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Agricultural Systems
Editors

To the editors:

With this letter and accompanying documents, I am submitting for publication in *Agricultural Systems* our manuscript titled "Strategic approaches to targeting technology generation: Assessing the coincidence of poverty and drought-prone crop production."

The paper presents a novel approach to priority setting in international agricultural research and development.

I have put supplementary information on our Web site. This information includes the two appendices and drought frequency curves, providing additional information to figures 3 and 4. The page is at: **http://gisweb.ciat.cgiar.org/drought/**.

Please let me know if you need any other information, or how I can help in your review of the manuscript. Please confirm that you have received the manuscript.

Thank you for your attention to my request. I look forward to your reply.

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Strategic approaches to targeting technology generation: Assessing the coincidence of poverty and drought-prone crop production

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Abstract

The world's poorest and most vulnerable farmers on the whole have not benefited from international agricultural research and development. Past efforts have tried to increase the production of countries in more favourable environments; farmers with relatively higher potential for improvement benefited most from these advances. This study prioritizes areas of high poverty, the key problem of high drought risk and the crops grown and consumed in these areas. We used global spatial data on crop production, climate and poverty (as proxied by child stunting) to identify geographic areas of high priority for crop improvement. Using spatial overlay, drought modelling and descriptive statistics, we identified where best to target technology generation to achieve its intended human welfare goals. Analysis showed that drought coincides with high levels of poverty in 15 major farming systems, especially in South Asia, the Sahel and eastern and southern Africa, where high diversity in drought frequency characterizes the environments. Twelve crops make up the bulk of food production in these areas. We developed a database for use in agricultural research and development targeting and priority setting to raise the productivity of crops on which the poor in marginal environments depend.

Keywords: Farming systems; Child stunting; Drought; Staple food crops; Risk

1. Introduction

Over the last 50 years, progress in reducing poverty and malnutrition has been mixed (World Bank, 2004, FAO, 2005). A reduction in the proportion of the poor and undernourished has been achieved in most regions of the world. But the absolute numbers of poor people continues to grow across sub-Saharan Africa and, between 1991 and 2002, the number of hungry has grown by over 40 million people in central and eastern Africa and South Asia. These negative trends exacerbate a situation in which many regions are already projected to fall short of international poverty and hunger goals (UNDP, 2006). Given the importance of agriculture in the food security and livelihoods of the poor, any strategy to address poverty in such regions must pay particular attention to raising the productivity, profitability and sustainability of agricultural enterprises (Gryseels et al., 1992, Dixon et al., 2001).

Unfortunately, most farmers in marginal environments have had little benefit from agricultural research and development (Freebairn, 1995, CGIAR, 2000, Evenson and Gollin, 2003). The dominant humanitarian goal of early international research and development efforts, including that of the Consultative Group on International Agricultural Research, was to “increase the pile of rice” in poor and famine-prone countries (Shah and Strong 1999). But, while the new Green Revolution technologies succeeded in raising overall levels of food security, they were primarily adopted by relatively well-off farmers with access to resources and capital. There is now a growing commitment to the notion that accelerating progress in reducing poverty and hunger requires an urgent refocusing of development efforts on resource-poor farmers in marginal environments.

In the past it has proved difficult to respond to this challenge because the necessary layers of information and the tools to analyse them in an integrated fashion, were not available. In this study we bring together a unique combination of new spatial data and analyses that allows research investors and scientists to take a broad, strategic perspective of the most important geographical regions, farming systems and crops for which development of drought-tolerant traits would likely bring major benefits to the poorest people.

Specifically, this study identifies the coincidence of poor populations in developing countries, the production of key food staple crops on which the poor depend and drought-prone production environments. We used farming systems as our geographic units of analysis (Fig. 1, Dixon et al., 2001). Our study used malnutrition, identified by childhood stunting, as a proxy for poverty (FAO, 2003). We developed a model to appraise the susceptibility of regions more and less prone to drought. We assessed the relative importance of different crops in the farming systems using a global database of harvested area and production for the main food staples (You and Wood, 2006).

Fifteen farming systems have between 2.5 and 28 million stunted children each, accounting for over 70% of the world's stunted children. High average crop production losses from drought are found in these systems. They have evolved largely to support the production of 12 food staple crops, with at least 5% of the global harvested area of the dominant food staples in each system. They include a large area in Mesoamerica, the African Sahel, parts of eastern and southern Africa and large areas of South Asia, Southeast Asia and East Asia. Our study ranks the farming systems according to the total scale of poverty, the average drought frequency and the total area of food staple crops. The derived information base is intended to support priority setting for research and development on raising the productivity of food staple cropping systems targeted to addressing the needs of poor people in marginal environments.

2. Materials and Methods

2.1. Population, poverty and crop production

We developed a spatial database to support assessments of poverty and crop production and acquired global data sets with estimates for grid cells of 1-km^2 to 400-km^2 spatial resolution. The database includes population information from the Gridded Population of the World (GPW) Version 3 project (CIESIN et al., 2004). We used infant mortality rates and the prevalence and absolute number of underweight and stunted children as measures of poverty (FAO, 2003, CIESIN, 2005, CIESIN, 2006). The data sets of underweight and stunted children are based on health surveys such as the Demographic and Health Survey (FAO, 2003, Balk et al., 2005). The data report the percentage and absolute number of children under 5 years of age that are -2 standard deviations from the international growth reference standard. We linked tabular data for administrative units to maps in a geographic information system (GIS).

We chose to use stunting as our principle poverty indicator because:

- Stunting occurs in households that cannot provide sufficient food or income for healthy nutrition;
- Poor families first try to improve their food and nutrition with greater income or crop production;
- Income or wealth as indicators are difficult to elicit or standardize in a way that allows comparison and are highly variable as a contributing factor to well-being; and
- Only 20 to 30 countries in the world have detailed mapping of income or consumption that is sufficiently reliable and of significant resolution; while
- The measurement of stunting is straightforward and comparable globally.

A full table of population and stunting by farming system is given in the Appendix (Table A1). We derived estimates of the spatial distribution and productivity of crops for 10-km grids using a novel allocation approach involving the fusion of sub-national crop production statistics (You and Wood, 2006). This we combined with an array of digitally mapped data on the distribution of rainfed and irrigated cropland, the potential biophysical yield of each crop and population density. We derived sub-national crop production data from agricultural censuses and surveys and scaled all values so as to obtain national production estimates that were compatible with the annual average FAO national crop statistics for 1999-2001. The prototype crop distribution database used in this study is available from the authors upon request but is currently being regenerated using newer and additional data sources (including revisions based on expert validation) and an enhanced allocation algorithm. A large share of the sub-national crop production can be downloaded directly from FAO's (2006) Agromaps site at http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp. The following digital crop maps in GIS formats were used in our analysis:

- Barley
- Bean
- Cassava
- Groundnut
- Maize
- Millet
- *Musa*
- Other pulses
- Potato
- Rice
- Sorghum
- Soybean
- Sweet potato
- Wheat

Three of the crop maps in the list above are combined categories. "Other pulses" include cowpea, chickpea, pigeon pea and lentils. *Musa* includes banana and plantain. Millet includes pearl millet and finger millet. These three maps combined crops because of difficulties in reporting them separately at the global scale. Accounting for the combined categories, the list above includes 19 crops.

Irrigated areas are obviously less susceptible to weather variability and drought (albeit lower than normal rainfall may reduce ground and surface water needed for irrigation). A focus on poor farmers in marginal environments largely excludes the targeting of irrigated areas. Our analysis excluded irrigated areas based on estimates from the global digital crop maps (You and Wood, 2006).

2.2. Farming systems

We used the farming system region (Fig. 1) as the geographical unit of analysis. Dixon et al. (2001) mapped 72 farming systems in the developing countries. The map includes Latin America and the Caribbean; sub-Saharan Africa, the Middle East and North Africa; South Asia, East Asia and the Pacific; and Eastern Europe and Central Asia. The map was based on the knowledge of agricultural experts of these regions at local, regional and global scales. The regions were defined based on the dominant pattern of the natural resources base, farm activities and household livelihoods. The expert panels used about 12 to 15 spatial surfaces including agro-ecological zones, rainfall, irrigation, slope, human population, cultivated extents, livestock systems and livestock distributions where available. Factors such as climate, water availability, land cover, tenure and organization, farm size, dominant crop types, off-farm activities, technologies that determine production intensity and integration of crops, livestock and other activities were used in drawing the boundaries of the farming systems.

(Fig. 1 near here)

Using these factors as criteria, Dixon et al. (2001) identified eight broad categories:

- Irrigated farming systems,
- Wetland rice-based farming systems,
- Rainfed farming systems in humid areas of high resource potential,
- Rainfed farming systems in steep and highland areas,
- Rainfed farming systems in dry or cold areas of low potential areas,
- Dualistic (mixed large commercial and smallholder) farming systems,
- Coastal artisanal fishing and
- Urban-based farming systems.

Urban-based farming systems are excluded from the global map because of their relatively small size. This leaves 63 systems, which had average agricultural populations of 40 million, ranging from less than one million to several hundred million people.

Our analysis relies on comparing the 63 farming systems according to their levels of poverty, crop production and drought. We converted the data to grid cells with 10-km spatial resolution within the 63 farming systems shown in Fig. 1. We then used *zonalstats* in ArcInfo to calculate population, poverty and crop production statistics for each agricultural region. The algorithm considers each 10-km grid cell falling within an agricultural region. The method can calculate the mean, median, maximum, minimum, standard deviation, sum and other statistics for each region.

2.3. Assessing the frequency of drought by farming system

In order to map drought risk, we estimated the probability of a failed growing season. At a conceptual level, a failed season is one in which the harvest was not worth the costs of producing the crop, one in which less food has been harvested than the human effort expended. What we need here is a simple surrogate measurement for this concept that might apply across a number of crops. There is no hard-and-fast rule for these assumptions, so we have designated a failed season as that which has rainfall at the start sufficient for germination and establishment, less than 50 growing days and a clearly defined end. This definition is clearly generic and does not apply to any specific crop. Thus the failed-season approach depends upon the use of a reliable means to assess the water- and temperature-constrained length of growing period in each locale.

Rainfed crops rely on soil water available to their roots to support growth and yield. The amount of water available depends upon rainfall, the water-holding capacity of the soil profile, the rooting depth of the crop and the potential and actual rates at which a crop can consume soil water during its growth cycle. Although reasonably accurate soil maps are available for most of the world, it is difficult to determine the actual soil water-holding capacity of any given square metre of soil. Our analysis assumed that all soils were capable of storing 100 mm of available soil water—a value that holds true for most of the agricultural areas in the drought-prone regions of the tropics. Where the storage capacity is larger, this assumption will lead to the under prediction of growing season lengths. For example, Fluvisols (flood plain soils) by definition are likely to have extra soil water resources within rooting depth for which this analysis cannot account.

The actual rate at which a crop consumes water (actual evapotranspiration, Ea) can often be less than the potential rate at which the crop could consume water if it was in abundant supply (potential evapotranspiration, Et). This happens, for example, when soil water content is low and it becomes more difficult for the roots to extract water. Thus the ratio Ea/Et is a well-established index of the water stress a plant experiences during its growth. Ea/Et ratios of between 0.8 and 1.0 imply little or no yield-reducing water stress. An Ea/Et ratio of less than 0.4 is, for most crops, an indication that severe drought stress is being experienced and that the ability of the crop to deliver an economic level of yield is severely compromised. The soil water accounting model (WATBAL, see below) uses the ratio internally to determine the dynamics of the water balance and the extent of drought stress on a daily basis.

Our method establishes rules for defining a growing season. To have a reasonable chance of seed germination, certain minimum levels of soil water and temperature must prevail. Thus we stipulate that a growing season cannot start until at least 5 days have occurred with an Ea/Et greater than 0.8 and that the mean temperature during those days is above 8 ^{o}C. Conversely, we define the end of a growing season for annual crops such as maize or beans as following 12 consecutive days with Ea/Et less than 0.4 (stress days) or any sequence of 12 consecutive days with temperatures less than 4 ºC. Crop physiologists will differ on the meaning of water stress for relevant crops but we used these rules to enable us to define a generic growing season. Some crops such as cassava would easily tolerate this stress, where beans would be deeply stressed—folding their leaves and closing their stomata, thus shutting down photosynthesis. The temperature criteria are aimed at tropical and subtropical crops. They do not represent truly temperate crops and will not reflect the correct situation for cold-adapted, temperate cereals.

To implement the length of growing period analysis, we used the model WATBAL (Kieg and McAlpine, 1974), which directly assesses available soil moisture in each time period based on the factors highlighted above. WATBAL assumes that the Ea/Et ratio is proportional to the ground cover; thus a wet soil surface and/or a complete cover of an unstressed growing crop have a value of 1.0 and a completely dry soil open surface will have a ratio close to 0. This is termed the CROP FACTOR. For simplicity we have assumed a value of 0.8 during a crop cycle.

We simulated 100 years of daily rainfall, temperature and radiation data for 30 arc-second pixels within the study area using MarkSim® (Jones and Thornton, 2000, Jones et al., 2002). We used Linacre's (1977) method to calculate potential evapotranspiration and WATBAL (originally Keig and McAlpine, 1974, here applied as a FORTRAN subroutine as in Jones, 1987) to calculate daily water balance.

The failed seasons model can be used as a standardized index of the agricultural reliability. The model is not calibrated to specific crops; for example a failed season may apply more to long- rather than short-season maize. It would be more accurate if we knew on which soils the crops were grown but in most areas this is dependent on local variability that we cannot determine from the FAO soils map.

Secondary growing seasons occur sporadically in wide geographic areas. They often do not occur with a frequency that can be reasonably planned for and exploited. Since they can be either the first or the second season in any one place or year it is not correct to label them first and second. Analysis excluded the secondary or shortest growing season because global crop production and area data are not linked to a particular growing season. Thus, drought assessment is based on the longest growing season of the year.

Images are speckled, particularly in marginal areas, due to the stochastic process generating the climate data (Fig. 2). The effect highlights the true environmental variability in these areas.

(Fig. 2 near here)

We developed two drought indicators using data on the harvested crop area and the failed seasons model. A full table of the farming systems and the respective drought indicators is given in the Appendix (Table A2). Table 1 lists the 15 farming systems with over 2.5 million stunted children and the respective drought indicators. Our principle drought indicator, labelled “Potential Drought Impact Index” in the table, is a reflection of the expected loss of production due to drought. This indicator is derived by multiplying the area of rainfed food staple crops by the probability of a failed season. An example of two hypothetical grid cells illustrate its calculation:

	Rainfed staple crop area (ha)	Mean probability of a failed season (%)	Potential drought impact index
Grid cell no.1	1000	60	600
Grid cell no. 2	3000	40	1200

(Table 1 near here)

The index accounts for the scale of staple food crop production weighted by the probability of a failed season. Some form of drought can occur in all farming systems. In systems where the probability of drought is low, the index may still be high if the cultivated area is large. For example, the intensive mixed system in Latin America covers relatively well-watered areas that are less prone to drought. But because the cultivated area of this system is extensive, the potential impacts of droughts when they do occur can be severe.

The mean probability of a failed season within the farming system region is a second drought indicator, labelled “Avg fail” in Table 1. The value was derived by averaging the probability of a failed season (Fig. 2) over all the pixels in each of the 63 farming systems

(Fig. 1). Within some systems, some areas are very dry or experience temperature extremes that render them unsuitable for crop growth. Those pixels falling into this category we excluded from the calculation of the mean probability of a failed season. This indicator locates the most drought-prone and marginal environments. As might be expected, many of the systems with high values have very little cultivated area.

Our study also assessed the distribution of drought frequencies within the farming systems to better understand the heterogeneity of drought conditions across those regions and where the mean probability of failed seasons could be biased by a few large or small drought frequency values. The assessment also allowed us to identify the mix of crops under different drought frequency conditions across the farming systems. We developed cumulative frequency curves that show the extent of areas under all probabilities of failed seasons. The curves are discussed below in the results section.

3. Results

3.1. Population and stunted children by farming system

The study area includes 5 billion of the planet's 6 billion people (see Appendix, Table A1). About 60% of these 5 billion people live in rural areas and 40% in urban areas. The total number of stunted children is 184.3 million, a figure that corresponds well with the World Health Organization's estimate of 181.9 million stunted children in developing countries in the year 2000 (WHO, 2000).

Table A1 (see Appendix) shows the average prevalence of stunting within the farming systems. Since this figure combines all the sub-national administrative districts in a farming system, high prevalence values reflect serious malnutrition throughout the region. Of the top 20 systems, in terms of the absolute number of stunted children, only one has a stunting prevalence below 34% (i.e., the temperate mixed system of East Asia and the Pacific, 26%).

Rural population data also indicate that the systems with high numbers of stunted children have high rural populations. Unfortunately, no global data set distinguishes between urban and rural stunting, potentially biasing our results towards farming systems that include large cities.

The total number and the prevalence (or percentage) of stunted children agree reasonably well. High stunting prevalence coincides with high absolute numbers of stunted children. Farming systems with high prevalence of stunting, however, have a wide range of absolute figures. Of the top 10 farming systems according to absolute numbers of stunted children, four systems are in South Asia; and three each are in sub-Saharan Africa and East Asia and the Pacific. In terms of stunting prevalence, 8 of the top 10 systems are in South Asia, with the remaining two in sub-Saharan Africa.

3.2. Drought

The 10 systems in which the potential impact of drought on the production of staple crops is the largest are found in South Asia (3), sub-Saharan Africa (4), East Asia (2) and Latin America (1) (Table A2, Appendix). The next group of 10 systems is dominated by five Latin American systems, added to four other systems from the three regions in the first group and an additional system in Eastern Europe and Central Asia. The remaining 43 systems in the ranking are varied in their regional composition. Systems in the Middle East and North Africa tend to be found in the lower half of the ranking, reflecting the smaller cultivated area in these regions. The bottom third of the list is made up of systems that are marginal for cropping. Although these areas are drought prone, they have insufficient cultivated area to rank high on the list. In other words, people usually cultivate very little where drought is a frequent problem; because of this we emphasized target areas where many people can and do grow crops and where drought is a major problem affecting food security.

The values for mean probability of a failed season show a wide distribution throughout the list of 63 systems. The top third of Table A2, sorted by the potential drought impact index, includes a wide range of values. Some systems in the top third of the table have relatively low mean values of the probability of a failed season. For example, the root crop system in sub-Saharan Africa has a high potential drought impact index, indicating large areas susceptible to drought but a relatively low drought intensity value (mean failure) of eight. Even though droughts may be relatively infrequent compared to other systems, the large cultivated area of the root crop system in sub-Saharan generates higher losses to production. The middle and bottom thirds of the table have higher probability of failed seasons, including a few farming systems with very high values. The highest values in these two groups are associated with arid farming systems with a small aggregate of cultivated areas. For example, the sparse arid system in sub-Saharan Africa has a 94% probability of failed seasons. This system occurs in the Kalahari Desert and has very little area under cultivation.

3.3.The spatial variability of drought frequencies within farming systems

The incidence and frequency of drought varies within individual farming systems, ranging from completely absent to always present. Figs. 3 and 4 show the distribution of drought in four important regions of the developing world. (Cumulative frequency curves for each of the 63 farming systems in the entire developing world can be found at http://gisweb.ciat.cgiar.org/drought/freqcurves.htm.) The driest systems have large areas where the probability of a failed season is high. Well-watered systems have small areas with a high probability of a failed season. At these two extremes, the farming systems rely on fewer crops. Not surprisingly, high value and perennial systems are all found in well-watered areas, while pastoral systems are found in the drier areas. Farming systems that have values with a wide range of failed seasons rely on a greater number of crops. These high poverty, priority systems all show moderate to severe drought risk in between the extremes.

Figs. 3 and 4 show the cumulative frequencies of failed seasons of selected highest-poverty farming systems in the context of their respective regions. With the exception of the South Asian rice system, all show a wide range of drought frequency as evidenced by the gently sloping curves. The curves closer to 45 degrees show more varied environments. Farmers in these high-poverty systems are therefore attempting to cope with a range of drought regimes; and this is probably the reason for the diversity of cropping in these systems.

(Figs. 3 and 4 near here)

3.4. Combination of poverty, crops and drought indicators

Poverty and drought are a combined problem in Latin America and the Caribbean, sub-Saharan Africa, South Asia and East Asia (Table A2). These regions are discussed in greater detail below. Farming systems in Eastern Europe and Central Asia and in the Middle East and North Africa, generally have fewer poor and less cultivated areas susceptible to drought. While these regions do suffer from drought combined with poverty, they are relatively less important in the context both of population and cultivated area.

Table 2 shows poverty and drought in the farming systems of the region of Latin America and the Caribbean. The maize-bean system in Mexico and Central America stands out, with 2.8 million stunted children, global drought ranking of 15 and regional drought ranking of 4. The second in the ranking is coastal plantation mixed, a system that follows much of the coast of northern South America, Central America and Mexico. This system has high numbers of urban population related to the port cities on the coast. The third, the irrigated system, is found in northern Mexico and along the Peruvian coast. This system also has high urban population, including one of the region's largest cities, Lima, Peru. The fourth, dryland mixed, is often considered to be particularly drought prone but it ranks in the middle third of the global ranking of farming systems according to drought. While some of the remaining systems in Latin America have high drought rankings, they all have relatively fewer numbers of stunted children compared to other farming systems. Overall, Latin America and the Caribbean conforms to the accepted view that the region is less poor than Africa and Asia and suffers less from drought.

(Table 2 near here)

Sub-Saharan Africa, the Middle East and North Africa suffer more from poverty and drought: each of the poorest top 10 systems has more than 2 million stunted children (Table 3). Four of these systems are in the top 10 globally in the crop drought rankings. The cereal root crop and maize mixed systems, each with 6.3 million stunted children, span the southern portion of the Sahel and a large part of East Africa and have high rural populations. The root crop system has a high number of stunted children (5 million), even though drought intensity is relatively low. The other notable system in this region is agro-pastoral millet-sorghum, a Sahel system with more than 3 million stunted children and high drought intensity.

(Table 3 near here)

Areas of high drought risk in Asia have even higher numbers of stunted children (Table 4). Five of these systems each has more than 10 million stunted children. Five of the top six drought systems are also the top five systems with stunted children. The rainfed mixed system in South Asia stands out, with the second highest stunting value and the highest global drought ranking. The rice-wheat system in South Asia has the highest number of stunted children and the fourth highest drought ranking. The lowland rice system in East Asia and the Pacific has the second highest drought index but less than half as many stunted children compared to the South Asian rice-wheat system. These three Asian systems are marked by large populations with large cultivated areas. The upland intensive mixed system of East Asia and the Pacific has somewhat lower poverty and drought figures compared to the top two South Asian systems but these are still among the top rankings of the 63 systems. The Asian systems rank very high for poverty and drought throughout their top 10.

(Table 4 near here)

Poverty and drought are more severe in the farming systems of Asia and Africa, with notably lower severity in Latin America. Table 5 shows the top 15 farming systems ranked by the absolute number of stunted children. Each of these systems has more than 2.5 million stunted children, a number we chose as a threshold for inclusion here because these systems rely more heavily on staple crops. The values just below 2.5 million in Table A1 are mostly livestock-based systems. Below these, the number of stunted children begins to decrease substantially.

(Table 5 near here)

The main crops of the farming systems with high levels of poverty and drought are also shown in Table 5. Each of these crops covers at least 5% of the total cultivated area in each respective farming system (Table 6). This list suggests that poor farmers in drought-prone areas rely largely on 12 crops:

- Rice
- Wheat
- Chickpea
- Maize
- Millet
- Sorghum
- Groundnut
- Cowpea
- Cassava
- Sweet potato
- Bean
- Barley

The drought ranking of the 15 systems shown in Table 5 are all within or near the top third of the 63 farming systems globally. Nine of these 15 systems are in the top 10 in terms of their drought ranking. Only the East Asia temperate mixed system (drought rank = 23) and the East Asia highland extensive mixed system (drought rank = 28) did not fall into the top third of the 63 systems.

4. Conclusions

This assessment of poverty, crops and drought suggests that 15 farming systems should be given high priority for agricultural research and development (Table 5 and Fig. 5). These systems account for substantial populations of the poor, including over 70% of stunted children in the world. The 15 systems have large areas of cultivated lands susceptible to drought. Land use and the agricultural economy in these systems rely largely on just 12 crops.

(Fig. 5 near here)

With few exceptions, the poorest, most drought-susceptible systems have diverse environments and farmers have developed effective mechanisms to cope with risk. These farmers cope through diversity of livelihoods, including livestock. Judicious employment of improved crops may well be successful if the varieties can fit into such diverse and risky systems.

The databases used and developed in this study have great potential for research and priority-setting for developing country agriculture. Our assessment used criteria that would help focus on a reasonable number of regions and crops that could be given priority for investment in agricultural research and development. These criteria could be easily modified to reflect other priorities than those developed in the study to date.

The aggregate scale of the analysis limits the results of this study. Future work could include other poverty indicators and poverty analysis at finer geographic resolutions within the farming systems. Further work should develop crop-specific drought models that distinguish the main drought types according to the crop cycle (establishment, around flowering and terminal) in order to provide more detailed information to crop improvement programmes. This analysis excluded assessment of factors within farming systems such as variety adoption and the potential to use agricultural technology. Nor did we make economic assessments to estimate the potential impact of focusing on the priority crops and systems identified in the study. While further research could complement the results obtained here, this study provides an initial assessment of the previously bypassed poor that face high drought risk and the principal crops on which they depend.

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Figure Legends

Fig. 1. The sixty-three farming systems used for the analysis (from Dixon et al., 2001).

Fig. 2. Modelled percentage of failed seasons due to drought in the study areas.

Fig. 3. The proportion of area within each farming system experiencing at least a given number of failed seasons in a 100-year period for (A) Latin America and the Caribbean and (B) sub-Saharan Africa. Systems represented by solid lines are among the 15 systems of the world with more than 2.5 million stunted children.

Fig. 4. The proportion of area within each farming system experiencing at least a given number of failed seasons in a 100-year period for (A) South Asia and (B) East Asia and the Pacific. Systems represented by solid lines are among the 15 systems of the world with more than 2.5 million stunted children.

Fig. 5. Priority systems in Latin America and the Caribbean (LAC), sub-Saharan Africa (SSA), South Asia (SA) and East Asia (EA) with over 70% of all stunted children and substantial drought.

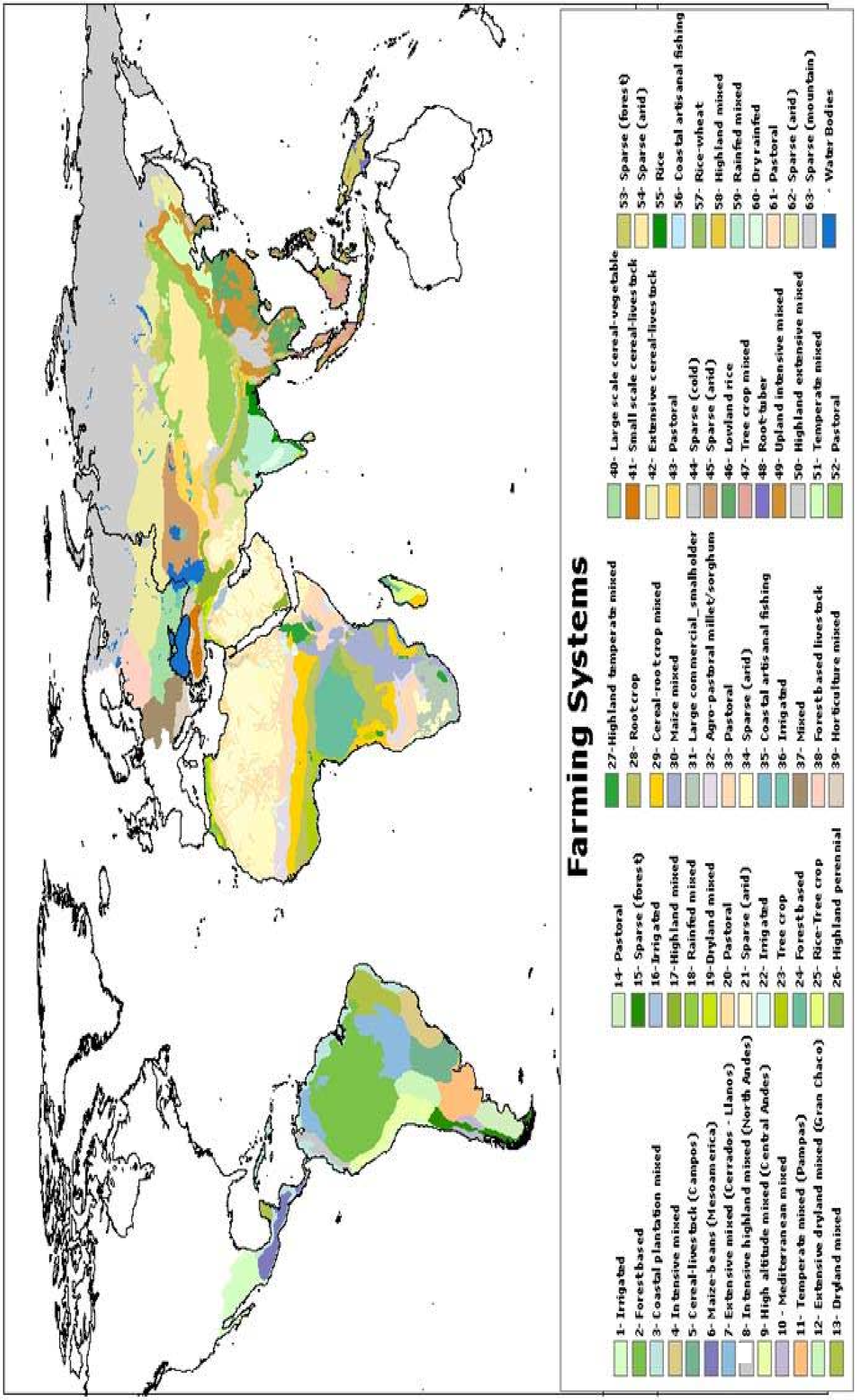

Farming Systems
1- Irrigated
2- Forest based
3- Coastal plantation mixed
4- Intensive mixed
5- Cereal-livestock (Campos)
6- Maize-beans (Mesoamerica)
7- Extensive mixed (Cerrados - Llanos)
8- Intensive highland mixed (North Andes)
9- High altitude mixed (Central Andes)
10 - Mediterranean mixed
11- Temperate mixed (Pampas)
12- Extensive dryland mixed (Gran Chaco)
13- Dryland mixed
14- Pastoral
15- Sparse (forest)
16- Irrigated
17- Highland mixed
18- Rainfed mixed
19- Dryland mixed
20- Pastoral
21- Sparse (arid)
22- Irrigated
23- Tree crop
24- Forest based
25- Rice-Tree crop
26- Highland perennial
27- Highland temperate mixed
28- Root crop
29- Cereal-root crop mixed
30- Maize mixed
31- Large commercial_smallholder
32- Agro-pastoral millet/sorghum
33- Pastoral
34- Sparse (arid)
35- Coastal artisanal fishing
36- Irrigated
37- Mixed
38- Forest based livestock
39- Horticulture mixed
40- Large scale cereal-vegetable
41- Small scale cereal-livestock
42- Extensive cereal-livestock
43- Pastoral
44- Sparse (cold)
45- Sparse (arid)
46- Lowland rice
47- Tree crop mixed
48- Root-tuber
49- Upland intensive mixed
50- Highland extensive mixed
51- Temperate mixed
52- Pastoral
53- Sparse (forest)
54- Sparse (arid)
55- Rice
56- Coastal artisanal fishing
57- Rice-wheat
58- Highland mixed
59- Rainfed mixed
60- Dry rainfed
61- Pastoral
62- Sparse (arid)
63- Sparse (mountain)
- Water Bodies

Fig. 1.

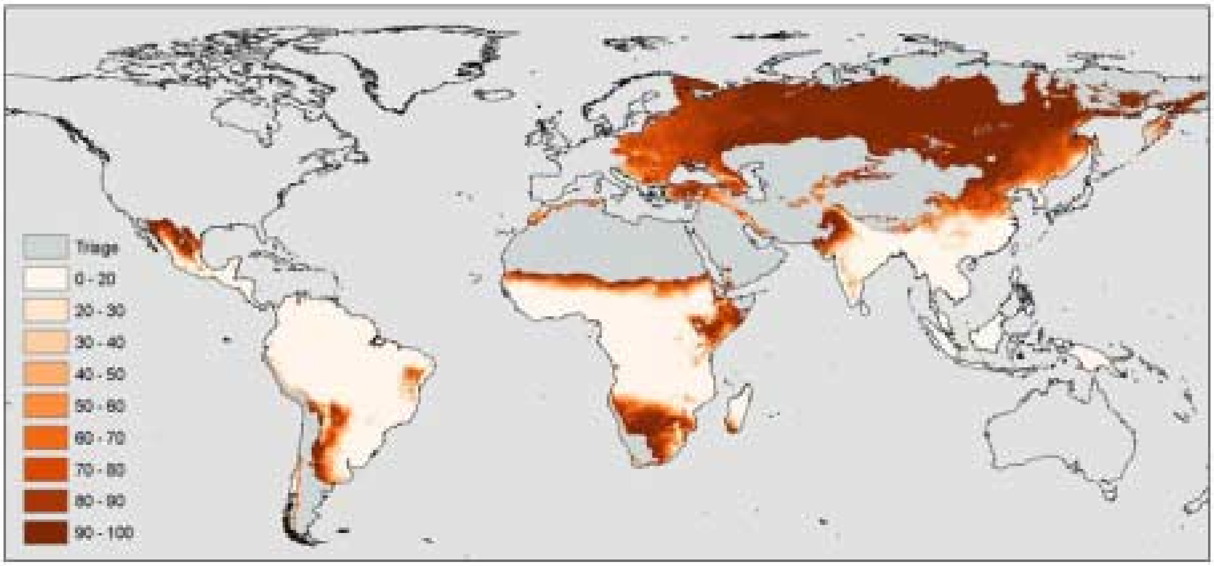
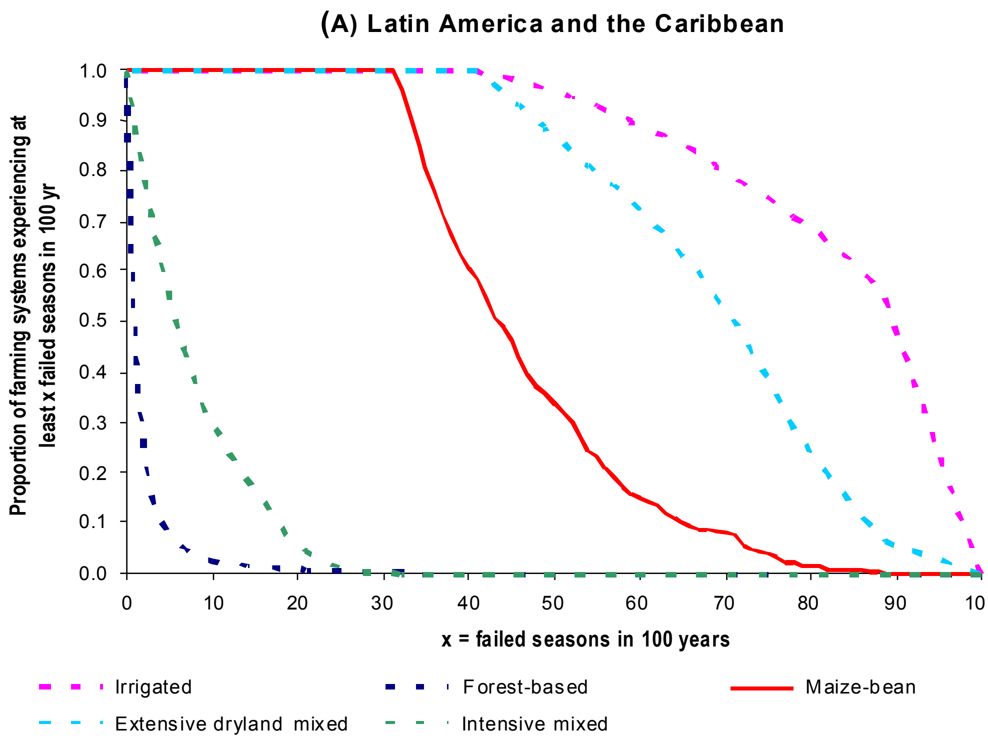
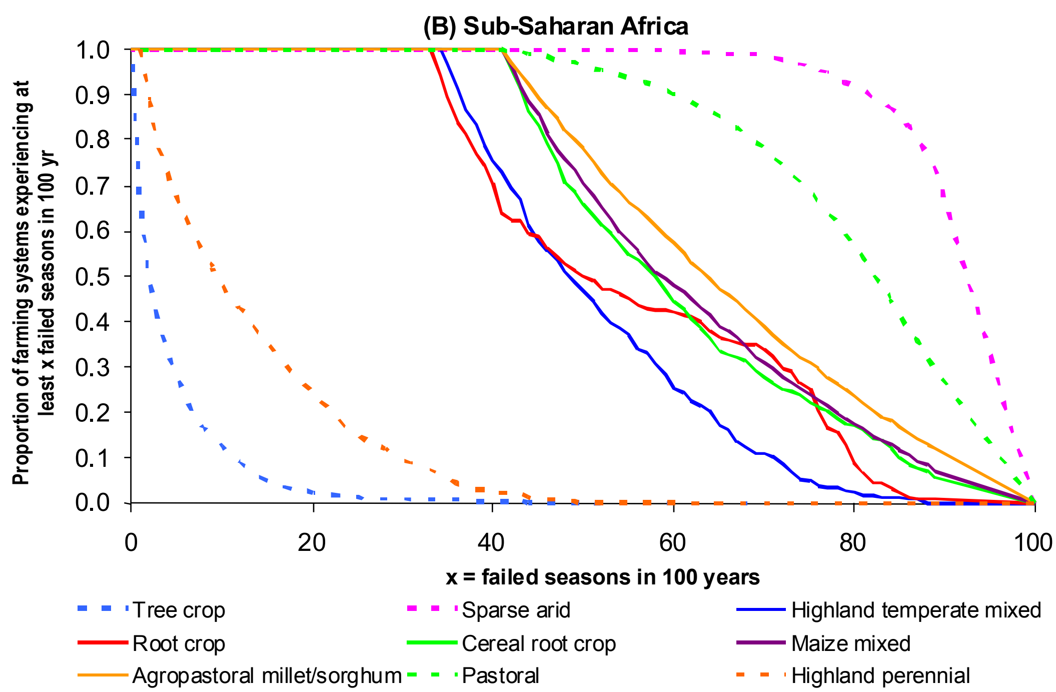
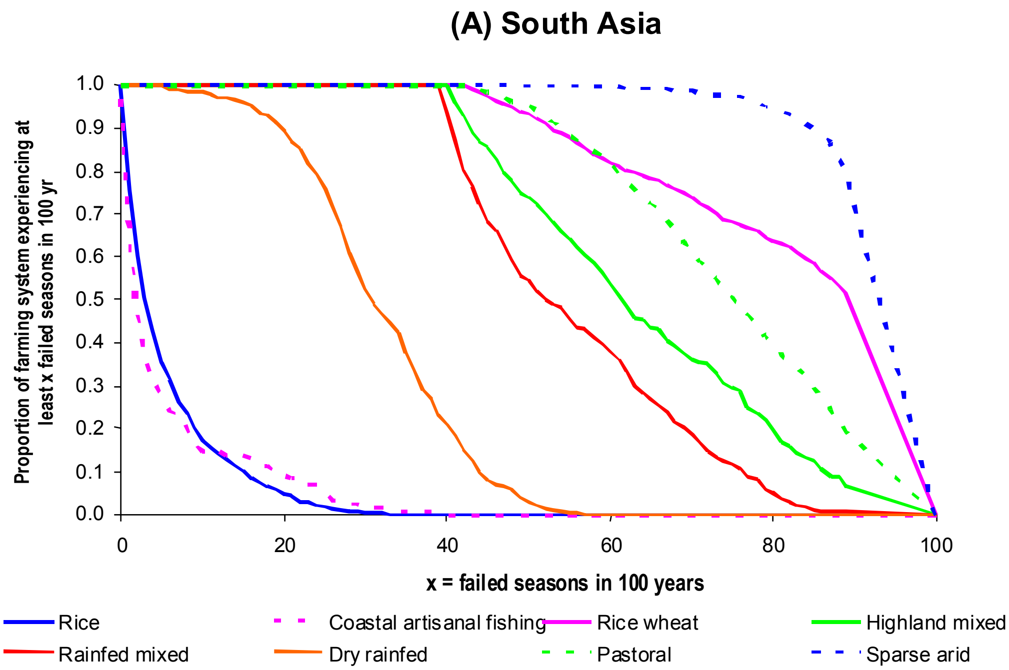


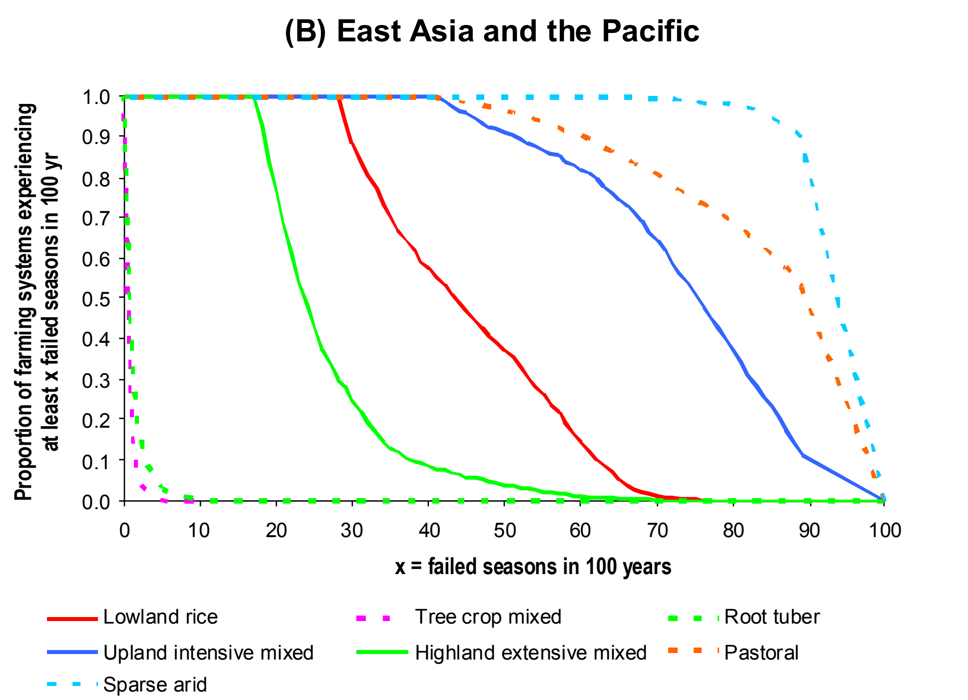
Fig. 2.





Figs. 3A and 3B.





Figs. 4A and 4B.

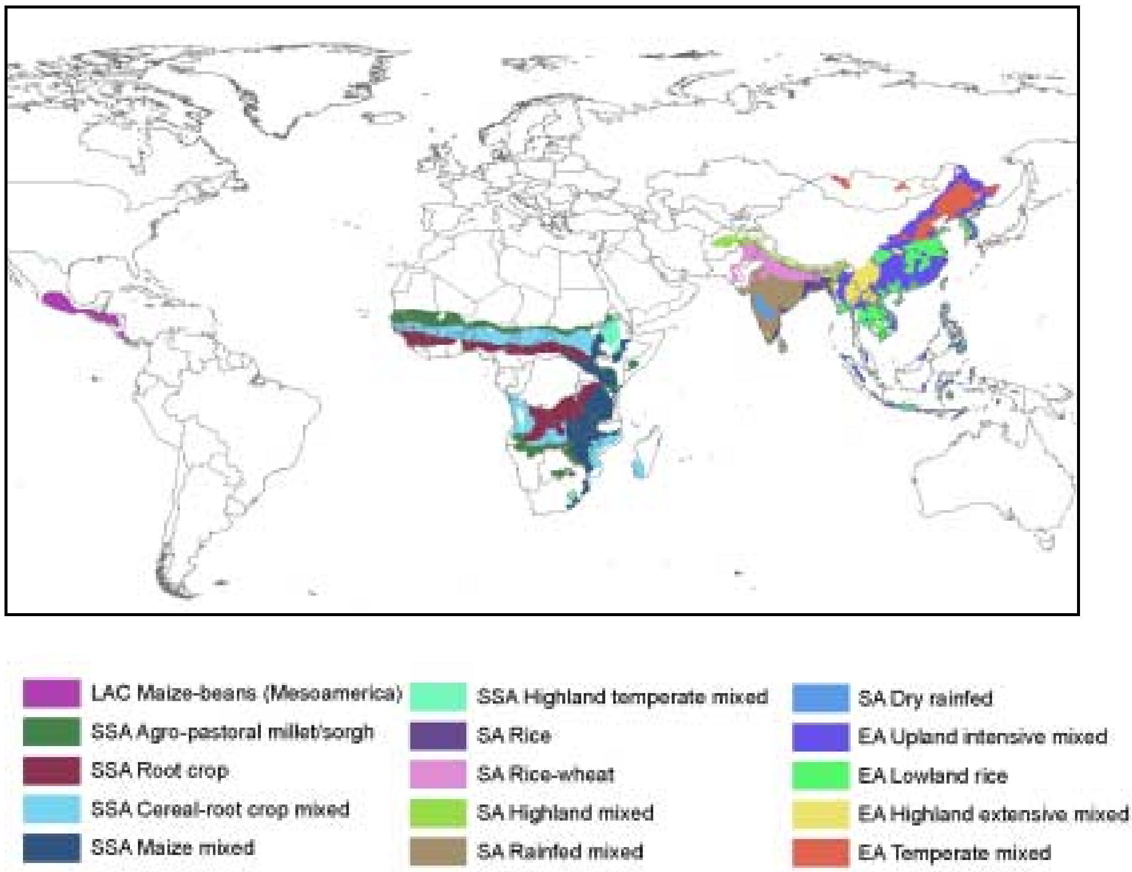

LAC Maize-beans (Mesoamerica)
SSA Agro-pastoral millet/sorgh
SSA Root crop
SSA Cereal-root crop mixed
SSA Maize mixed
SSA Highland temperate mixed
SA Rice
SA Rice-wheat
SA Highland mixed
SA Rainfed mixed
SA Dry rainfed
EA Upland intensive mixed
EA Lowland rice
EA Highland extensive mixed
EA Temperate mixed

Fig. 5.

Table 1. Rankings of 15 farming systems with over 2.5 million stunted children according to the failed seasons drought model.

Farming system	Region[a]	Stunted children ('000s)	Stunting prevalence (%)	PDII[b]	Avg fail[c]	Rank[d]	
						Global	Regional
Rainfed mixed	SA	24547	63	8,176,456	16	1	1
Lowland rice	EAP	13368	34	7,963,917	15	2	1
Cereal-root crop mixed	SSA	6319	43	5,331,317	17	3	1
Rice-wheat	SA	28310	52	4,050,261	42	4	2
Upland intensive mixed	EAP	15435	35	3,725,591	28	5	2
Agro-pastoral millet/sorghum	SSA	3135	37	2,633,259	52	6	2
Rice	SA	11664	51	2,632,872	5	7	3
Maize mixed	SSA	46318	43	2,535,536	23	8	3
Root crop	SSA	4989	40	1,802,876	8	10	4
Dry rainfed	SA	13610	65	1,227,981	31	14	4
Maize-beans (Mesoamerica)	LAC	2837	37	1,218,125	15	15	4
Highland temperate mixed	SSA	2761	50	909,683	18	21	7
Temperate mixed	EAP	2596	26	849,686	77	23	3
Highland mixed	SA	5162	48	827,142	18	24	5
Highland extensive mixed	EAP	2537	44	682,635	12	28	5

a. SA, South Asia; EAP, East Asia and the Pacific; SSA, sub-Saharan Africa; LAC, Latin America and the Caribbean.

b. The PDII (Potential Drought Impact Index) takes account of staple crop area and the frequency of drought. Drought index values are based on non-irrigated crop area.

c. The "Avg fail" indicator is the mean probability of a failed season in the farming system.

d. Both global and regional rankings are based on non-irrigated crop area.

Table 2. The top 10 systems in Latin America, both regional and global, by stunted children and failed season rankings based on expected loss to production for non-irrigated areas.

Farming system	Region[a]	Stunted children ('000s)	Failed	
			Global	Regional
Maize-beans	CA	2837	15	4
Plantation mixed	Coastal	1692	9	1
Irrigated	LAC	809	38	10
Dryland mixed	LAC	684	22	7
High altitude mixed	Central Andes	600	42	11
Forest-based	LAC	464	31	8
Intensive highland mixed	N. Andes	380	37	9
Intensive mixed	LAC	309	11	2
Extensive mixed	Cerrados-llanos	225	19	6
Cereal-livestock	Campos	221	16	5

a. CA, Central America; LAC, Latin America and the Caribbean.

Table 3. The top 10 systems in sub-Saharan Africa (SSA) and the Middle East and North Africa (MENA) by stunted children and both regional and global failed seasons rankings, based on expected loss to production for non-irrigated areas.

Farming system	Region	Stunted children ('000s)	Failed	
			Global	Regional
Cereal-root crop	SSA	6319	3	1
Maize mixed	SSA	6318	8	3
Root crop	SSA	4989	10	4
Forest-based	SSA	3243	18	6
Pastoral	SSA	3230	27	9
Agro-pastoral millet-sorghum	SSA	3135	6	2
Highland temperate mixed	SSA	2761	21	7
Highland perennial	SSA	2625	26	8
Sparse arid	MENA	2417	56	5
Tree crop	SSA	2291	13	5

Table 4. The top 10 systems in South Asia (SA) and East Asia and the Pacific (EAP) by stunted children and both regional and global failed seasons rankings.

Farming system	Region	Stunted children ('000s)	Failed	
			Global	Regional
Rice-wheat	SA	28310	4	2
Rainfed mixed	SA	24547	1	1
Upland intensive mixed	EAP	15435	5	2
Lowland rice	EAP	13368	2	1
Rice	SA	11664	7	3
Highland mixed	SA	5162	24	5
Sparse (forest)	EAP	4360	36	6
Dry rainfed	SA	3610	14	4
Tree crop mixed	EAP	3106	25	4
Temperate mixed	EAP	2596	23	3

Table 5. Fifteen farming systems with over 2.5 million stunted children, with global (fsg) and regional (fsr) farming systems rankings according to potential drought impact index.

Farming system[a]	Stunted children ('000s)	Crops[a]	fsg	fsr
SA rice wheat	28310	*Rice, pulses (chickpea) millet, wheat, maize, bean*	4	2
SA rainfed mixed	24547	Rice, millet, *sorghum*, chickpea, bean, *groundnut*, maize, wheat	1	1
EAP upland intensive mixed	15435	Maize, rice, wheat, *sweet potato, potato*, bean	5	2
EAP lowland rice	13368	Rice, maize, wheat, sweet potato, groundnut	2	1
SA rice	11668	Rice, pulses (chickpea)	7	3
SSA cereal-root	6319	Sorghum, millet, *pulses (cowpea),* maize, groundnut, cassava	3	1
SSA maize mixed	6318	Maize, cassava, sorghum, pulses, groundnut, millet, bean, sweet potato	8	3
SA highland mixed	5162	Rice, maize, wheat, potato, groundnut, pulses (chickpea)	24	5
SSA root	4989	Maize, cassava, rice, sweet potato, cowpea, sorghum, groundnut, bean	10	4
SA dry rainfed	3610	Sorghum, millet, chickpea, groundnut, bean	14	4
SSA agro-pastoral millet/sorghum	3135	Millet, sorghum, pulses groundnut, maize	6	2
LAC maize-beans	2837	Maize, bean, sorghum	15	4
SSA highland temperate mixed	2761	Maize, wheat, sorghum, *barley*, millet, pulses	21	7
EAP temperate mixed	2596	Maize, wheat, potato, groundnut, millet	23	3
EAP highland extensive mixed	2486	Rice, maize, wheat, potato, groundnut, pulses	28	5

a. SA, South Asia; SSA, sub-Saharan Africa; LAC, Latin America and the Caribbean; EAP, East Asia and the Pacific.

b. Crops appearing for the first time in the list are in italics.

Table 6. The proportional area (%) of each crop in the agricultural systems with more than 2.5 million stunted children. Areas shaded in grey have more than 5% of the area in their respective system.

Farming system	Region[a]	BANP[b]	Barley	Bean	Cassava	Groundnut	Maize	Millet	OPUL[c]	Potato	Rice	Sorghum	SWP[d]	Wheat
Maize-beans (Mesoamerica)	LAC	0.017	0.008	0.161	0.002	0.007	0.668	0.000	0.009	0.005	0.009	0.098	0.000	0.016
Cereal-root crop mixed	SSA	0.007	0.001	0.032	0.052	0.093	0.125	0.224	0.126	0.004	0.045	0.255	0.033	0.002
Maize mixed	SSA	0.000	0.004	0.057	0.091	0.063	0.461	0.059	0.073	0.023	0.024	0.075	0.056	0.016
Root crop	SSA	0.004	0.000	0.060	0.222	0.074	0.275	0.030	0.027	0.002	0.117	0.074	0.117	0.000
Agro-pastoral millet/sorghum	SSA	0.003	0.002	0.010	0.018	0.125	0.065	0.377	0.146	0.001	0.009	0.238	0.006	0.001
Highland temperate mixed	SSA	0.000	0.166	0.040	0.009	0.008	0.251	0.062	0.051	0.008	0.003	0.168	0.016	0.218
Rice-wheat	SA	0.002	0.009	0.053	0.000	0.011	0.101	0.109	0.118	0.023	0.428	0.038	0.001	0.106
Rainfed mixed	SA	0.002	0.002	0.109	0.001	0.071	0.066	0.170	0.150	0.001	0.205	0.166	0.001	0.056
Rice	SA	0.015	0.001	0.011	0.011	0.020	0.009	0.038	0.100	0.021	0.722	0.023	0.003	0.026
Highland mixed	SA	0.009	0.023	0.026	0.007	0.007	0.196	0.081	0.117	0.021	0.281	0.013	0.002	0.217
Dry rainfed	SA	0.001	0.000	0.053	0.000	0.064	0.021	0.327	0.132	0.001	0.020	0.358	0.000	0.023
Upland intensive mixed	EAP	0.012	0.009	0.060	0.035	0.045	0.267	0.017	0.021	0.062	0.249	0.005	0.080	0.137
Lowland rice	EAP	0.012	0.012	0.043	0.041	0.060	0.166	0.004	0.009	0.026	0.379	0.004	0.097	0.148
Temperate mixed	EAP	0.000	0.010	0.037	0.005	0.070	0.532	0.057	0.026	0.080	0.002	0.041	0.049	0.093
Highland extensive mixed	EAP	0.004	0.008	0.041	0.012	0.056	0.144	0.022	0.055	0.094	0.427	0.002	0.015	0.119

a. LAC, Latin America and the Caribbean; SSA, sub-Saharan Africa; SA, South Asia; EAP, East Asia and the Pacific.
b. BANP, combined category of bananas and plantain.
c. OPUL, combined category of cowpea, chickpea, lentils and other pulses.
d. SWP, sweet potato.

Appendices, for posting additional data to web site