural population of about 11 million - including a substantial indigenous population - this system covers 65 million ha and is historically and culturally based upon the production of maize and beans for subsistence. Although there are 2.4 million ha of irrigation within the system (40 percent; the highest concentration of irrigation outside the irrigated farming system), the historical loss of the better valley lands to non-indigenous settlers and commercial operations has led to extensive and severe poverty and serious land degradation in many hillside areas.

ANNEX 3.
METHODOLOGY: THE DELPHI METHOD

Description of the technique

The Delphi Method is based on a structured process for collecting and synthesising knowledge from a group of experts by means of a series of questionnaires accompanied by controlled opinion feedback (Adler and Ziglio 1996). The questionnaires are presented in the form of an anonymous and iterative consultation procedure, generally, by means of surveys (postal and/or e-mail).

The Delphi Method originated as part of a post-war movement towards forecasting the possible effects of technology development in relation to economic and social re-generation. Such forecasting has to confront and overcome uncertainty, as well as reconcile diverse sources of information. The Delphi method was designed to 'align' the sometimes conflicting positions of experts into a coherent and unified perspective.

The technique is relatively simple. It consists of a series of questionnaires sent to a pre-selected group of experts. These questionnaires are designed to elicit and develop individual responses on a specified issue and to enable the experts to refine their views as the group's work progresses. The rationale behind the Delphi method is to address and overcome the disadvantages of traditional forms of 'consultation by committee', particularly those related to group dynamics.

Delphi is primarily used to facilitate the formation of a group judgment (Helmer 1977). It developed in response to problems associated with conventional group opinion assessment techniques, such as Focus Groups, which can create problems of response bias due to the dominance of powerful opinion-leaders (Wissema 1982). It may be used in forward planning to establish hypotheses about how scenarios are likely to develop, and on their socio-economic implications. For example, it has been widely used to generate forecasts in technology, education, and other fields (Cornish 1977). Fundamentally, the method serves to shed light on the evolution of a situation, to identify priorities or to draw up prospective scenarios.

Circumstances in which it is applied

Although the approach was originally developed to capture expertise in uncertain and emergent domains, it tends to be used in evaluation when significant expertise exists on the subject, for example in the case of programmes that are not innovative. The method is recommended when the questions posed are simple (a programme with few objectives, of a technical nature) and for the purpose of establishing a quantitative estimation of the potential impacts of an isolated intervention (e.g. increase in taxes or in the price of energy). It is also recommended in an ex ante evaluation context if the evaluation concerns public intervention of a technical nature. Thus, it was very often used in the framework of energy policies, for example, for prospective studies on the impact of changes in taxation. In the case of the evaluation of Structural Funds, the Delphi inquiry has been recommended for obtaining macro-economic estimations when the phenomena involved are complex; for example, to quantify the impact of a major infrastructure project. It may also be used to specify relations of causes and potential effects in the case of innovative interventions. It is particularly useful when a very large territory is being dealt with since there are no experts' travel expenses, only communication costs.

It has found to be particularly useful in programmes related to public health issues (such as, policies for drug use reduction and prevention of AIDS/HIV) and education (Adler and Ziglio 1996; Cornish 1977). According to a number of commentators, context is everything in deciding whether and when to use the Delphi method. According to Adler and Ziglio (1996), the key questions that need to be asked are:

- What kind of group communication process is desirable in order to explore the issue?
- Who are the people with expertise on the issue and where are they located?
- What are the alternative techniques available and what results can reasonably be expected from their application?

The main steps involved

The approach consists of questioning the experts by means of successive questionnaires, in order to reveal convergence and any consensus there may be. The main stages of this process are (Fowles 1978):

- Step 1. Determination and formulation of questions. Particular care must be given to the choice and formulation of questions, so as to obtain useful information.
- Step 2. Selection of experts. They must have specific knowledge on the subject and be prepared to become involved in this type of procedure. The panel is generally composed of up to fifty persons.
- Step 3. Formulation of a first questionnaire that is sent to the experts. The first questionnaire must contain a reminder of the nature of the study and include two or three semi-open and open questions.
- Step 4. Analysis of the answers to the first questionnaire. The answers are analysed in order to determine the general tendency and the most extreme answers.
- Step 5. Formulation of a second questionnaire that is sent to experts. Each expert informed of the results of the first round is asked to provide a new answer and to justify it if it differs from the general tendency.
- Step 6. Sending of a third questionnaire. Those experts whose answers were "extreme" are asked to criticise the arguments of those who supported the opposite point of view. The comparison of opinions has a moderating influence and facilitates the appearance of convergence between the points of view.
- Sufficient convergence of opinions generally appears with the fourth questionnaire. If that is not the case, the cycle continues.
- Step 7: Summary of the process and drawing up of the final report.

Strengths and limitations of the approach

As has often been remarked, the results of a Delphi survey are only as valid as the opinions of the experts involved (Martino 1978). Martino is only one of a number of critics of the Delphi approach. His suggestion that the technique represents a 'last resort' when there are no other techniques suitable or available echoes the results of a number of systematic reviews and meta-analyses of the application of the technique. The key problems reported include: poor internal consistency and reliability of judgments among experts, and therefore low reproducibility of forecasts based on the results elicited; sensitivity of results to ambiguity and respondent reactivity in the questionnaires used for data collection; difficulty in assessing the degree of expertise held by participating experts (Makridakis and Wheelright 1978).

A major problem identified by research into the implementation and application of Delphi surveys has been the tendency for experts to over-simplify particular issues, and treat them as isolated events. This is particularly the case in forecasting, where experts tend to think in terms of linear sequential events, rather than applying a holistic view that involves complex chains and associations. This has led to the development of techniques such as 'cross impact matrix forecasting', which are intended to compare a range of 'possible futures' against each other, and to consider the displacement, substitution and multiplier effects associated with the scenarios identified by the experts involved (Gordon and Hayward 1968; Gatewood and Gatewood 1983; Adler and Ziglio 1996).

On the other hand, there have been several studies (Ament 1970; Wissema 1982; Helmer 1983) supporting the Delphi method. These studies seem to suggest that in general, the Delphi method is useful to explore and unpack specific, single-dimension issues. There is less support for its use in complex, multi-dimensional modeling. In these cases, the evidence does suggest that data gathered by Delphi surveys is a useful input, when supported by data gathered from other sources, to complex scenario-building.

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Key terms

- Delphi survey – the actual process through which expert opinion is elicited – in the form of iterative questionnaire surveys
- Cross-impact matrix forecasting – comparing the results of Delphi surveys against other possible scenarios, and predicting the possible 'unforeseen effects' that might apply.

ANNEX 4.
HIGHLIGHTS OF RESULTS

Table A 4.1. Highlights of panelists' responses on maize production constraints

Farming systems	Approx. maize area [2] M ha	Abiotic	Biotic	Crop management	Socio economic
Africa					
Maize Mixed	6.3	Drought Low soil fertility Acid soils Heat stress Low N	Weeds, MSV, Stem borer, Chilo partellus, Striga, Grey spot dis.,Mottle virus, Cob rots, Weevils	Late planting, Low plant population, low fertilizer use, poor weed management, post harvest losses.	Poorly developed markets for grain, seed supply poor, high input prices, price controls, Export restrictions, poor credit access, low labour
% Yield reduction		43	22	15	20
Cereal root crop mixed	4.1	Drought Low soil fertility Acidity, Low N.	Leaf rust, Maize streak virus. Grey leaf spot	Harvesting Earlier and later planting	Price of product Poor marketing infrastructure, late input availability
% Yield reduction		44	21	11	24
Agropastoral Millet Sorghum	1.7	Drought Low soil fert. Acidity Low Nitrogen	Maize streak virus Stem borer Chilo Partellus	Late planting Low fertilizer use Late weeding Competition with livestock	Product price Late input availability Market access Access to water
% Yield reduction		42	20	20	18
Root crop	1.7	Drought Low soil fertility Acidity Heat stress Low N	M.Streak virus Stem borer Chilo Partellus Striga, Blights, Grey spot disease Cob rots, weevils	Late planting, Low fertilizer use, Poor plant population, Poor weed management Zn deficiency Post harvest losses	Poorly developed markets, Poor seed supply, Grain colour not acceptable, Tough price controls Export restrictions
% Yield reduction		38	22	18	22
Highland Temperate mixed	1.0	Drought Low soil fert, Acidity Low N Frost	Leaf rust, Maize Streak Virus. Fusarium,Turcicum ,stem borer,	Late planting, Late harvesting, low fertilizer use, late weeding , high density planting	Product price No market for grain, Late inputs, poverty, high input prices, Lack of improved germplasm
% Yield reduction		31	25	28	16
Asia					
Temperate Mixed (E.A.)	10.2	Drought Low soil fertility Wind Hail storms	Corn borer, earworms, aphids , armyworm, Rusts, Maydis, Turcicum, stalk rot , Head smut, Mosaic virus	No minimum tillage, late sowing, weed management, poor nutritional management	Access to inputs, Price support policies, poor market infrastructure, late input availability, access to varieties, no credit.

[2] Figures from GCP 2006.

% Yield reduction		42	30	15	13
Lowland Rice (E.A.)	8.5	Drought, Waterlogging, low soil fertility. Acid soil, low temp. at planting, Low N , High winds	Stem borer, Cut worms, army worms, Downy mildew, stalk rots, rusts, Blast, leaf an sheath blight, rust , viruses	Weed management, poor fertility management, low plant population, late planting, low level of knowledge, poor water management, low tolerance to continuous cropping	Access to inputs, Market and access , knowledge of technology, seed shortages, high production costs, transfer of technology
% Yield reduction		36	31	17	16
Upland Intensive Mixed (E.A.)	7.0	Drought, Low N, Low soil fertility, Acid soils, Strong winds	Leaf rust, Maize streak virus, Grey leaf spot, Downy mildew, Rusts, Blights, Stalk rot, Corn borer, Aphids, White grubs	Tillage, early and late planting, harvesting, nutrient management, seed production, low population density	Access to inputs , price support policies, poor market infrastructure, late input availability, labour shortage, old farmers
% Yield reduction		41	31	15	13
Rice-Wheat (S.A.)	3.4	Drought Waterlogging Low soil fertility, acidity, cold, salinity	Stem borer, birds and rodents at planting, downy mildew, stalk rots, rusts	Weed management, fertility management, low plant population, late planting, low knowledge , poor water management	Seed costs , markets and access, knowledge of technology, seed availability, high production costs
% Yield reduction		32	30	26	12
Highland Mixed (S.A.)	0.99	Drought, Cold, Low soil fertility, soil erosion, low N	Stem borers, Downy mildew, stalk rots, leaf and sheath blight, Turcicum blight	Weed management Poor soil fertility management Low population density	Assess to inputs and credit, Markets and access, Knowledge on technology, seed shortages and cost, high production costs, consumer preferences, seed availability
% Yield reduction		33	22	23	22
Rice (S.A.)	0.17	Drought, Waterlogging, Low soil fertility,acidity, low N	Stem borers, cut worms, army worms, Birds and rodentls at planting, Downy mildew (?) Stalk rots, rusts, Blast, Blights, viruses.	Weed management, poor fertility management , low plant population, late planting, low level of knowledge, poor water management, low tolerance to continuous cropping	Access to inputs and credit, Markets and access, knowledge on technology, seed shortages and cost, high production costs, transfer of technology, low prices of products,
% Yield reduction		32	19	26	23

Latin America					
Maize-Beans	4.4	Drought, Low N, Low soil fertility, acid soils,	Viruses, Aspergillus, cutworms, army worm, weevils in storage, Claviceps gigantea, Aspergillus falvus; Puccinia lolysora, P. sorgi, Exserohilum turcicum, Phaeosphaeria maydis, Cercospora zeae-maydis;, Fusarium moniliforme, F.	No minimum tillage, late sowing, weed management is poor, Poor nutrient management practices	Access to inputs , Price support policies, Poor market infrastructure, Late input availability, Access to varieties No credit
% Yield reduction		37	32	15	17

Table A 4.2 Ranking of constraints and yield reduction on small farm yields.

Farming systems	**Area of maize** M. ha.	**Range and Average yield on small farms Kg/ha.**	**Rank**	**Top ten Constraints**	**Yield reduction (Kg/ha) and (%) on small farms**
AFRICA					
Maize Mixed	6.3	(0.5-1.5)0.92	1	Low soil fertility	573 (62)
			2	Drought	495 (54)
			3	Low soil nitrogen	704 (76)
			4	Acid soils	122 (13)
			5	Weeds generally	282 (31)
			6	Striga	126 (14)
			7	Late planting	166 (18)
			8	MSV	88 (9)
			9	Grey Leaf spot	151 (16)
			10	Maize stem borer	83 (9)
Cereal root crop mixed.	4.1	0.57(0.5-0.60)	1	Drought	551 (97)
			2	Low soil nitrogen	902 ? (100)
			3	Low soil fertility	472 (83)
			4	Striga spp.	373 (65)
			5	Weeds in general	502 (88)
			6	Grain weevils	137 (24)
			7	Zinc deficiency	58 (10)
			8	Termites	126 (22)
			9	Lodging : High winds	53 (9)
			10	African Pink Borer	34 (6)

Highland Temperate mixed	1.0	1.8 (1.0-3.5)	1	Low soil fertility	122 (6.8)
			2	Acid soils	34 (1.9)
			3	Turcicum leaf blight	16 (0.8)
			4	Late planting	21 (1.2)
			5	Weeds in general	84 (4.7)
			6	Grain weevils	50 (2.8)
			7	Grain borers	20 (1.1)
			8	Late weeding	33 (1.8)
			9	Maize stem borer	36 (2.0)
			10	Grey Leaf spot	32 (1.8)
Agro pastoral Millet-Sorghum	1.7	0.75 (0.4-1.0)	1	Drought	367 (49)
			2	Low soil fertility	226 (30)
			3	Low soil Nitrogen	215 (29)
			4	Grain weevils	119 (16)
			5	Grain borers	20 (2.7)
			6	Weeds in general	127 (17)
			7	Turcicum blight	5 (0.6)
			8	Maize streak virus	37 (4.9)
			9	Late planting	126 (18)
			10	African pink borer	2 (0.3)
Root crop	1.7	1.10 (0.6-2.0)	1	Low soil Nitrogen	912 (83)
			2	Drought	341 (31)
			3	Weeds in general	435 (40)
			4	Late planting	264 (24)
			5	Fusarium and Gibberella rots	63 (5.7)
			6	African stem borer	310 (28)
			7	Maize streak virus	182 (17)
			8	Lodging from High winds	90 (8.2)
			9	Grain weevils	135 (12)
			10	Zinc deficiency	53 (4.8)
ASIA					
Lowland Rice EA	4.0	4.0 (3.0-5.0)	1	Drought	873 (22)
			2	Low soil fertility	770 (19)
			3	Downy mildew	305 (7.6)
			4	Rusts	249 (6.2)
			5	Low soil nitrogen	455 (11.4)
			6	Flooding	165 (4.1)
			7	Maize dwarf mosaic virus	235 (5.9)
			8	Weeds in general	229 (5.7)
			9	Asian corn borer	62 (1.6)

			10	Corn earworm	48 (1.2)
Upland intensive mixed EA	7.0	3.3 (0.5-4.0)	1	Drought	598 (18)
			2	Low soil nitrogen	428 (13)
			3	High winds /lodging	219 (6.6)
			4	Asian Corn Borer	522 (16)
			5	Corn Leaf Aphid	154 (4.7)
			6	Banded leaf and sheath blight	217 (6.6)
			7	Fusarium and Gibberella stalk rots	201 (6.1)
			8	Weeds in general	396 (12)
			9	Maydis Leaf Blight	206 (6.2)
			10	Wire worms	220 (6.7)
Highland Mixed South Asia	0.99	3.1 (2.0-5.0)		Drought	180 (5.8)
			2	Low soil fertility	100 (3.2)
			3	Turcicum leaf blight	190 (6.1)
			4	Grain weevils	104 (3.4)
			5	Fusarium and gibberella ear rots	70 (2.3)
			6	Banded leaf and sheath blight	66 (2.1)
			7	Downy mildews	48 (1.5)
			8	Late planting	108 (3.5)
			9	White grubs	84 (2.7)
			10	Acid soils	120 (3.9)
Rice/wheat SA	3.4	3.1(2.0-5.0)	1	Late Planting	598 (19)
			2	Low soil nitrogen	428 (14)
			3	Birds	219 (7.1)
			4	Flooding	522 (17)
			5	High winds/lodging	154 (5.0)
			6	Cutworms	217 (7.0)
			7	Low soil fertility	201 (6.5)
			8	Weeds in general	396 (13)
			9	Drought	206 (6.6)
			10	Low plant population	220 (7.1)
Temperate mixed EA	10.2	6.3 (5.5-8.0)	1	Drought	304 (4.8)
			2	Asian Corn borer	258 (4.1)
			3	Turcicum leaf blight	101 (1.6)
			4	Maydis leaf blight	108 (1.7)
			5	Head smut	100 (1.6)
			6	Fusarium and	106 (1.7)

				Gibberella stalk rots	
			7	Yellow Peach moth	57 (0.1)
			8	Common smut	59 (0.1)
			9	Cotton Bollworm	62 (0.1)
			10	Banded leaf and sheath blight	46 (0.1)
Rice SA	0.17	2.4 (2.0-3.0)	1	Late planting	342 (14.3)
			2	Low soil fertility	312 (13.0)
			3	Low soil nitrogen	342 (14.3)
			4	Flooding	96 (4.0)
			5	Lodging /high winds/storms	205 (8.5)
			6	Birds	78 (3.2)
			7	Low temperature	50 (2.1)
			8	Cutworms	85 (3.5)
			9	Weeds in general	78 (3.2)
			10	Drought	136 (5.7)
Latin America Maize -Beans	4.4	1.6 (1.2-3.0)	1	Low soil fertility	462 (28.9)
			2	Drought	257 (16.1)
			3	Fusarium and Gibberella stalk rots	40 (2.5)
			4	Low soil nitrogen	289 (18.1)
			5	Tar spot complex	15 (0.9)
			6	Birds	10 (0.6)
			7	Weeds in general	36 (2.3)
			8	Stenocarpella ear rot	5 (0.3)
			9.	Corn Stunt Complex	14 (0.9)
			10	Armyworm	12 (0.8)

ANNEX 5.
SELECTED REMARKS OF PANELISTS ON SECONDARY TRAIT CHARACTERISTICS AND THE LINKS TO POVERTY AND THE WIDER CONTEXT

Many panelists offered additional comments, for example when they were asked to provide their opinion on the links between maize yield improvement and poverty reduction on small farms with particular emphasis on the farming system that they knew well. Naturally, all these comments were directed towards small farm systems which were found in areas where poverty was common. Quite a number of panelists stated that there was a very strong link between maize yield improvement and poverty reduction, although generally without providing concrete supporting evidence. However, a few panelists made carefully considered responses which addressed not only what the main ways in which maize production needed to be changed in order to contribute to poverty alleviation but also how research and extension might be improved to develop more relevant and sustainable outputs. Some of these comments related to specific systems, but many were relevant to maize based systems in general. These are some of the themes (not in any priority order) that emerged from these comments are presented for general information, with out endorsement, rebuttal or elaboration by the assessment team, as follows:-

High yielding varieties

It was pointed out that the availability of new, high yielding varieties (not only hybrids) is widely known, but many are still not accessible to poorer farmers. Moreover, cost and price controls remain a problem for many.

Use of nitrogen efficient maize

There was wide evidence to shown that nitrogen was severely limiting in many soils. One approach might be to develop maize varieties that had greater nitrogen use efficiency

Intercropping and crop sequences

The Latin American farming system illustrates an example of a deeply embedded, old, intercropping system with beans and other legumes that complement maize production. This has not yet happened in many areas in which maize has been an introduced crop over the past 300 years and yet it might be one key to improved productivity, particularly in Africa and wherever soil fertility is a continuing problem. The recognition of a systems perspective among professionals who are engaged in maize system improvement is still weak and this slows the understanding of what might be possible with linked changes to complex systems.

Adaptation to more extreme environments or climate change

Changing climate, particularly in relation to increasing droughts and in Asia, increased flooding occurrences, presents a major challenge to all those involved in maize production systems. Improving the stability and productivity of maize that will perform in increasingly hostile environments can make a major contribution to the alleviation of poverty.

Dependence on crop systems or farming plus other income sources

One panelist pointed out that where small farmers were highly dependent on farming for their livelihoods, yield improvement of maize could have a major effect on poverty alleviation and food security. However, wherever families had diversified their livelihoods and income sources from employment outside agriculture, maize improvement might only make a marginal difference to income, but might improve food security significantly.

Access to inputs and to markets

Access to seeds and other inputs remains a major issue with poorer farming people. This might involve transport, costs and the absence of credit.

Diverse products, uses and markets for maize

There is evidence, particularly in Asia, that there are growing markets for maize as feed for livestock. Crop improvers need to recognize and study this opportunity along with others that present themselves such as fodder and intercropping types.

Farmer training : technology, markets and new products

There is still some concern among many agencies that farmers are not made aware of new technologies and how to access new markets and products that might be relevant to their system

Modernisation of agriculture and appropriate technical change

The long time assumption that farmers of all kinds will "modernize" (high inputs, machinery, chemical fertilizers and pest and disease control) in the same way in which farming has changed in capital intensive systems, is still widely held despite much evidence to the contrary. This simplistic approach is not appropriate to many small farm systems. Maize varieties are still required that can fit into complex crop sequences and also be managed by small farmers who have very limited resources. Such systems can be highly productive on small amounts of land.

Research partnerships and the development of greater relevance and context

Much of current research is still based on specially constructed environments (research stations and the replication of station environments on farmers' fields). There is a need to reduce on station research and reallocate resources into the context of small farm environments. Partners need to be not only from National Research Programmes, but also NGOs and CBOs who have a greater knowledge and understanding of real environments in which poor people operate.   This calls for a continuing transformation of how research is conducted and how relevant research outputs are developed. It again calls for a systemic approach to livelihoods improvement and the need to understand that low yields and poverty are not only related to technical or natural resource limitations, but are they are also interdependent on socioeconomic and institutional contexts.