Sustainability of pearl millet (*Pennisetum glaucum*) productivity in northern Namibia: current situation and challenges

C.M. Matanyaire

Agrisystems (Overseas) Ltd UK, c/o Ministry of Agriculture, Water and Rural Development, PB 5556 Oshakati, Namibia 9000.

Pearl millet production in northern Namibia is characterised by an unfavourable crop growth environment, limited cultivar availability, low cropping intensities and low, unstable productivity. Farmers operating in the region have developed knowledge and practices adapted to the situation and this should be the starting point for building improved and sustainable production systems. Technology may only be attractive to the resource-poor farmers living in northern Namibia if it is low cost and complementary to indigenous knowledge. It should, according to the farmers' judgement, reduce risk, give high returns to the resource perceived to be most limiting and ensure security of food and income. While recognising demands of other subsystems, technologies that rely on internal and renewable resources provide the greatest hope for sustaining pearl millet productivity in northern Namibia. Potential system components for sustainability include agroforestry, rotations, nutrient cycling, genetic tolerance and diversity, and efficient use of moisture and soil nutrients.

Sustainable agriculture may be defined as the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources.[1] According to Erskine,[2] a farming or production system will be sustainable only if it can maintain or enhance environmental quality, satisfy society's demand for food and ensure the economic and social well being of producers. These requirements need to be met with maximum reliance on internal and renewable resources,[3] which must be accompanied by high use efficiency of the available water and nutrients, especially for the resource-poor subsistence farmers living in the arid and semi-arid zones. A number of technology options to satisfy these requirements exist and the degree to which these strategies are currently employed by pearl millet farmers in northern Namibia, the opportunities available and challenges ahead are reviewed in this article.

The production system

Agricultural production in northern Namibia is based on mixed crop and livestock farming. The infertile sandy soils having low water-holding capacity together with short seasons of low and erratic rainfall, make pearl millet the only cereal that can be grown productively in most of Kavango and the North Central Division (NCD). Generally, pearl millet is considered more efficient in its utilisation of moisture and has higher levels of heat and moisture stress tolerance than do sorghum or maize, giving it ability to grow in harsher environments.[4–9] Pearl millet in northern Namibia is therefore grown on land that is both marginal and fragile. Consequently, the greatest challenge is to increase and maintain the productivity of a crop grown in environments of which the inherent production potential is very low.

System productivity levels

Cropping in northern Namibia is done largely for subsistence, although some households perceive pearl millet (their dominant crop) as both a food and cash crop. Access to markets is poor and the main inputs into pearl millet production are land and labour. The productivity of both factors is low. Keyler[10] estimated labour productivity in northern Namibia for households that were not self-sufficient in grain to range from 2 kg in Kavango to 5 kg of pearl millet per labour-day in the NCD. The grain self-sufficient households were estimated to have labour productivity levels of 6 kg in Kavango and 10 kg in the NCD. Average land productivity in northern Namibia, for the period 1990 to 1993, was 225 kg ha^{-1}.[11] This is similar to levels reported by Keyler[10] and Agrecona[12] in Namibia, and ICRISAT[13] in the Sahel, an almost identical environment. Water deficits are largely responsible for the low and unstable crop yields. In addition, nutrient and/or environmental stress may make the water deficit environment even more unfavourable for crop growth and productivity. The concern nationally is that a productivity level of 225 kg ha^{-1} is too low and a realistic target at least to double this level has been suggested by Agrecona.[12]

Farmers' adaptation and opportunities for change

Part of the solution to sustainability problems of arid and semi-arid environments is to be found in a study of the rationale for the adaptation of the existing systems of production.[9] This requires that we think of individual crops in the context of the systems in which they are grown. The knowledge and well-tried practices of farmers should be the starting point for building improved and sustainable production systems. Our knowledge of the pearl millet production system in northern Namibia is presented below, together with an assessment of constraints and opportunities for improvement.

Shifting cultivation

The peasant farmers in northern Namibia have traditionally used shifting cultivation as a strategy to sustain crop productivity. This is low input farming, relying on nature to restore the nutrients removed by cropping. As long as nature is given a long enough time to do so (up to 10 years following cropping for 2–3 years), the system is stable and sustainable. Evolution of the farming system from forest/bush fallow through short-term (grass) fallows to continuous cultivation is seen as a natural phenomenon.[14] The rate of the evolution is influenced by population growth, access to markets and relative costs of technologies to intensify production.

The population density in northern Namibia ranges from 2.7 persons per km^2 in Kavango to 25.5 persons per km^2 in the Oshana region, while the national density is 1.8 persons per km^2.[15] These figures are low relative to Zimbabwe (for instance), which has an estimated national density of 33 persons per km^2. However, the value of these figures is limited because they do not consider the soil quality and climate. A better measure of population density is the number of persons per million kilocalories of production potential estimated at the intermediate technology input level for developing countries, such as Namibia.[14] Using this parameter, which is called 'agro-climatic population density', Namibia is the only country in sub-Saharan Africa that has already reached a very high density of more than 250 persons per million kilocalories of production potential. Binswanger and Pingali[14] estimated that Botswana would get to that density by the year 2023 and Zimbabwe by the year 2032. Accordingly, compared with the quality of its land endowments Namibia is already under extreme population pressure and this leaves little room for shifting cultivation.

There is evidence that shifting cultivation has almost ceased in the NCD, while an estimated 33% of the Kavango households reported that they still practised it.[10] In a related study, 21% of the respondents in Kavango indicated that they sometimes left their arable fallow to maintain fertility compared with only 3% of the respondents in the NCD.[16] The element of permanent land occupation in the NCD can also be confirmed by high investments in land clearing[16] and fencing.[17] Cessation of long fallows in peasant agriculture is known to result in land degradation, evidenced by declining crop yields.[18–22] Due to land scarcity in northern Namibia, and the degradation that has started, it is therefore argued that, out of necessity, land-saving (input-intensive) technologies should now become attractive and cost-effective, giving them greater chances of sustainable adoption and success. With this opportunity on the table the challenge for research is to provide appropriate and affordable technology options for the farmers' consideration.

Cultivar choice

Traditional pearl millet landrace varieties used by African farmers have been reported to be well adapted to low fertility and low management production systems.[18] However, according to Singh and Subba,[23] they are not necessarily the most efficient for moisture and labour use potential. Many of the varieties require longer periods to mature than the effective cropping season that normally occurs in the semi-arid and arid regions. They, therefore, often experience drought stress at critical periods during their growth cycle, resulting in low and unstable grain yields. Northern Namibia is no exception to the above scenario. An evaluation of the Namibian germplasm accessions collected in 1991[24] revealed that most of them needed 120 days to mature,[25] compared with the northern Namibia season extent of 90 to 120 days. To attain yield stability, it is important to grow pearl millet cultivars with water requirement patterns that match the effective growing season of the region. According to Malton,[8] Singh and Subba[23] and Bunting and Kassam,[9] the use of stable cultivars, combined with improved management of the cropping system, imparts stability to productivity in a given environment.[9,23] Early flowering tends to give higher yield and greater yield stability than late flowering if there is a terminal drought. Moreover, if it enables the cultivar to escape drought during the critical reproductive stages, the harvest index is improved.[26,27]

Early maturing cultivars, however, give maximum benefit where rainfall is reasonably predictable and terminal droughts are common. In unpredictable environments and intermittent stress situations, as commonly happens in northern Namibia, early maturing cultivars physiologically, fail fully to exploit longer seasons whenever they occur, resulting in low yield, although yield stability would be improved.[26,28] This provides good reason for farmers to prefer a mixed portfolio of short and long-cycle varieties. It is well known that farmers have always practised pearl millet plant type selection and in the process preserved desired types besides maintaining genetic diversity.[29] The genetic diversity found in the Namibian germplasm collection[24] is adequate testimony of the farmers' conscious attempts to maintain genetic heterogeneity as an insurance against total crop failure.

Cultivar choice for northern Namibian pearl millet growers was officially broadened only in 1990/91, with the introduction of Okashana-1. It is still the only improved variety available to farmers. The SACCAR impact study estimated that during the 1994/95 season the variety was sown on 17% and 45% of the pearl millet area in the NCD and Kavango, respectively.[30] The number of households using Okashana-1 during the same season was, however, estimated to be 72% in both regions. The high adoption rate of Okashana-1 is an indication that it had a definite niche in the production system. Its early maturity (85 days) compared with 120 days (average) for local landrace varieties provided a desirable variety combination (portfolio mix) for spreading risk that the farmers immediately grabbed. Okashana-1 offered farmers their most preferred trait in improved pearl millet varieties (i.e. earliness).[31–34] Improved seed is also cheap technology with potentially very high returns on invested capital. In the Omusati region where Okashana-1 has consistently demonstrated its grain yield superiority over the farmers' local varieties, the return per Namibian dollar invested was estimated at N$330 in 1992/93 and N$85 in 1993/94.[44] The adoption of improved varieties does not significantly alter the labour input into the production system. Marginal labour input increases may be associated with grain yield gain, resulting in large returns to the labour input.[35] Binswanger and Pingali[14] argue that farmers are always eager to adopt stress-tolerant varieties whether land is scarce or abundant, because they are cheap and do not require extra labour. The poor rainfall in northern Namibia from 1990/91 to 1993/94 may have played a part in the high adoption of Okashana-1. However, farmers had no intention of replacing all the landraces with Okashana-1.[30] These findings provide clear signals that farmers are more concerned about stable system productivity as opposed to yield maximisation, and that they recognise genetic diversity as a viable option.

The challenge posed by these observations is the maintenance of the genetic diversity in the system. Potential threats to this are the high level of pearl millet cross pollination, the dominance of the earliness genes in Okashana-1, the small fields cropped by the farmers making effective isolations impossible, and a popular practice by farmers of mixing Okashana-1 seed with their local variety before planting. These conditions make it very difficult for farmers to maintain the genetic purity of both the improved variety and their landrace varieties. Research, therefore, has to take up the challenge of providing farmers with the genetic diversity by releasing for farmers' use more improved varieties of variable maturity. Unfortunately, all improved varieties currently under on-farm testing are of similar maturity range to Okashana-1, and would therefore not add much towards system stability. In this regard it is proposed that, as an interim measure, the seed production project be asked by research to increase and sell some of the popular farmers' local landraces, such as Dauréni for Kavango and Egyptian for the NCD. Meanwhile, the pearl millet breeding programme needs to focus on the production of medium and long maturity improved cultivars, so that they can offer farmers the mixed portfolio of varieties.

Soil fertility management

Whereas varietal improvement effectively addresses the effects of low and variable rainfall, this is only an intermediate strategy. Without improvements in soil fertility this will not lead, in the long run, to a more sustainable production system. Agronomic trials in the Sahel and elsewhere have demonstrated that improving soil fertility increased water-use efficiency.[36–41]

The short cycle varieties, in general, do not raise farmer incomes much under harsh environments but reduce the risk from short seasons and irregular rainfall.[28] Genetically, the grain yield potential of Okashana-1 and the available local varieties is much greater than the average productivity of farmers.[32] It is also known that improved varieties have better grain yield responses to improved management than the farmers' landrace varieties.[18,38,42,43] Efforts, therefore, need to be directed to improvements in management strategies to utilise fully the available genetic grain yield potential.

Use of farmyard manure. Research on the sandy soils of the Sahel has shown that incorporation of crop residues and farmyard manure into the crop production system is a prerequisite for stable and sustainable productive cropping.[19,20] These researchers observed that unless organic amendments (manure or crop residues) are applied, continuous cropping leads to a decrease in organic matter, leaching of bases, subsequent acidification, and a decline in yields. Soils in northern Namibia are known to be low in organic matter and extractable/water-soluble cations[44] and farmers' reports of declining soil fertility (crop yields) have been documented. Keyler[10] found that most of the farmers in the NCD judged their arable soils to have poor and declining fertility. On the other hand, most of the Kavango farmers reported that the fertility status of their arable soils was good.

Grain yield benefits of manure and crop residue incorporation in northern Namibia have been demonstrated both on-station and on-farm.[44–46] Manure is, however, widely used only in the NCD and rarely in Kavango and Caprivi. A 1992/93 survey indicated that 40% of the respondents in the NCD regularly used manure and 48% sometimes used it, compared with only 8% of the Kavango respondents, who reported occasional use and zero for Caprivi.[16,32] Similar results were found by Keyler,[10] who reported that 81% of farmers in the NCD used manure compared with 22% for Kavango. The quantities of manure applied during 1992/93 were estimated to be 2.5 tonnes in Kavango and 3 tonnes in the NCD per user.[16] Lack of livestock was established as the main reason (advanced by 98% of non-user households) for not using manure in the NCD while lack of transport (raised by 25% of the households) was the main reason in Kavango.[10]

The results of the studies reported above clearly suggest that population pressure in the NCD has already made land-saving technologies attractive, starting with the use of manure. Binswanger and Pingali[14] argue that increasing population makes input-intensive techniques cost-effective and this is the case in the NCD. Here observations of farmers bringing manure from cattle posts (more than 100 km away) for spreading on the crop lands have been made.[47] However, the situation in Kavango is still able to accommodate shifting cultivation, and there is no incentive for farmers to adopt land-saving techniques. Alternative uses for transport and labour in the Kavango remain more attractive than investing these resources into manure application.

In the NCD sustainability of manure use and therefore pearl millet productivity is under an ever-increasing threat with rising population pressure. The growing numbers of households result in increasing land proportions being opened for cropping at the expense of livestock grazing and, therefore, an ever-decreasing number of cattle can be sustained in the settled areas. In the process the less enterprising livestock owners or those with limited resources lose their livestock (usually due to starvation), while the more wealthy owners establish cattle-posts far away from the human settlements. Bringing manure back from cattle-posts is an expensive venture that can be afforded only by a few. It is therefore necessary for extension in collaboration with farmers to develop strategies for more efficient farmyard manure production. Possible options that need on-farm evaluation and demonstrations include: the use of 'mobile kraals' within the arable; the addition of weeds (before they flower) to cattle kraals during the summer, and improved siting of permanent cattle kraals, which may be accompanied by removal of the sand above the solonetz layer, to reduce the mixing of dung with sand. Some of these strategies, such as 'mobile kraaling', may be attractive to farmers in the Kavango, where transport and labour have been reported as the major constraints for manure use.

Use of inorganic fertilisers. In the Sahel, an environment very similar to northern Namibia, low to medium phosphorus doses (15 to 45 kg P_2O_5 ha^{-1}) have been demonstrated to be profitable.[18] On-station application of 20 to 40 kg of P ha^{-1} increased grain yield by three- to fivefold.[48] Trials at farmer level were, however, less spectacular; with 44 to 130% yield increases; but economical, even in years of severe drought.[37] In Namibia, use of 15 kg of P ha^{-1} increased pearl millet grain yield by 33%.[49] During 1995/96 (a year of severe drought in Kavango and the NCD), on-farm N-P response trials showed the largest response rate from P.[50] In a good rainfall year neither delayed P application nor placement method significantly affected the efficiency of P fertilisers.[20] Good P residual effects have been reported, for example, four years after application, 90 kg of P_2O_5 ha^{-1} still increased pearl millet grain yield four times over the control.[39]

In the Sahel, nitrogen was reported to improve pearl millet grain yield only in the presence of adequate P.[51] The sandy, low organic matter soils of the pearl millet growing areas, however, make nitrogen management difficult because the soils have a low buffering capacity.[52] Under the erratic rainfall situations that prevail in these areas, the risk of losing the applied N without realising any yield increase becomes great. When urea was used as a nitrogen source in the Sahel, high volatilisation losses were recorded and use of calcium ammonium nitrate significantly reduced these losses.[39]

Application of 30 kg of P_2O_5 plus 30 kg of N ha^{-1} in the Sahel increased pearl millet grain yield by 250% in farmer-managed on-farm trials.[20] On-farm research-managed, farmer-implemented trials in northern Namibia using 10 kg of P and 20 kg of N ha^{-1} during 1993/94 showed grain yield increases of 75% in the NCD and 159% in Kavango.[53] The following season the same levels of N and P doses resulted in double and treble the control yields in the NCD and Kavango, respectively. Under farmer management 15 kg of P and 20 kg of N ha^{-1} produced grain yield gains over the control of 24% in the NCD and 89% in Kavango.[50]

Despite the demonstrated potential yield gains cited above, all studies on the level of chemical fertiliser use in northern Namibia indicate that it is low. Only 3% of the farmers were reported to be regularly using fertiliser in 1992/93, while 22% sometimes used fertiliser.[16,33] All respondents in Caprivi recorded occasional use. Keyler[10] reported that 3% and 9% of the households in Kavango and NCD, respectively, used fertiliser. Most of the Kavango households (64%) reported high cost as the reason for not using fertiliser while no reason was given for the NCD.

Before manure use becomes a widespread practice in the Kavango, it is unlikely that fertiliser use may increase because land-saving techniques are still unattractive. However, in the NCD, factors militating against fertiliser use may be cost, labour demand and unavailability of appropriate fertiliser formulations. The cost is already subsidised and this is the best government can do to promote fertiliser use. It is recommended that this situation be maintained for long enough to allow farmers to test and evaluate the technology and, one hopes, give a chance for the early adopters to build up the phosphorus status of their soils through generous applications before the subsidy is removed. Meanwhile, the procurement of single element P fertilisers and more efficient N sources has been recommended to government. The labour input for basal fertiliser hill placement is noted to be higher, although it has not been measured. Sowing and fertiliser hill placement at the same time is estimated to increase the labour demand over traditional planting by a factor of two to three. Slow sowing means greater risk of poor/unsuccessful crop establishment. Good timing of sowing relative to soil moisture field capacity is critical for successful germination, emergence and establishment.[54]

Moreover, under conditions of limited moisture, seed-fertiliser placement positions on the hill are critical. Seed-fertiliser contact must be avoided and the fertiliser should be placed below and to the side of the seed. Placing fertiliser below the seed (in a bid to save time) has always resulted in poor crop emergence. A potentially viable option to reduce the labour input for basal fertiliser application is to broadcast it. Research in the Sahel[20] reported no significant difference in the efficiency of P fertilisers between hill-placed and broadcast applications. Such on-farm investigations need to be initiated in Namibia's pearl millet growing areas.

Incorporation of crop residues. Additional benefits occur when inorganic fertiliser and organic matter are used together.[20,39,55] Use of crop residues and fertiliser together at Sadore (Niger) resulted in more than 75 times more pearl millet grain than the control.[18] At Mashare, a 16-times yield gain over the control was realised with the use of 4 tonnes crop residues, 8 tonnes manure, 15 kg of P and 20 kg of N ha^{-1}.[50] However, pearl millet stover yields of the magnitude added are never realised in northern Namibia. The stalks are an important material for homestead fencing and fuel in the Oshana region. Elsewhere they are a valuable source of feed for livestock, that is normally allowed to graze them on the land.[16] Where lands are fenced (a more common situation in the NCD), only the land owner's animals are allowed to graze in the crop lands. In the NCD, a zone of high fodder scarcity, very little (if any) crop residues are available for incorporation into the soil at the start of the rainy season. Therefore, the livestock subsystem here has priority on the use of crop residues. However, in the Kavango there are usually some crop residues at the start of the rainy season that 42% of the households collect and burn. They claim that this provides better soil fertility and makes land preparation easier.[44] It is, therefore, necessary for extension in Kavango to conduct on-farm demonstrations on the benefits of crop residue incorporation into the soil as opposed to burning.

Crop husbandry technologies

Sowing period. Farmers in northern Namibia traditionally sow their pearl millet over a long period each season, starting in November and going on until February/March.[10] This prolonged sowing time is used as an insurance against within-season droughts. Under conditions of rainfall uncertainty it is logical for farmers always to assume that 'if the early plantings fail the later plantings may succeed'. Until reliable season quality predictions are in place, this is a strategy that the farmers should continue to use to improve stability of system productivity while sacrificing any chances for maximising production.

The observed practice in northern Namibia of planting the farmers' local variety early and then planting Okashana-1 later[30] is a contradiction of the above indigenous wisdom of risk management. This does not take full advantage of the new variety, especially if there is an early season termination, which has occurred on a number of occasions. To counteract these potentially negative effects, planting of Okashana-1 early in the season needs to be promoted. An appropriate sowing strategy may be 75% to 80% farmers' local variety combined with 20% to 25% Okashana-1 at the start of the season, followed by a progressive replacement of the farmers' Local with Okashana-1 as the season advances until, for the very late sowing, it becomes 100% Okashana-1.

Dryplanting. It has been estimated that 86% of the Kavango cultivators dryplant their pearl millet crop.[50] With no study figures available, a similar approximation is made for the NCD. The practice is more common where cropping is done on aeolian sands. Due to long and dry winters the soil profile in northern Namibia is, by the onset of the rains, so dry that the uppermost layers may be approaching air dryness. Once the upper soil layers become wet, at the start of the rainy season, microbiological processes quickly begin to mineralise the little organic matter and liberate nitrate. As the rains establish, the wetting front moves down the profile carrying with it the nitrate and other readily soluble minerals.[9] In the heavily leached deep sandy soils such as the aeolian sands of eastern NCD and Kavango, these nutrients are then totally lost to any late-planted crops. By choosing to dryplant on these soils, farmers demonstrate their full awareness of the consequences of late planting. This is valuable indigenous knowledge. Dryplanting is therefore a practice that should continue to be encouraged and promoted. The initiation of on-farm tests with the Magoye ripper tine as a tool for speedy dryplanting where animal power is available may be an appropriate strategy to enhance dryplanting in the northern Namibia pearl millet production system.

Land preparation. Like other pearl millet-based production systems elsewhere, the northern Namibia smallholder farmers are heavily dependent on family labour. They supplement it with animal power whenever it is available.[18,21,56] For land preparation the hoe and the animal-drawn plough are the primary tools. Keyler[10] established that 20% of the households in the NCD depended solely on the hand hoe for land preparation compared with 4% in the Kavango. Further findings of this study included the following:

- 53% and 86% of the NCD and Kavango households used animal traction for land preparation,
- in the NCD most of the draught animals were donkeys while only oxen were used in the Kavango,
- tractor hire services were used by 30% of the households in the NCD and only 4% in the Kavango,
- five privately owned tractors were identified in the NCD (an ownership level by household of 2.5%) whereas none was recorded in Kavango,
- the total proportion of households depending on draught power hire (tractor and animal) was 42% in the NCD and 39% in the Kavango,
- the largest household group in the NCD (32%) used a combination of hand hoe and animal plough, whereas in Kavango the largest group (69%) used oxen only.

Similar results were found in another study in Kavango, where 93% of the households indicated that the animal plough was their primary tool for land preparation. Seventy-two per cent used their own animals while 21% borrowed or hired the animals.[50]

The above situation suggests that sustainability of pearl millet productivity for the poor households in the NCD is really under threat. There appears to be an apparent reversal of evolution from the plough back to the hand hoe. The farming system is here no longer able to maintain the livestock needed for draught power (and manure). An increasing number of households are being reduced to the hand hoe. The findings by Keyler[10] suggest that 20% of the households are already on the hand hoe and another 32% are heading in that direction. It is also worth noting that the value of donkeys in the farming system is much less than cattle because their manure is inferior. This makes recycling of crop residues through them an inefficient and wasteful process. Furthermore, many communities in the NCD do not eat donkey meat. While in the short term donkeys are providing the draught power needed for pearl millet production, their failure to have multi-purpose utility like cattle means that environmental degradation and crop yield decline is accelerated as donkeys replace cattle in the farming system while they are not a perfect substitute. There is merit, therefore, to develop strategies that would halt the influx of donkeys into the NCD and promote reduction through slaughter, canning and export to countries and regions where donkey meat is normally eaten.

On the other hand, the Kavango still has plenty of pasture from forest/bush and grass fallows, and keeping cattle is cheap. It is also a more secure investment (compared to the NCD) because of the larger pasture resources. The Kavango cattle owners have not yet developed the culture of 'cattle posts' and all cattle are kept at home year-round. Therefore, although ownership of animals is rather low (72%), access to draught power is high (93%), despite the observation that no cows and heifers are used.[50] In the NCD it is normal practice to use both male and female donkeys for draft power. An important challenge in Kavango is to promote the use of female cattle for draught and avoid a large influx of donkeys as has happened detrimentally in the NCD.

The high usage of tractors in the NCD, and particularly in the Cuvelai catchment area, is promoted by a combination of factors, among them are:

- higher cost of fodder relative to diesel,
- easy access to spares, repair and service facilities in the Oshakati-Ondangwa urban complex,
- existence of open grassland associated with old settlements and crop lands cultivated for generations that minimise physical damages and breakdowns,
- high population density resulting in short distances between clients,
- a very high hire charge for animal draught power, N\$86 ha^{-1} for tractor compared with N\$240 ha^{-1} for animal power,[10]
- the large number of part-time farmers running successful and vibrant commercial trading ventures in the area and their realisation of the importance to prepare their lands quickly and plant once conditions are ideal as well as help others through a hire service,
- relatively low labour availability, which makes timely sowing difficult to achieve,
- the practice of taking all cattle to 'cattle posts' during the dry season, making them unavailable for draught power at the start of the rainy season and
- the need at times to carry water to the cattle posts during the dry season has often obliged large herd owners to acquire tractors for towing water bowsers.

The relative importance of each factor cited above is unknown and this may be a topic for further investigation. Meanwhile, the National Agriculture Credit Programme, through its low interest rate, may facilitate the acquisition of additional tractors. Use of tractors in the Cuvelai catchment is likely to grow because the cost of tractor hire is likely always to be lower than that of keeping cattle in the village, including the potential cost of losing them. Here, the use of tractors has become attractive and cost effective, for those with at least average resources. Consequently, there is merit to promote private group and individual ownership of tillage tractors in this zone.

Seedbed configuration. Over 90% of the farmers in Caprivi, Kavango and eastern NCD plant their pearl millet on the flat. The majority (62–81%) in the Cuvelai catchment plant their crops on ridges and/or broadbeds.[16] These land forms (products of the farmers' own ingenuity) are put in for drainage purposes on the shallow sandy soils with an underlying calcrete horizon of very low permeability. Whenever heavy rains are received in this zone, waterlogging and flooding of the low-lying areas occur. This may result in root damage and the degree to which this happens and affects pearl millet grain yield in this zone needs investigation. Equally important is the degree to which cultivars may be recovering as the profile dries. The most successful crops and cultivars may be those whose roots are least damaged and/or whose root recovery system takes place rapidly as the profile dries.[9] The land forms may be increasing productivity by increasing the crop root volume.[57,58] The Cuvelai catchment area is the most populous zone in northern Namibia, and there is merit for research to investigate the optimum land form(s). Investigation coverage would include orientation, width, height, and even possibilities of tying the ridges/broadbeds in the middle of the crop growth cycle, etc. for the variable soil depths to give operational guidance to farmers. The possible use of ridges to improve seedling establishment on aeolian sands prone to wind erosion and sand blasting also warrants investigation.

Plant densities and seeding rates. High crop densities require more water to complete the growth cycle than low densities. Adjusting crop densities to suit the environment is also known to be beneficial to crop yield.[18,26,42] Therefore, one management decision to be made by rainfed crop farmers is the balance between water supply and crop density. Smallholder pearl millet peasant farmers all over the world have often selected a target water supply level below the median for two reasons: a) it is the best way to assure survival all the time and, therefore, stable productivity[26] and b) they have low risk bearing capacity,[8,35,42,59] that is, they have not had extra resources with which to gamble by purchasing fertilisers and chemicals in the hope of a good rainfall season.[60] Moreover, those willing to gamble have not found ready lenders willing to take the risks involved. Even the Namibia National Agriculture Credit Programme, launched in 1995 to address the needs of the small farmers, has not been visibly able to take risks of crop producers in the arid NCD.

A study conducted in 1993 found that 84% of the respondents planted their pearl millet on hills.[32] If land is prepared by hand hoe, this involves digging sowing holes at the desired spacing, dropping the seed and covering. When sowing is done on ploughed land, this involves the dropping of seeds at the desired spacing and covering, almost at the normal walking speed. As practised elsewhere in the semi-arid zones, high seeding rates are used to offset potential losses due to biotic and abiotic stresses.[29] Forty-eight per cent of the households interviewed in a study during the 1992/93 season indicated that they placed 5 to 10 seeds per hill and 23% reported placement of more than 10 seeds per hill. This indigenous technology enables the seed mass to emerge even where soil crusting is a problem. There is a possibility (which needs investigation) that farmers who reported placement of more than 20 seeds per hill may be experiencing severe soil crusting problems. During establishment the seedlings are often subjected to sand blasting that is most severe on the heavily leached grey aeolian sands. The more seedlings there are on the hill the better they withstand the damage as the seedlings in the centre get protection from those on the outside that usually die when the sand blasting continues without intermittent rain. Planting pearl millet on hills in northern Namibia is, therefore, a sound practice on which all alternative (new) sowing interventions should build.

Plant counts in Kavango have estimated the plant densities to be between 12 000 and 18 000 hills ha^{-1}.[16] In a number of fields, counts were often as low as 8000 hills ha^{-1}. It is known that pearl millet grain yield changes very little with increasing plant population.[61] Tillering will add more leaf surface and increase yield as environmental conditions improve. Farmers generally plant the crop at low densities to reduce competition for water and nutrients and maximise the chances for grain yield stability. The wide spacing is a strategy to make the best use of the limited and uncertain supplies of soil moisture for crop establishment, survival and grain formation in variable environments. An area of concern, however, is the spatial distribution that is often very irregular with traditional sowing. The current extension drive to promote row sowing for purposes of weeding by means of animal power, together with the row-planted fertiliser and variety demonstrations, may help to promote better crop spatial arrangements in northern Namibia.

Weeding. Early weeding contributes to high yields[18,62,63] and saves land.[14] It is an easy practice that helps conserve soil moisture and such technologies have been reported to enhance the use efficiency of organic and inorganic fertilisers.[18,62] Any given field will support the production of a finite amount of biomass, depending on its moisture and nutrient resources. This biomass is partitioned into either weeds or crop because weeds directly compete for nutrients and water.[41] The competitive effect of weeds is known to be more detrimental if the moisture and nutrient resources are low.[64] Timely weeding in the Sahel has resulted in grain yield gains over the control of more than 100 times.[20,39,42] On-station trials in northern Namibia demonstrated yield gains due to weed control of more than 10 times.[50]

Under forest or bush fallow very little or no weeding is required. As the farming system develops into short fallows and permanent cultivation, the weed problem increases sharply.[14] Where farmyard manure or chemical fertilisers are used weed control becomes even more crucial to ensure that the added nutrients are not wasted by weeds. It has been found that 76% of the pearl millet growers in northern Namibia target to weed their crop within three weeks of emergence and the majority (68%) target to weed each crop at least twice before harvest.[16,32] Wherever these targets are not achieved, this may be due to labour constraints and/or poor labour management because a 1993 survey found that 85% of the households depended entirely on the hand hoe for weed control. Animal weeding was reported only by 24% of the respondents in Kavango, 16% in Caprivi and 3% in Omusati.[16] The extension drive to promote animal weeding is, therefore, likely to improve pearl millet productivity through timely weed control on larger areas, especially in the NCD, where it is largely an innovation.

Intercropping and rotations. The use of legume-based intercropping and rotations is a well-known fertility management strategy. Pearl millet grain yield increases of up to 100% following groundnuts/cowpeas have been recorded by researchers in India[51] and West Africa.[65] While legume/pearl millet intercrop experiments have not consistently demonstrated pearl millet grain yield increases, they have almost universally reported an increase in the land-equivalent ratio.[18,19,66–69] The economic returns in Niger under traditional farming have been reported to be substantially higher for intercropped pearl millet than sole cropped millet.[19] Intercropping has also been reported to have more stable productivity than sole-cropping.[18]

In their indigenous wisdom pearl millet farmers in northern Namibia have adopted intercropping (random rotation). A survey conducted in 1993 found that 45% of the lands were regularly intercropped while 34% were occasionally intercropped.[32] Regular intercropping was most common in Oshikoto where aeolian soils are dominant. Ninety-eight per cent of the farmers used cowpeas for intercropping. Keyler[10] also estimated that at least 95% of the farmers in northern Namibia grow cowpeas. While the cowpea to pearl millet ratio has not been measured, it is generally estimated to be low. Studies are needed to determine the optimum ratios for increasing and sustaining pearl millet productivity.

Crop rotation is uncommon and a study in 1993 estimated that only 5% of the lands were regularly rotated.[16,33] The greatest impediment to crop rotation is the lack of alternate crops that can be productively grown in northern Namibia. During the 1992/93 season pearl millet was sown on 96% of the cropped arable.[32] In a separate study the aggregated contribution of maize and sorghum towards total grain production was found to be less than 8% in the NCD and 16% in Kavango.[10] Bambara nuts were found to be an important legume in the production system. Eighty-two per cent and 67% of the NCD and Kavango households, respectively, grew bambara nuts during the 1992/93 season. However, the areas sown are generally small and seed is usually a limitation. Studies in Zimbabwe have shown that bambara nuts fix more atmospheric nitrogen than groundnuts.[70] Increasing the area sown to bambara nuts therefore has good potential for enhancing pearl millet productivity. In the short term, seed of the most popular nut types may need to be increased and sold to farmers. A long-term research and development strategy would entail some on-station selection and on-farm evaluation with the farmers' participation. There is merit in including groundnuts in this programme. It is important that seed multiplication of types preferred and selected by farmers in on-station trials be done early to avoid unnecessary delays in starting the evaluation under the farmers' own conditions.

Agroforestry. Agroforestry is a term to describe all practices that involve a close association of trees or shrubs with crops, pastures and animals.[71] It is also considered an improved 'continuous tree fallow' system.[72] Several researchers have demonstrated higher economic returns from crops grown in association with leguminous trees than the use of chemical fertilisers.[73] Higher returns to labour under agroforestry compared with monocropping have also been demonstrated.[74] Intercropping of *Faidherbia albida* with pearl millet and sorghum in the West African Sahel is one of the best known examples of a successful traditional agroforestry practice.[71] Studies in the Sahel have estimated that *F. albida* can account for 30–45% of the total livestock's feed in the dry season.[75] Fuelwood and protection of the soil from erosion are additional benefits that accrue when agroforestry practices are employed.[74] In zones where fuel wood is scarce, agroforestry has the potential to save animal dung and crop residues from becoming fuel sources when crop lands desperately need these inputs. Moreover, labour that would be needed to search for scarce fuel wood may be saved and invested elsewhere in the system.[71]

The diversion of dung and crop residues from crop lands to fuel has long started in the south of the NCD and the people appear to be resigning themselves gradually to a livelihood without fuel wood. Dust storms are becoming a common sight, and degradation is occurring at an increasing rate. Sustaining pearl millet productivity is under the greatest threat in this zone. Farmers, however, are reluctant to plant trees. Acacias are generally disliked for fear of attracting birds into the pearl millet fields. The fact that trees are not easy to establish in this arid environment, perceptions of their high land requirement and slow growth rate, are cited as further disincentives. Therefore, the challenge for research and extension is to get some community-based agroforestry tests and demonstrations started, not only in the south of the NCD but throughout northern Namibia. The success of such innovations would facilitate fast adoption by other communities through farmer to farmer diffusion.

Harvesting. In most areas the mature crop is allowed to dry on the land and then heads are cut off and stored either on the threshing floor or on an elevated wooden platform next to the threshing floor. In the NCD, the threshing floor is normally prepared by removing the top soil to expose the hard calcrete solonetz layer (locally called *oluma*). Threshing may be done on the ground or in a bag and grain always becomes contaminated with grit that is very difficult to remove, ending as part of the grain yield.

In Uukwaludhi (Omusati), the removal of grain heads from the mature crop may not be done until the king has given the farmers permission to start harvesting. To avoid losses due to lodging, all farmers generally cut and stook all the early crops before they are completely dry. The removal of grain heads is then done at a later stage when the king has given the go-ahead. This harvesting technique has two potential advantages:

a) It conserves moisture by avoiding transpiration losses from an already mature crop, especially if it is accompanied by destruction of all weeds and green plant material. This destruction is best done by early (autumn) ploughing as soon as the crop is cut, and in the process all plant matter and edible weeds could be picked up and stored for livestock feed. Furthermore, the early ploughing breaks capillary pore linkages with the subsoil, which reduces moisture evaporation losses. At harvesting time draft animals are in good condition and can plough as much as is desired with minimum strain. Once the land is ploughed, it is then ready for dryplanting before the start of the next rain season.
b) It concentrates the egg laying of the armoured cricket on to the pearl millet stooks. With training the farmers can dig the egg pods and destroy them and therefore reduce the pest problem for the coming season.

The extension challenge is to promote the adoption of these potential advantages of the harvesting practice in Uukwaludhi through on-farm demonstrations.

Storage

In all regions in which agriculture is conducted in an uncertain and unpredictable environment, the production systems seem always to include an element of storage — of water, food, cattle or other livestock on the hoof, or valuables including money hidden in the house or more securely in the bank.[9] One of the most important strategies against drought is to store excess production during bumper years for use during years of scarcity. This means that an important policy in offsetting drought effects is to reduce storage losses.

Grain storage

Excess pearl millet grain, other cereals and pulses harvested in the system during a good year are normally stored as insurance against future droughts.[10,18,76] In a field study, Keyler[10] revealed that in the NCD 90% of the households stored their pearl millet grain in traditional storage baskets, while the largest group in Kavango (29%) kept it in jute or polypropylene bags, 21% used sealed drums and another 19% stored the bulk grain in storage huts. The mean storage time was two to three years, although some farmers indicated that they could safely store the pearl millet grain for up to 8 years. Another study conducted in the Kavango found that 54% of the households would store any excess grain, while 39% would sell and 6% would give to needy relatives. Most of the part-time farmers and cattle owners tended to sell any excess grain produced, since they were already in possession of assets that could be easily liquidated if there was any need to purchase grain in future.[76] According to farmers' estimates, in the NCD 19%, 65% and 16% reported no storage loss, less than 25% loss and more than 25% loss, respectively. In the Kavango, corresponding figures were 42%, 51% and 7%. Because of the high losses envisaged in the NCD, 82% of the households took measures to control storage pests, with 70% using traditional methods and 12% using chemical control.[10]

Farmers, especially in the NCD, have complained about the poor storability of Okashana-1. Research has shown that it is a large soft endosperm grain that is more susceptible to insect damage than the small-sized hard types.[77] No estimate of storage loss has been done in northern Namibia. The observations by Keyler[10] that farmers in the NCD are, on their own initiative, practising some control measures to reduce storage pest damage suggests that the losses are high. In the interest of improving food stability in the production system it is therefore very important in the short term to do the following:

- undertake a storage loss estimation study comparing all the storage methods identified by Keyler[10] in his report,
- identify superior methods for promotion,
- identify weaknesses in the currently most popular storage structures and propose strategies for their improvement,
- identify the most important storage pests and develop guidelines for their control,
- produce an inventory of all the traditional methods used by farmers to combat storage pests, assess their effectiveness and consider possible improvements and
- evaluate the storability of improved cultivars against the farmers' landrace varieties.

Cattle storage

Cattle in marginal subsistence farming systems, like the one in northern Namibia, are an important capital source (security/savings bank) to provide cash in case of emergences.[78–82] As food insecurity increases with decreasing crop production potential, there is greater dependency on livestock for food security.[56,81]

A study in the Kavango during 1993 established that 30% of the households depended on livestock for food security, while 25% and 18% relied on salaries/wages and pension, respectively.[76] There was a tendency for an inverse relationship between herd size owned and dependence on cattle for income and food security. In particular, women who owned small herds tended to be more dependent on them, and this may be due to lack of alternative assets that could be easily liquidated. On the other hand, 48% of those owning more than 20 head of cattle did not use their cattle as income sources or for food security. These herds were a real 'store of wealth'. These huge accumulations of livestock wealth are resulting in heavy over-exploitation of communal grazing, as has been observed elsewhere,[56,78] which is attributed to 'the tragedy of the commons'.[83,84]

The current practice of 'open access', which results in large migratory grazing strategies, across community and administrative boundaries and accompanied by illegal fencing of large tracts of land by the wealthy cattle owners, is a recipe for disaster. As individuals these 'cattle barons' are exploiting the open access grazing to the detriment of the poor. When pastures are good they graze on the 'commons' and when the common pastures are overgrazed they put their animals into their illegal enclosures where no one else is allowed access. This has serious implications for the sustainability of pearl millet productivity considering the complementary nature of the crop and livestock subsystems. By their behaviour to exploit the 'common good' to a maximum, the cattle barons are crowding out the small herd owners (who often sell for lack of alternative liquidity) and lose cattle due to feed shortage whenever the 'commons' are not able to provide because of drought or over-exploitation. These factors also make it difficult for new herd owners to enter the 'ownership arena'. Operating without cattle (and therefore no manure), the poor farmers are forced to mine the soil that accelerates degradation accompanied by declining grain yields and yield stability.

The challenge for policy makers is to dismantle the illegal fences and move from 'open access' to 'common property' as soon as possible, while ensuring that the communities are fully empowered to control their 'common grazing' as well as to negotiate access for outsiders upon request.

Conclusions

In practice, sustainability of any production system has to be dynamic. Human demands change with time and sustainability calls for the production system to respond to the ever changing requirements in a way that maintains or enhances stable productivity. However, introducing production technologies in marginal and fragile areas of low agricultural potential like northern Namibia is more difficult than in areas of higher potential.[28,85–88] The low household incomes and high poverty levels of most farmers in the marginal semi-arid tropics[10,89,90] also militates against the use of high-cost technologies that may have greater yield enhancing potentials. The poor soils and undependable rainfall also result in low and highly variable returns on invested resources. Small farmers in the semi-arid zones are, therefore, not likely to invest scarce cash resources in crop production.[8,28,35] Should new technologies become available, farmers are more likely to invest in low cost inputs, such as improved seed, requiring limited labour allocations and offering large labour returns.[35] Wasting policy, research and extension effort on developing and promoting farming practices that are likely to have marginal production impacts on the system should therefore be avoided.[91,92] At the same time traditional strategies for coping with drought should be encouraged[93] and used as the basis for improving the sustainability and productivity of the production system.

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State support for research journals in South Africa: investigation seeks submissions

The Department of Arts, Culture, Science and Technology is conducting an investigation into state support for research journals. The purpose of the investigation is to collect data to enable government to establish and maintain a stable of high quality scientific journals that will meet the needs of the South African science and technology community in the best possible way. In this context scientific journals refers to publications that cover the basic and applied sciences, both natural and social, and including the humanities, provided that all or a significant portion of the space in the journal is devoted to the publication of material dealing with research.

The scope of the investigation covers the following: a) the present situation of science journals in South Africa, including publications that are currently state-funded and those that do not receive a state subsidy; b) international trends in the publication of science journals; and c) policy options for improving the economy, effectiveness and efficiency of state-funded journals.

Journals sampled for investigation will be reviewed with respect to: size, coverage and readership characteristics; quality and status assessed through both quantitative bibliometric analysis and by analysing expert opinion; and financial aspects, including subscriptions, advertising income and infrastructural costs. In addition, the perceived strengths, weaknesses, opportunities and threats identified for South African journals will be reviewed through an analysis of key stakeholder views, including the opinions of selected editors, authors and spokespersons for scientific societies.

The investigation will also include a conceptual review of government involvement in scientific publishing internationally and in selected countries which are comparable with South Africa in specified ways or are considered to follow best practice as far as government involvement in the field is concerned. Lastly, the enquiry will examine some possible future scenarios, particularly with respect to increasing multi-disciplinarity and advances in electronic publishing.

The Department of Arts, Culture, Science and Technology has awarded the tender to conduct the investigation into state-funded journals to Dr Anastassios Pouris from Science Consultancy Enterprises and Professor Linda Richter from the University of Natal. Structured questionnaires will be sent out towards the end of April to identified respondents, to gather information and views pertinent to the investigation. Scientists, research managers, editors, members of scientific societies, and other interested parties, however, are invited to submit comment on any aspect of the enquiry with particular emphasis on the role of scientific publishing, possible support schemes and the value of local journals.

Submissions should be received by 30 May, 1998 and can be sent to: c/o Mr Arno Webb, Department of Arts, Culture, Science and Technology, Private Bag X894, Pretoria, 0001. Tel: (012) 314-6357; fax: (012) 323-8308; e-mail: wb04@acts2.pwv.gov.za **or directly to**: Professor Linda Richter, Department of Psychology, University of Natal, Private Bag X01, Scottsville, 3209 Pietermaritzburg. Tel: (0331) 260-5016; fax: (0331) 260-5809; e-mail: richterl @psy.unp.ac.za