Report to DFID (1997) Blench, RM G. Gill C. Turton

PEARL MILLET IN DEVELOPING COUNTRIES

1. Introduction

Millets rank sixth in importance in terms of contribution to global cereal supply, after wheat, rice, maize, barley and sorghum. Ninety four percent of the world's millet production is grown in developing countries. Pearl, or bulrush millet is the most important millet crop, contributing nearly half of world production and 54 per cent of developing country production. It grows in places to which very few other crops, and no other cereals, are suited: areas of high temperature, low and uncertain rainfall, and shallow or sandy soils with poor fertility and low water holding capacity. Pearl millet is the staple food of millions of the world's poorest and food-insecure people, particularly in India and Africa.

The taxonomic name usually considered valid for pearl millet is Pennisetum glaucum (L.) R. Br. but Pennisetum americanum and Pennisetum typhoides are commonly found as synonyms. The millets of Northern Ghana are so distinctive that they were originally classified as a separate species, Pennisetum gambiense, Stapf and Hubbard. This was later considered unnecessary and they are now classified as race globosum (Brunken et al. 1977; Appa Rao et al. 1985). The wild relatives of bulrush millet are found on the southern edge of the Sahara (Brunken 1977) and it is usually considered that this was its locale of domestication (see also Amblard & Pernes 1989). In south-eastern Africa, the first record of cultivated Pennisetum is at Inyanga, in modern-day Zimbabwe where carbonised seeds have been recorded from the eighth century.

Millet is usually characterised as a crop of the semi-arid zone and the majority of cultivation is found there today. However, there is a variety of evidence that prior to the introduction of maize, millet played an important role in farming systems even in the humid coastal regions of West Africa. Perrot (1990) shows that unpublished journals of the seventeenth and eighteenth centuries clearly describe millet cultivation in the lagoon areas of Côte d'Ivoire. Millet continues to be cultivated in small quantities in sandy areas of the coast west of Accra in Ghana.

Millet is the most important cereal in Saharan oases, although it is gradually yielding to wheat, although it remains important as a fodder plant (Gast and Adrian 1965). Millet was first grown in Europe in the sixteenth century and these forms, under the name *Pennisetum spicatum*, are still grown in Spain and North Africa.

Map 1 shows the distribution of pearl millet in India, the world's largest producer.[1] This indicates the importance of the crop to the country's semi-arid areas, namely Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana. It is particularly important in the drier, hotter parts of western Rajasthan, the only part of the country where it remains the staple food. Map 2 shows distribution in Africa and indicates how widespread the crop is in the Sahel and in the drier areas of western, eastern and southern Africa.

The crop has relatively high nutritional value for a cereal, it digests slowly (and so staves off hunger longer), has higher protein and fat than wheat or rice (partly because of low yields) and its amino acid balance is better than wheat and polished rice, and comparable to unpolished rice (which is not actually eaten). Pearl millet also has an impressive ability to withstand drought. If this occurs after the seedling stage, the plant will go into "suspended animation" and then resume growth when a rainfall event occurs. At the seedling stage moisture is very critical, but it usually rains at that time, because it is not sown until the rains start.

Livestock typically play a crucial part in pearl millet based farming systems. It can provide grazing, green fodder or silage, while its stover is a valuable source of feed, making it a dual purpose crop for subsistence farmers. The stover remains green to the point of harvest, thus lifting its nutritional value above that of other cereal residues.

[1] Although this map covers the period 1979/80, it is not believed that there have been such major shifts in the distribution of the crop as would render the information out-of-date.

2. Production and Productivity Trends

Accurate figures on pearl millet production in developing countries are unusually difficult to obtain. As the authors of a recent study observed:

> Statistical documentation for millet is generally poor and fragmentary. Few national statistics distinguish between the various botanical species. Some countries combine millet figures with those of sorghum and other cereals, and include millet under the general category "other coarse grains". Many of the statistics are only rough estimates.
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> (FAO/ ICRISAT 1996, p.31).

This generalisation holds true for most of Africa and some Asian countries, but the figures for India are generally more reliable.

Table 1 presents estimates of area, production, yield and per capita production of the crop at two points within a 16-year time frame.[2] The yield figures shown here are clearly very low compared to other cereals, to the extent that millets as a whole occupy 5 per cent of global cereal area, but produce only 1.5 per cent of global output (*ibid* p.33). The situation with pearl millet is even more extreme in these respects than is the case for millets generally. This reflects the even more hostile production environment, poor soil nutrition, and a dearth of purchased inputs and irrigation.

Some estimates of changes in pearl millet production and productivity over time are given in Table 2. However problems of data reliability mean that these figures should be treated with caution. It is certainly not possible to read anything into small apparent changes. However some of the comparisons shown in Table 2 are large enough to be meaningful. The general picture for Africa is fairly clear, and is consistent with what is known about African subsistence farming systems generally. Yields at best stagnating and production increase depends upon either area expansion into increasingly marginal areas, or reduction in fallow period. Either way it is unsustainable. This trend is particularly marked in the Sahel, as is indicated by the fact that all of the Sahelian countries in Table 2 exhibited yield decline and area expansion during the period in question.

Nevertheless, a surprisingly large number of African countries, particularly in western Africa, have managed to increase per capita production (Table 1), even if these gains cannot be regarded as sustainable. Per capita production is highest in Niger, at around 230 kg/annum, but even this is falling. In Eastern Africa there has been a very marked decline in per capita production, largely as a result of area contraction as the land is switched to preferred cereals such as maize.

Yields in India began the period in Table 1 lower than those of most African countries, but they have risen sharply until by the early 1990s they had surpassed the average figures for both Africa as a whole and most African countries. This is largely because of the development and popularisation of improved cultivars in India, an area in which most African countries have lagged seriously behind. Figure 1 reveals a fairly remarkable set of developments, given the difficulty of improving this crop. The introduction and spread of high yielding varieties (HYVs) since the 1960s has meant that, comparing the early 1990s with the late 1950s, national production virtually doubled (from 3.5 to 6.9 million MT), while the area planted to this crop has fallen by around seven per cent.

In less hostile environments pearl millet is grown as an animal and poultry feed. Its importance for this purpose has been growing in certain developed countries in recent years- for example in drier parts of the USA, where it has been introduced as a forage and feedgrain crop. In developing countries too the crop's importance in

[2] The points in question are 3-year averages, which is necessary in order to reduce the influence of individual years. The original publication provided country- and region-wise estimates of (a) production area and yields of all Millets combined, and (b) the relative importance of millet species in total production (FAO/ICRISAT 1996 Table 1 and Annex II) respectively. These figures have been combined here to produce estimates of area and production of pearl millet. Except where the figure for pearl millet is close to 100%, this clearly introduces a further source of uncertainty.

the livestock economy has been growing, for example in the Indian states of Gujarat, Karnataka and Andra Pradesh. This impact is not widespread, however. Over the developing world as a whole an estimated 95 per cent of pearl millet is grown for food, with only the stover being fed to livestock.

An important use of pearl millet, especially in Eastern and Southern Africa, is for making beer. Indeed, where maize is the staple food crop, both pearl millet and finger-millet tend to be grown principally for beer in rural areas. For this reason, farmers' priorities in terms of phenotypic characteristics are often very different from those in West-Central Africa.

There have been some valuable developments in the agronomy of pearl millet in the more favoured areas. Gujarat is a case that reveals the potential of this crop in such areas. Here, as in India as a whole, there has been a large decrease in net sown area, accompanied by a large increase in productivity, so that production is slowly growing. What is especially interesting about the Gujarati case is that farmers have shifted all production into the summer season, when they use irrigation, hybrids and fertiliser to produce all of their requirements. Some of this production is for subsistence, and some is for seed: by shifting the season these farmers now harvest the crop in time for it to be used as seed in other parts of India. More importantly, the season shift also releases the land to produce commercial crops at other times of year. Some Gujarati farmers have taken to producing pearl millet seedlings in nursery beds, transplanting them at 30 days. The resulting net gain of 20 days enables them to take three or even four crops a year.

Another remarkable change in the agronomy of pearl millet has been in Brazil. In the south of that country it has been produced as a foodgrain for more than 40 years. It was introduced into the semi-arid northeast in the early 1970s as a livestock and poultry feed (Netto 1997). There has now been a further development, and today it is most extensively grown in the acid savannas, or *cerrado*, as a cover crop for the zero tillage planting of maize and soya beans, a purpose for which its acid tolerance makes it well suited. In the state of Goiás in the *cerrado* region, the area on which this millet is used as a cover crop has increased from 400-600 ha in 1980s, when it was introduced, to around a million hectares today (*ibid*).

3. Trends in Commercial Production and Prices

Pearl millet is primarily a subsistence crop in the developing world. In Africa all millet production for the market is risky because of an absence of large markets for the crop, which means that fluctuations in output cause price fluctuations; only an estimated 5 to 10 per cent of African production enters the commercial market, although in surplus years it is locally bartered with people both in the Sahara and to the south (FAO/ICRISAT 1996, pp. 31 and 43). However there are some areas in the developing world where the crop is grown commercially, especially in India, although even there only an estimated 15-20 per cent is marketed. There its short growing season, higher productivity per unit of inputs (such as seed, water and nitrogen) and the low opportunity cost of the land lead to low production costs, which in turn are reflected in relatively low market prices. In mid-1997, Indian open market prices of rice and wheat are around Rs.10-11 per kg, while that of pearl millet is Rs.4-5 per kg. However Indian growers are unable to take full advantage of this competitive edge because state ration shops supply heavily subsidised rice and wheat to poor consumers at even lower prices. As long as this policy continues, the future of pearl millet as a commercial crop in India will be largely restricted to livestock and poultry feed, specialised seed production (about 20,000 ha in India today) and a limited volume of export sales.

India is now the only significant exporter of pearl millet. In 1992-94 she was exporting an annual average of almost 60,000 MT, mainly from Gujarat to the Persian Gulf. This is in sharp contrast to the position just over a decade earlier, when India had no recorded exports and Niger was the only significant supplier on the world market. During 1979-81, Niger was exporting on average almost 37,000 MT per year, but the figure had declined to zero by the early 1990s (*ibid* Table 4a). It is likely that there is an important informal trade in both millet and sorghum from the north of countries such as Nigeria and Ghana as part of the classic livestock for cereals exchange. However, such traffic rarely if ever finds its way into international statistics.

Figure 2 compares price indices for pearl millet with three other cereals over a 23 year period in India. Clearly growth in all four series has kept quite closely in step over the period. However, compared with rice and wheat prices, those of pearl millet and maize have been relatively volatile, reflecting absence of the price stabilising effect of official intervention, which has helped keep variation in rice and wheat prices within narrower bands.

4. Projections and Outlook

As part of its *2020 Vision* initiative, IFPRI has made supply and demand projections to the year 2020 for various agricultural commodities. Unfortunately, there are no separate projections for pearl millet, or even for millet as such. The crop is lumped into the "other coarse grains" (i.e. other than maize) category. In the developing world as a whole, per capita demand for this commodity class is expected to increase by 13.6 per cent to 34.42 kg by 2020. In Sub-Saharan Africa the corresponding figures are 15.9 per cent and 68.36 kg. The increases are partly explained by the fact that world prices of "other coarse grains" are projected to decline over the period by 25 per cent to US$67/MT at constant 1990 prices. This compares with projected price reductions of 15, 22 and 23 per cent for rice, wheat and maize respectively (Rosegrant *et al* 1995).

The 1996 FAO/ICRISAT millet study projected supply and demand figures for millets to the year 2005. The main features of these projections are that:

- In Africa area expansion will fall to 1.1%, while yields will grow at 1.4 per cent, but per capita production will fall.
- Asian production will increase marginally and most of this will occur in India.
- Food use will continue to dominate demand; in Asia its use as a food will fall while in Africa's it will grow.
- Africa will have major millet food deficits by 2005 totalling 66 thousand MT/year, compared with a 1992/94 "surplus" of 170 thousand MT.

An attempt has been made here to adjust the FAO/ICRISAT projections to a "pearl millet only" basis. As in Tables 1 and 2, the basis of this adjustment is the relative importance, in a given country or region, of pearl millet in total millet production. The results can therefore be regarded as indicative only.

5. Pearl Millet and Food Security

The fact some of the world's poorest and most food-insecure people in the world depend on pearl millet, indicates that its importance to world food security is significantly greater than its contribution to world food supply. Food security is usually considered on three levels: national, household and individual. At each level, three aspects should be considered: availability, stability and access (Thomson and Metz 1997, p.4).

(i) National Level Food Security

As far as pearl millet producing countries are concerned, Africa, particularly Sub-Saharan Africa (SSA), must be the major focus of concern. The situation in SSA contrasts strongly with that found in India. First, at the national level in India pearl millet is very much a minor foodgrain (although it is regionally important). This is not true for African countries, many of which produce several times India's per capita level (Table 1). Second, whereas India has made, and is expected to continue to make, substantial progress in improving productivity of this crop, Africa has not. Third, India, unlike Africa, has developed an efficient seed production and distribution system for pearl millet (and other crops). Fourth, Indian pearl millet production is projected to increase at least over the coming decade or so, while Africa is expected to move from its present "surplus" to a 66,000 MT deficit by 2005 (ICRISAT/FAO 1996). Finally, while India's population over the period 1990 to 2020 is forecast to increase by 57 per cent, the corresponding figure for SSA is 134 per cent (United Nations 1993).

The earlier-reported projections of falling cereal prices and growing per capita consumption to 2020 would be good news for national-level food security in Africa but for one thing. These developments will be accompanied by a steady withdrawal of food aid.[3] In recent history food aid has been a means of disposing of subsidy-generated surpluses from OECD countries and several very poor countries have come to rely on them. Now, as a result of the agricultural production and export subsidy reductions agreed under the *Agreement on Agriculture* (a part of GATT 1994) these surpluses will fall significantly before the end of the century. Further rounds of subsidy reductions are likely to be the subject of new negotiations to be held under WTO auspices from 1999 onwards. Some commentators are predicting that subsidy-generated surpluses in OECD countries will disappear in the near future (e.g. Islam 1996).

At the national level net food importing countries are particularly vulnerable to food insecurity, and the number of these in SSA will continue to grow, as growth of demand continues to outstrip that of supply and food import requirements mount. Figure 3 indicates two alternative sets of projections for the development of the supply-demand balance in SSA up to 2020: under either alternative set of assumptions the region's food deficit is projected to grow by 165 per cent to 16.5 million MT. Today's net food importers in Africa have already voiced great concern about the scaling down of food export subsidies by OECD countries, which will increase the cost of their food imports by and estimated 10 to 20 per cent. The FAO backs these concerns, calculating that the subsidy cuts agreed under GATT 1994 will, between 1988 and 2000, add US$500 million to Africa's food import bill (FAO 1995).

Most Sub-Saharan countries are not, therefore, food secure in terms of availability, stability and access. Although, according to IFPRI's analysis of the situation, food will continue to be available on the international market at falling real prices, such countries' access to it is constrained by a combination of dwindling food aid and rapidly-growing import requirements. Stability is also a problem, because they are primary producers and exporters. The prices of primary commodities are notoriously volatile on the international market, so that the ability of exporters to pay for imports will fluctuate.

One effect of the recent history of free or subsidised imports of wheat, rice and maize into Africa has been to add further impetus to the consumption trend away from traditional grains like sorghum and millet, particularly in the continent's rapidly growing urban areas. Higher future prices for these cereals will mean that many African countries will face increased food security at the national level. One strategy to limit this impact would be to develop their own resources to feed their burgeoning populations. To the extent that this materialises, domestic commercial demand for, and production of, foodgrains like pearl millet in many African countries will rise.

(ii) Household Level Food Security

Obviously national level food security does not guarantee food security at the household level. In a cash economy, even if sufficient food is available on the market, poor families often do not have access to enough of it to meet their needs. This is because access is a function of purchasing power. With a mainly subsistence crop like pearl millet, however, access is largely a function of availability, but availability is itself a problem, and one that is getting worse in many areas. Population pressure, reduced fallows and depleted soil fertility have caused the build up of disease and pest problems, so that yields are falling.

There is an important trade-off here that requires investigation. Yield is a measure of land productivity, and scientists' preoccupation with yields suggests an unspoken assumption that the availability of land is the constraining factor. However in the unimodal rainfall areas in which pearl millet is grown labour, rather than land, can be the critical factor. Such areas have a single cropping season, so that the onset of the rains signals a frantic rush to get the land prepared and the crop established so as to (a) give the plants maximum access to soil moisture and avoid terminal drought, (b) take advantage of the "nitrogen flush" (produced by a sudden upsurge in the activity of nitrogen releasing soil bacteria), and (c) get a head start on the weeds (Chambers *et al* 1981, Ch.1).

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[3] The forecasting model used by IFPRI for its 2020 projections does not take account the impact of falling food aid on the cost of food imports in deficit countries (Rosegrant *et al* 1995, p.6 and Appendix 1).

Research suggests that in areas where land is not in critically short supply, increasing population pressure will, for a time at least, substitute for scarce land resources by easing the labour constraint at peak seasons and so increasing the productivity of other factors of production. In one heavily populated area of Tanzania, pearl millet yields were found to be the same in the mid 1990s as they had been in the mid 1940s, despite the fact the fallows had been reduced to virtually nil. This happened because of improved crop management due to increasing labour input (Holtland 1996).

The stability aspect of food security is also a serious problem for households dependent upon pearl millet, since production is totally dependent on uncertain rainfall and therefore varies greatly from year to year. This variability is illustrated by the fact that in Niger average yields of pearl millet went from 510 kg/ha in 1988 to 240 kg/ha in 1990 and to 360 kg/ha in 1992 (FAO/ICRISAT 1996p.33). However a crucial feature of pearl millet that helps reduce farm households' vulnerability in this respect is its excellent storage properties. These spring from the fact that the crop is usually harvested and stored in dry weather conditions, while the hard hull covering the endosperm protects it against insect attack, even in traditional grain stores (*ibid* p.43). This in turn means that, provided the average level of production is adequate, and provided a reserve can be built up against emergencies, even quite extreme year-to-year variation in production need not cause food insecurity. Of course, the poorer the household the less likely is it to be able to build up stocks, even in good years.

The evolution of mixed crop and livestock farming in pearl millet areas must have helped reduce the food instability problem to some extent, and pearl millet residues make a vital contribution to this economy. Livestock provide households with an additional means of accessing food in normal times, as well as providing them with a "safety net" against times of crop failure. This, however, is only a partial alleviation of households' vulnerability, as the conditions that produce food scarcity also produce feed scarcity. In such lean years livestock quality declines, mortality increases and prices are often depressed by a glut of poor quality animals reaching the market.

A facet of the stability aspect of food insecurity that requires wider recognition is seasonality of food supply. The existence of an annual hungry season is a feature of many third world farming systems, but none more so than those found in areas of unimodal rainfall pattern. This means, among other things, that food produced during the hungry season has a much higher marginal utility to the household than food produced during the main harvest (Gill 1991, pp.21-22). Like the question highlighted earlier, as to whether land or labour supply is the constraining factor in some pearl millet-based farming systems, this is another example an issue that has a fundamental bearing on research policy, and which suggests that some agricultural scientists' continuing preoccupation with yield increase may be too simplistic an approach.

(iii) Food Security of the Individual

This has been defined by FAO as "assuring all human beings the physical and economic access to the basic foods they need" (Thompson and Metz 1997). It is the most fundamental level at which food security can exist, and, just as national level food security does not guarantee the same condition applies at the household level, so too household level food security does not guarantee the same assurance to its individual members.

Poverty impinges differently on women and men, the old, the middle aged and the young, the healthy and the sick, and the food security aspect of poverty is no different. Individual food security is bound up with economic and cultural factors that determine intra-household access to food. Gender distinctions are particularly important here. Case studies from many different societies indicate that among adults women share a disproportionate share of poverty and among children girls suffer more than boys (Bhatia 1995). In many communities there is a tradition of men eating first and the women and children waiting for what is left. Sons tend to eat before daughters.

In such societies, when there is food scarcity it is disproportionately borne by women and children - particularly girls. In famine years and hungry seasons they are first to suffer and the last to be assuaged. An important implication of this is that short duration varieties that can be harvested in the hungry season are of greatest value to women and girls. The same is true of varietal characteristics that resist the conditions that lead to scarcity and famine. These and similar gender differences have fundamental implications for research policy in pearl millet and other crops and will be examined in some detail later.

Not all intra-household differences in food security are attributable to social relations and cultural factors. Some individuals have special nutritional needs, and if these are not satisfied that individual's food security suffers. Obvious examples are pregnant and lactating women (and most women in the developing world are always either pregnant or lactating during a large part of their adult lives). Other examples include those who are sick or convalescent, people who have to do hard physical labour, and growing children. Weanlings are particularly vulnerable to intra-household food insecurity. During breast-feeding an infant's nutritional status is qualitatively ideal. When weaning commences there can be a sudden drop in nutritional status, and this is in fact the age group - around six months to two years of age - when death from malnutrition is most common (Gill 1991, Ch.3).

Pearl millet plays a vital role in alleviating this problem. It is a high-energy food and has a high protein content. Unlike other cereals it is not deficient in the amino acid lysine, so that, for a cereal, its protein efficiency is unusually high. These qualities make the crop especially suited to pregnant and lactating women, convalescents and weanlings. Moreover, if ICRISAT's work in developing yellow-grained varieties fulfils its early promise, the nutritional status of the crop could be further enhanced. These cultivars have nutritionally significant quantities of beta-carotene, which can help counter the problem of vitamin A deficiency, which is very common in areas like the semi-arid tropics, where alternative sources of vitamin A are in very short supply.

The better-than-average nutritional quality of their starchy staple is one of the few advantages that pearl millet-dependent households presently enjoy. But this is threatened by the fact that, with the exception of Namibia, pearl millet is not the preferred cereal, even in areas where it is grown as a subsistence crop. As a result, farmers tend to switch to other crops wherever this becomes technically possible - the example of conversion to maize in East Africa was mentioned earlier. Where such a switch is in the subsistence crop, the implications for the nutritionally vulnerable are direct, immediate and profound.

6. Constraints on Improvement

Pearl millet has been described as a virtually "unimprovable" crop because of the way it has evolved both naturally and through farmer selection to suit environments some of which are so harsh that not even weeds will grow (ICRISAT 1996). Yet considerable improvement has already been made. Scientific work on this crop in India pre-dates ICRISAT. The earliest research was conducted under the auspices of the Indian Council on Agricultural Research and dates from at least the 1950s. The Indian system began releasing newly-developed hybrid varieties at the beginning of the 1960s, and these have now been adopted by Indian farmers on a large scale. More than half of India's pearl millet area is now under modern varieties and the proportion is growing (see Figure 1). Nevertheless, pearl millet has been something of a poor relation within the Indian research system, and since ICRISAT was founded the pace of work on the crop has greatly increased. An estimated 80 per cent of new varieties now released in India are based on parent material from the Institute. Indian pearl millet producers are estimated to reap annual returns worth US$54 million per annum from this varietal improvement (ICRISAT 1997, p.10).

Research on the millets of West Africa, conducted under the auspices of ORSTOM in collaboration with ICRISAT, FAO and IBPGR has concentrated on the collection and identification of the genetic characteristics of both cultivated millet and its wild relatives (Amoukou & Marchais 1993; Marchais 1994; Tostain 1994). A particular thrust of research has been apomixis, present at low-levels in wild plants and which is apparently controlled by a single gene. If it proves possible to transfer the gene to cultivated races then higher yields could be sustained even under conditions of extreme drought-stress.

Hybrids and improved open-pollinated varieties have helped address the yield constraint, as has development of cultivars that are resistant to diseases like downy mildew. ICRISAT's development of short duration varieties (from African landraces) has meant that the threat of end-of-season drought has been reduced. Although there is a trade-off between yield and length of season, the short duration variety confers its own advantages by providing grain in the hungry season as well as reducing the risk of crop failure. As noted earlier, this can be especially important to poor households and to the nutritionally-vulnerable within all households.

All in all the impact of HYVs of pearl millet is greatest where the environment is least hostile. In India, improved cultivars are grown on more than 90 per cent of the area in Gujarat, where of all pearl millet growing areas soils are relatively fertile, water control is good and there is a strong input and seed delivery system. At the other end of the spectrum in western Rajasthan, only very few farmers grow improved cultivars, and then only small areas of them (ICRISAT 1997, p.9). In Africa, where production environments can be even worse than those of western Rajasthan, adoption rates are very low. For example in Niger, the world's third largest producer of pearl millet, improved varieties account for only an estimated 5 per cent of the area under this crop (FAO/ICRISAT 1996, p.39).

A multitude of constraints and limiting factors continue to hold back the development of pearl millet. However, as will be argued later, it is only quite recently that efforts have been made to involve the farmers and farm families that depend on this crop in the process of constraint identification. The views of scientists, development specialists, extensionists and others field workers are extremely relevant and important in identifying constraints, but until the end user of research is also fully, rigorously and systematically involved in the identification process, any listing of constraints such as that attempted below, will be at best incomplete.

(i) Diseases

In 1996 ICRISAT won the King Baudouin International Agricultural Research Award for its work in developing pearl millet varieties with resistance to downy mildew, a fungal disease which causes the head to produce tendrils instead of grain. Evolution of this disease is a major problem with pearl millet, so that resistant strains of the crop quickly succumb to new strains of the fungus. Hybrids have proven themselves particularly susceptible because of their genetic uniformity. Downy mildew remains the most widespread disease of pearl millet, with the continuing potential to cause catastrophic loss. Grain yield losses of 10 to 60 per cent have been reported from various African and Asian countries (Singh *et al* 1993).

Smut and ergot are panicle diseases which cause fungus spores to replace the grain. They are episodic diseases, peaking when there is heavy rainfall at the time of flowering. They are said to be important, but it is difficult to obtain formal estimates of the physical and losses they cause in farmers' field conditions (Thakur and King 1988; Thakur *et al* 1992; Thakur *et al* 1993). Informal estimates put losses at 1 or 2 per cent in normal years and less than 5 per cent in bad years.

Heliculeria leaf spot is a foliar disease of pearl millet. If it could be controlled the quality of stover would be improved.

(ii) Weeds

Striga hermonthica and *S. asiatica* are parasitic weeds which attach themselves to the roots of pearl millet and sorghum and rob them of nutrients. *Striga* is regarded as the single most important biotic constraint on grain production in SSA. It is estimated to affect 44 million hectares and to cause yield losses valued at US$7 billion a year (ICRISAT 1997). The weed also exists in Asia, but the strain is much less virulent, and is therefore less of a scourge.

The main reason that the problem is growing in seriousness in the region is repeated cropping on the same land as a result of falling fallows. This provides the weed with successive generations of hosts, so that the seed load builds up in the soil. Lightly infested fields can be hand-weeded, but when infestation becomes severe, farmers are forced to abandon their fields altogether. *Striga* weeds can remain viable in the soil for up to 15 years.

The parasite is able to attack its host successfully because the latter is in poor nutritional status. Since there is little prospect of lengthening fallows, better soil fertility would probably be the best way to help minimise the effects of infestation - especially in view of the other benefits of better soil fertility.

Presently there is no genetic tool for improved *Striga* resistance, although one may be available in 5 years or so. Even then the new variety might not be high yielding. A better approach would be to tackle the thorny and growing problem of poor soil fertility, which leaves the plants undernourished and open to parasite attack.

(iii) Pests

In West Africa there is an estimated $100m loss/annum from stem borer and head miner. Head miner is a major pest and there is at yet no genetic solution. Even if there were, the use of genetic engineering is coming under increasing scrutiny. Spraying is a possible solution, but again there are environmental and health concerns, and in any case poor farmers cannot afford it. The basis of a solution may lie in the fact that this pest produces just one generation per crop cycle and damage will be avoided if the crop does not flower during the brief period when the moth is present. Unfortunately, early flowering millets, which are bred to escape terminal drought, are especially vulnerable. There is no problem with late flowering types.

Stem borers can be very effectively controlled by simple inexpensive traps.

Bird damage can be severe in pearl millet, especially with early varieties which set seed when birds have little else to eat. The damage can be controlled by developing cultivars with sharp bristles on their glumes, as these make it difficult for the birds to reach the seed. ICRISAT has developed such varieties.

(iv) Abiotic Stress

Problems of poor soil fertility and unreliable rainfall have been mentioned several times as major constraints on productivity increase. However most plant physiologists would now agree that water is not the limiting factor in except in drought years.

Negative nutrient balance is a major problem in the Sahel, as both phosphorus and organic matter are flowing out of the region with animal exports. Phosphorus is the major limiting factor. Even 5-10 kg of P per hectare gives a significant return on a pearl millet/cowpea intercrop, raising the cereal yield from 300-400 kg to 600-700 kg. However, with a subsistence crop grown by poor farmers in inaccessible areas, standard commercial fertilisers are unlikely to play an important role in easing the problem of nutrient stress. That being the case, it seems that either cheaper mineral fertilisers must be found, or organic fertilisers introduced (or both).

In the former case, the International Fertilizer Development Center and ICRISAT have been exploring means of using locally produced rock phosphate fertiliser both alone and in combination with commercial phosphatic fertilisers and crop residues. Early results are encouraging, with yield increases of up to 250 per cent and a long-term improvement in soil fertility (ICRISAT 1997, p.74). The potential for using this resource may be high, at least in areas close to commercially viable rock phosphate deposits. The economic relationship between distance and profitability would obviously have to be investigated.

Agroforestry offers interesting prospects. One system would be to have leguminous trees and broad alleys of pearl millet between, so that the trees would act as windbreaks. ICRISAT and the International Centre for Research in Agroforestry (ICRAF) have been conducting collaborative research in this domain for some years and have had encouraging results with both pearl millet and sorghum (Shivakumar *et al* 1994). In west Africa good results have been achieved in experiments growing pearl millet in association with the leguminous tree species *Faidherbia albida*. In addition to being nitrogen-fixing, this tree is summer deciduous, so that it produces foliage in the dry season and loses it in the wet. Farmers in parts of Africa to which *F. albida* is native make great use of this "perverse phrenology", feeding the leaves to their livestock when fodder is otherwise very scarce and growing crops in the understory during the wet season. Not only does no leaf canopy remain to shade out the crop, but any leaves left on the ground act as a mulch and provide additional nutrients (Leakey 1986; Sall 1992). Improved feed for livestock also means more organic manure.

(v) Factors of Production

Since little else will grow in pearl millet areas, the land itself has little opportunity cost. However reduced length of fallows and extension of cultivation into marginal areas indicate that the availability of land for pearl millet is a constraining factor in some areas.

The problem of highly peaked labour demands in areas with unimodal rainfall patterns was mentioned earlier, and labour scarcity during the planting season is a major constraint. Male migration and a growing level of school enrolment means that the burden of labour supply is often thrown onto the women, whose time is already severely constrained (Holtland 1996). This particular constraint is sometimes eased by labour circulation, i.e. the men migrating seasonally back to the land for peak period operations such as land preparation and harvesting. (Also by the older children absenting themselves from school). However male labour circulation it eases one problem at the cost of creating another. It causes a peak in conceptions, and when this is at harvest time, the resultant peak in births occurs during the next hungry season, with negative implications for the food security of both the mothers and their babies (Gill 1991, Ch.3)

In terms of improved technology specifically for pearl millet, the greatest constraint on adoption in the least favoured areas is lack of reliable seed supply. The cost of seed is not as important an issue as availability. Seeding rates are really low at 3-4 kg per hectare, and seed multiplication rate are high, at 200-500 fold per generation (FAO/ICRISAT, p. 44). This contrasts with a crop like groundnut where seeding rates are 70-80 kg per hectare and the seed multiplication rate only around 20 fold.

Private seed companies now market around half the pearl millet seed sold in India, but the quality is very variable and the geographical coverage very uneven. A few large companies have invested in their own research facilities, have formal relations with institutions like ICRISAT, and are determined to build a reputation for quality and reliability. However there are also some very dubious small firms operating in the Indian seed sector. Geographically speaking, India's commercial seed suppliers - especially the larger and more responsible ones - are concentrated in the areas with the best production potential and the most commercialized pearl millet production, i.e. in states such as Maharashtra and Gujarat. In the less favoured areas like Rajasthan, and most especially western Rajasthan, the lack of an organized seed market is one of the main reasons for the low level of uptake of improved pearl millet cultivars. It must be added that many of the problems mentioned are no more than teething troubles. The important point is that the industry is in place and strong enough to survive. As it develops further, pressure will grow for better quality control and branded seed from reputable companies will become the norm. Even the geographical problem is not an insuperable problem. As demand in the more favoured areas is fulfilled, companies are moving into less favoured areas in search of markets. It is only a matter of time before improved seed will be available in all pearl millet growing areas.[4]

In most of Sub-Saharan Africa the position is very different. A few countries, such as South Africa and Zimbabwe, are somewhat similar to India in that they have a developed a commercial market for inputs, including seed. However again these are the relatively advantaged among African pearl millet growing countries. Even so, the strong commercial bias towards maize production in these countries, discourages farmers from investing in millet-production, even in areas of very low rainfall, where maize is an unsuitable crop.

The situation in the Sahelian areas of West-Central Africa is very different. There are now five or six good pearl millet varieties available off-the-shelf in the Sahel, but there is no seed production and modern marketing infrastructure. However, the existence of complex long-distance trade routes and markets throughout the region have allowed new varieties of crops to spread rapidly during this century. Farmers in this area have an extremely good record of transmitting cultivars that they consider of value and the failure of these improved varieties to spread may indicate some problematic aspects of their breeding characteristics. In a few countries such as Chad there is some physical infrastructure for seed supply (usually as a result of some past aid project), but this does not reach as far as the villages. Apart from Sudan, it will be a huge challenge to bring about any improvement in this situation during the foreseeable future.

(vi) Markets

The situation regarding marketing infrastructure parallels that for inputs. In the more favoured agroclimatic areas, the situation is good and often improving. However in the least favoured areas like western Rajasthan and the Sahel there is no commercial market for the crop.

The large year-to-year variation in pearl millet production that is a feature of the more disadvantaged production areas makes the development of markets very difficult, as traders look for stability and reliability in their sources of supply. There is a vicious circle in operation here, because lack of a market for produce inhibits the development of a market for inputs, which in turn constrains the productivity gains that could otherwise generate a regular marketable surplus. In Zimbabwe and South Africa government marketing boards have maintained a floor price and acted as purchaser of last resort. Given pearl millet's excellent storage properties,

[4] The problem then will be what kind of seed. Hybrids, which the companies prefer because the rate of seed turnover is high, do not do well in these relatively unfavoured environments.

this approach elsewhere would make it possible to build up buffer stocks, which in turn would permit stabilisation of supply reaching the market. However such interventions are expensive and may not, for the foreseeable future, be an option in the poor countries of the Sahel.

This does not meant there are no prospects for improvement. One was already mentioned, namely the likely phasing out of food aid and the resultant increase in domestic demand for indigenous cereals. An alternative to commercialising pearl millet itself is the development of other enterprises within the farming system to supply cash that could then be ploughed back into inputs for the subsistence component. Livestock have traditionally supplied this need, but the feed situation would have to be improved in order to increase productivity. (The additional manure would also help increase crop production.) The possibility of developing agro-forestry was mentioned earlier in this context. Cash crops are another possibility. Those already grown in pearl millet areas include a bush called *Jojoba*, which does well in very dry areas of Nigeria, producing a valuable industrial oil. Cluster bean, which is grown in western Rajasthan, is another heat-tolerant crop. It is used in industry as an emulsifier and binding agent. Enterprises like these are included here only as illustrations, of course. Before recommending any cash crop rigorous market research would be required to investigate its commercial prospects, especially the danger of flooding the market.

7. Research Prioritisation

Traditionally the agendas of publicly-funded agricultural research organisations have been set by their scientists, who were assumed to know what the problems were. Any private sector organisation that followed the same path would be courting commercial ruin, because of the danger of getting out touch with its customers' requirements. It is particularly important in the case of a subsistence crop to ensure that the rural households that use it decide on the research agenda. With a commercial crop the outside expert has a much greater role to play, because farmers in transition are often unaware of what the market wants and will pay for.

In recent times the situation has been changing with the adoption by IARCs, and some of the NARCs, of the participatory approach to research agenda setting and prioritisation. To its great credit, ICRISAT was a pioneer in this area, its first effort being the release of the Michel Pimbert's video *Participatory Research with Women Farmers* in 1991.[5] The research team in question worked with a group of poor women farmers, their first task being to establish what qualities these women valued in pigeon pea and to use the matrix ranking approach to rank these criteria on a scale of 1 to 10.[6] The scientists then screened the Institute's pigeon pea accessions to find cultivars that met these criteria, grew them out and then asked the same farmers to evaluate them. Not surprisingly, the qualities valued by these farmers were different from those that had previously ranked highly with the scientists.

The Institute now explicitly accepts that "farmer participation in the design of new crop varieties is essential if these are to meet users' needs" (ICRISAT 1997, p.76). For example, in partnership with the Southern African Development Community, ICRISAT has developed the concept of the "diverse germplasm observation nursery" (DGON). Here a large number of contrasting types of sorghum and pearl millet are grown in order to let farmers see for themselves the different possible combination of crop traits. A scoring card then allows farmers to evaluate and rank the varieties. The results revealed:

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[5] Subsequently revised and released by the Television Trust for the Environment, Zeist, the Netherlands.

[6] Having said this, the most important development of the participatory approach is to change the perceptions and perspectives of those who conduct the research, to inculcate an attitude of respect and even humility towards rural people, their practices, perspectives and beliefs instead of the more familiar top-down, "expert-knows-best" approach.

A significant difference of emphasis between farmers' priorities and those traditionally adhered to by plant breeders. Breeders, at least of the old school, tend to focus narrowly on yield, whereas for farmers a range of other traits appears more important" (*ibid*, p.78)

The methodology for this approach is still being evaluated and refined in the light of experience. One early refinement was to stop using panels of only male farmers. The addition of women is crucial, partly for reasons given earlier about intra-household discrimination in food allocation, but also because of customary gender division of labour. This means that women's work (and therefore women's work-related problems and priorities) differ from those of men. Such differences did indeed emerge from the exercise in question. For example, in Namibia it was found that men preferred a particular variety of pearl millet on taste grounds, whereas the women gave it a low score because it is difficult to dehull, and dehulling is women's work.

It is planned to further refine the methodology, for example by moving the exercise out of the experiment station into the villages in order to involve more people and create a greater sense of ownership among rural communities.

This is an opportune time to consider further methodological refinements in exercises such as these. For example, it is not clear why scoring cards were substituted for the non-literacy dependent matrix ranking technique that was used by Pimbert and his co-researchers. A method that depends on literacy skews the panel towards the better-educated, and therefore better-off. Once the approach is taken out to the villages, consideration should be given to using more participatory tools, such as matrix ranking, or the newer refinement of this, matrix scoring.[7] Once in the villages care must be taken to ensure that all farmers - rich and poor, female and male - have the opportunity to express their views. Experience shows that if deliberate steps are not taken to ensure this, the voices of the rich and powerful will dominate the discussion.

Another change that the DGON initiative has made from Pimbert's approach has been to first grow the varieties and then invite farmers to evaluate them. ICRISAT has frankly acknowledged the limitations of this, one of which is that "farmers are not encouraged to imagine completely new types of plant or to express opinions about the more subtle physiological responses of plants to their environment" (*ibid*, p.79). Again this seems a regressive step. Pimbert's approach was first to ask the farmers to list and rank their criteria, and only then to begin searching through ICRISAT's germplasm collection to see if the farmers's requirements could be met.

One can, in fact postulate at least three different levels of participation by farmers in setting the research agenda. The type just described, in which farmers are presented with as wide as possible a range of choices and asked to evaluate them, is ex-post evaluation of completed work. It is a vast improvement on what went before, but it is still based on scientists setting the research agenda in the first place. The approach used by Pimbert and his colleagues was an ex-ante design, in which the farmers set the criteria first and the scientists then searched to see if they could come up with appropriate varieties off the shelf. Given that it takes around ten years to develop a new variety, there was little else they could have done. The third level would be for the farmers to state their criteria and the scientist to then breed to order, but with a 10-year time lag the problem could well have changed by the time the solution was found. An important question at this point is whether new techniques such as molecular marking can reduce both the time lag and the cost of developing new cultivars to the point that it becomes feasible to design to order in this way. Of course different farmers will have different criteria, according to farm size, gender and other variables, so that ICRISAT's present practice of developing a range of cultivars with different characteristics suited to different circumstances would continue.

It is clear that at the institutional level ICRISAT has made a firm and wholehearted commitment to adopting a participatory approach to setting the research agenda. However the underlying paradigm shift will still take time to become part of the Institute's ethos. The confusion this process is causing is exemplified by an ICRISAT publication that says on one page: "Anticipating the needs of tens of millions of poor people who depend on pearl millet, scientists from ICRISAT ...". On a later page the same document states that "ICRISAT's insistence on involving farmers in breeding research is not just a public relations exercise ..." (ICRISAT 1996, pp 3 and 11

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[7] For a description of matrix ranking, see, for example . Matrix scoring is explained in Chambers 1997.

respectively). No one could reasonably argue that ICRISAT's adoption of a participatory approach is just a public relations exercise. However neither can you fully involve other people in a process if you also take it upon yourself to anticipate their needs.

It is clear from interviews with those who must implement the new approach that some scientists are more firmly committed to it than others. There are many who have made the commitment and have made it wholeheartedly and enthusiastically. At the other end of the spectrum some scientists are still struggling with the concept and its philosophical underpinnings, still anticipating farmers' needs.

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Table 1: Estimated Changes in Pearl Millet Area, Yield and, Production, 1979/81 to 1992/94 (3-year means)

Country/ Region*	Area (million ha)		Yield (MT ha^{-1})		Production (million MT)		Per capita production kg $annum^{-1}$		Per capita production Percent change 1979/80 to 1992/94
	1979/81	1992/94	1979/81	1992/94	1979/81	1992/94	1979/81	1992/94	
Developing World[55]	19.09	19.58	0.68	0.73	13.02	14.63	n.a.	n.a.	n.a.
Africa[87]	10.01	16.10	0.67	0.61	6.68	9.88	13.9	14.3	3.3
Northern Africa[98]	1.08	1.92	0.40	0.18	0.43	0.54	4.0	3.5	-11.5
Sudan[82]	0.90	1.60	0.40	0.18	0.36	0.45	19.3	16.0	-17.0
Western Africa[95]	7.89	13.30	0.67	0.64	5.24	8.55	36.4	43.2	18.6
Burkino Fasso[99]	0.79	1.23	0.49	0.54	0.39	0.78	62.8	80.8	28.6
Côte d'Ivoire[85]	0.05	0.07	0.58	0.84	0.03	0.06	4.1	4.5	9.4
Ghana[100]	0.18	0.20	0.64	0.82	0.12	0.17	11.2	10.3	-7.5
Mali[95]	0.61	1.14	0.72	0.61	0.44	0.69	61.6	68.4	11.1

Niger[100]	3.01	4.87	0.44	0.38	1.31	1.86	246.6	222.5	-9.8
Nigeria[98]	2.35	5.10	1.04	0.89	2.45	4.53	30.4	43.0	41.4
Senegal[100]	0.93	0.89	0.60	0.61	0.56	0.55	98.2	69.6	-29.1
Togo[100]	0.12	0.13	0.36	0.50	0.04	0.06	15.7	15.4	-1.4

Table 1 (continued)

Country/ Region*	Area (million ha)		Yield ($MT\ ha^{-1}$)		Production (million MT)		Per capita production kg/annum^{-1}		Percent change 1979/81 to 1992-94
	1979/81	1992/94	1979/81	1992/94	1979/81	1992/94	1979/81	1992/94	
Central Africa[87]	0.55	0.81	0.59	0.48	0.32	0.39	6.2	5.1	-17.9
Cameroon[100]	0.13	0.05	0.75	1.01	0.10	0.06	11.8	4.8	-59.3
Chad[100]	0.36	0.59	0.50	0.47	0.18	0.28	40.2	45.9	14.2
Eastern Africa[35]									
Kenya[55]	0.04	0.05	1.05	0.65	0.04	0.03	2.6	1.2	-55.5
Tanzania[70]	0.32	0.22	0.80	0.71	0.25	0.16	13.6	5.7	-57.6
Zimbabwe[70]	0.25	0.18	0.43	0.27	0.11	0.05	14.8	4.6	-69.2
Southern Africa[100]									

	0.09	0.21	0.41	0.18	0.04	0.04	1.3	0.9	-28.9
Asia[34]									
India[58]	10.35	8.09	0.51	0.77	5.33	6.21	7.9	6.9	-12.8
Myanmar[85]	0.15	0.17	0.45	0.66	0.07	0.11	2.0	2.5	22.6
Pakistan[97]	0.49	0.42	0.50	0.44	0.24	0.18	2.9	1.5	-48.9

Sources: Based on (1) FAO/ICRISAT 1996 Part II Table 1 and Annex 2; and (2) UN 1990 and 1995.
* Superscripts in this column indicate the percentage of total millet area that is under pearl millet. Details are given only for countries and regions where this figure exceeds 50%.

Table 2: Estimated Annual Growth Rates in Pearl Millet Area, Yield and Production, 1979 to 1994

Country/ Region	Percent per Annum			
	Area	Yield	Produc-tion	Per capita Production
Developing World	0.3	0.4	0.6	-1.4
Africa	4.1	-0.6	3.4	0.6
Central Africa	3.6	-1.3	2.3	0.0
Northern Africa	2.7	-2.7	-0.1	-2.6
Southern Africa	5.9	-4.5	1.1	-1.8
Western Africa	4.7	-0.4	4.2	1.2
Burkino Fasso	3.8	2.0	5.9	3.0
Cameroon	-6.1	3.3	-3.0	-5.8
Chad	5.4	-0.5	4.8	2.0
Côte d'Ivoire	2.6	2.5	5.2	1.3
Ghana	0.7	3.0	3.7	0.4
Kenya	3.7	-2.4	1.2	-2.3
Mali	5.1	-1.0	4.0	2.3
Niger	3.9	-1.0	2.8	1.3
Nigeria	7.7	-2.3	5.2	2.2
Senegal	0.1	1.4	1.5	-1.4
Sudan	2.7	-2.7	-0.2	-2.5
Tanzania	-2.0	-2.4	-4.4	-7.3
Togo	3.5	-1.5	1.9	-1.2
Zimbabwe	-1.6	-2.6	-4.2	-7.2
India	-1.8	2.7	-0.9	-1.2
Myanmar	0.5	1.5	2.0	-0.2
Pakistan	-1.8	-1.2	-3.0	-6.3

Sources: Based on FAO/ICRISAT 1996 Part II Table 2; Annex 2.
Note: Details are given only for countries and regions where the proportion of pearl millet area in total millet area exceeds 50%.

Table 3: Indicative estimates of Pearl Millet Production Increase. 1992/94 to 2005			
Region/Country	Thousand Metric Tons		Projected Increase (per cent)
	1992/94 (estimated)	2005 (projected)	
Developing World	14,600	17,300	18.5
India	6,200	6,900	11.3
Africa	9,900	13,100	32.3
Central Africa	390	440	12.8
Northern Africa	540	750	38.9
Southern Africa	39	39	0.0
Western Africa	8,540	11,420	33.7