A Review of Soil Fertility in Northern Namibia: An Aid for Assessing Research Needs.

John F McDonagh[1]

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[1] **DfID PSP project**: "Increasing pearl millet production through improved use of grain legumes and animal manures". School of Development Studies, University of East Anglia, Norwich, UK. NR4 7TJ. email: j.mcdonagh@uea.ac.uk

Marina Coetzee

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are two often cited reasons explaining the size of the problem (e.g. Sanchez 1997). Farmers in Namibia may not always mention soil fertility as a major production problem (though they often do - e.g. Keyler, 1995; National Research Planning Conference, 1997) as there are several other serious constraints across most of the north of the country: low and unreliable rainfall, pests and diseases, loss of old and little availability of new crop seed varieties etc. But when farmers talk about historical crop yields it is clear most have noticed a severe decline in the productivity of their fields (Keyler, 1995) and this is supported if we look at typical pearl millet yields on farmers fields today of 200-400 kg/ha. These yields are low and, in adequate and more than adequate rainfall years, with improved soil fertility, there is potential for increasing them. In one sense they are perhaps sustainable, particularly when frequent poor rains enforce a fallow perhaps 2 years out of 5, but such a low level of production is not sustainability in a "development" sense. The livelihoods of people in northern Namibia have become increasingly diversified over the last decade, partly to fill the gap caused by increasing population and declining agricultural productivity (many households in the north harvest sufficient millet from their fields to last for four months after harvest: Keyler, 1995). Still, however, the overwhelming majority of people in the region are farmers growing pearl millet and other crops on poor soil with limited inputs. There is no reason to believe a significant proportion of the people will cease to be farmers in the future thus their livelihoods and prospects for an improved living standard rest largely on the productivity of their land.

Which is more important, water or nutrients?

There is sometimes a debate in semi-arid environments centering on whether it is water supply or soil fertility which is most limiting to crop production. Many researchers at ICRISAT in Niger believe soil fertility in the Sahel to be more limiting in production than rainfall (Shetty, et al., 1995). In northern Namibia, and other semi-arid regions, moisture is sometimes mentioned as the major constraint to pearl millet production (Matanyaire, 1995). Crop failure may be more spectacular when water supply fails completely than when fertility is low but both are required for moderate production levels, particularly if these are to be sustained. When rainfall is poor the level of soil fertility is irrelevant but in adequate and good rainfall years crops will only perform well if the nutrient supply is also adequate.

There are some irrigation schemes now in northern Namibia but a relatively small proportion of the cultivated land is irrigated or can be expected to have access to irrigation in the future. There is perhaps scope for more small-scale aquifer exploitation and rain-water harvesting initiatives but, in the short and medium term, it cannot be assumed that crop water supply will improve. Soil fertility management (SFM) strategies need to be tailored to rainfed systems in northern Namibia.

The environment in northern Namibia

North Central Region (NCR) and Kavango Region represent two of the major agro-ecological zones in northern Namibia and both will be discussed in this review.

North Central Region

About 45% of Namibia's population (total was 671,000 in 1995) live in NCR, an area of 52,000 km^2 (6.3% of Namibia's land area). 90% of the people in this region live in rural areas and thus the population density is relatively high at 11.9 persons/km^2. The vegetation is bush savannah with few trees remaining. Average annual rainfall totals increase from 360 mm in the West to 470 mm in the East. There is a sophisticated network supplying domestic water to most parts of the region.

Kavango Region

The population in Kavango was only 136,000 in 1995, with 95% living in rural areas. The population density is 2.7 persons km^2 across the region but 90% of the people are concentrated within a 10-20 km strip either side of the Kavango river. Annual rainfall rises from 540 mm in the West to 620 mm in the East. There is little provision of domestic water supply away from the river thus perennial settlements are unable to form far inland unless bore wells are provided.

Pearl millet is the cereal crop best adapted physiologically to the drier areas of NCR and Kavango. Most farmers in both regions grow some sorghum and maize but these are not [illegible] except in eastern Kavango, and provide a relatively

Good	19	18	29	22	29	33	21	28
Middle	33	39	21	31	27	30	40	32
Poor	48	43	50	47	44	37	39	40

Crops cannot be grown without water and medium to long duration crops will always fail if there is significant mid season or end of season drought. No SFM practice can change this fact but they need to be adapted to the system such that they :

- promote medium to high productivity in years with adequate or good rainfall

  and

- do not expose the farmer to increased risk in years where rains are poor.

The 'reluctance' of farmers to adopt some types of SFM strategy is often rooted in the failure of the new practice to deliver in one or both of these areas.

A moderate amount of work has been done over the last 15 years on soil fertility management in pearl millet systems, unfortunately not much of it in Namibia. It will become apparent that this review draws heavily on West African work, mostly at ICRISAT in Niger. Researchers have looked in detail at all the conventional pillars of soil fertility management in low external input systems: crop residues, legumes, manures and limited fertilizer use of fertilizers. Much of this is useful to researchers in Namibia where the physical environment is similar to that in Niger, and this work will be discussed in detail in the following sections. Much of the West African work lacks a systems perspective, however. This is an omission but, were it there, it might be of only limited use to Namibia as many defining characteristics of farming systems such as cultural preference, structure of markets and labour systems tend to evolve at a more local level. Thus, results from elsewhere can certainly help in identifying likely problems and interesting areas for soil fertility research in Namibia but may not offer many practical solutions. It is generally recognised in Namibia now that, without the full involvement of farmers in SFM research these solutions cannot be found.

2. Aim of this review

The objective of this review is not to give an exhaustive account of the general literature on soil fertility or soil fertility management (SFM) as this has often been done in the past. The aim is to synthesize information relevant to northern Namibia and, where possible, link what has been found out elsewhere to the situation in Namibia and identify areas for soil fertility research. This also represents the scientific base which, when integrated with the indigenous knowledge base provides the rationale for the DfID PSP research programme has been developed.

Clearly pearl millet is the most important crop in northern Namibia and there are no other cereal options in the drier areas of the region without irrigation. Thus this review and the PSP programme research will concentrate on pearl millet systems though much of what is discussed is relevant to sorghum or maize based systems in semi-arid Africa.

Cowpea is known in northern Namibia and is one of the legumes most commonly intercropped with cereals in Africa. Legumes have the potential to bring nitrogen into the system via N_2-fixation and a major focus of the DfID PSP project will be on legumes in the millet systems. Past research on millet/cowpea intercrops will be discussed in detail here as it is very relevent to Namibia.

The following sections are arranged under broad headings relating to specific aspects of pearl millet and cowpea agronomy, soil fertility and the farming system.

3. Main findings from West African work

Shetty et al. (1995) review the work on millet/cowpea cropping systems at ICRISAT in Niamey, Niger. Many of the problems with existing pearl millet systems and the requirements of improved systems are similar to northern Namibia. Cowpea is probably of greater traditional importance in Niger, and West Africa in general, than in northern Namibia.

3.1 Similarities in the production environment

of long duration varieties, particularly in dry matter (fodder, soil amendments) production but if the aim is to reduce risk this is a disadvantage. Thus these researchers are working with new shorter duration cultivars offering the prospect of more stable yields though with the likely penalty of smaller grain size, lower yields and, importantly, less fodder production. The picture is somewhat similar in northern Namibia with local crop varieties (pearl millet, cowpea) often having a longer duration than improved material. There is a wide range of local germplasm in northern Namibia, however, showing variation in duration as well as in other characteristics.

3.2. Millet sole crops: planting density and fertilizer response.

Bationo et al. (1990) looked at the effect of plant density and N fertilizer on pearl millet production in Niger. They tried to answer the question: why do farmers plant millet at low densities (3,000-8,000 hills/ha)? Their reasoning was that, when land is not limiting and few inputs are used, (ploughing, fertilizer etc.) there is no disadvantage from low density planting but when pressures on land increase or the investment in inputs per unit/area increase then higher plant densities are needed to use the full potential of the land. One commonly cited argument is that, in dry years, competition for water leading to crop failure is more likely when higher densities are used - this was one of the questions this research addressed. Nationally recommended density in Niger is 10,000 hills/ha with 3 plants/hill but farmers commonly use a much lower density (3-5,000 hills/ha) with more plants per hill. The researchers were fortunate in that, over the 3 years of their experiments there was a year of poor rainfall, one with adequate rainfall and one with good rainfall. They looked at millet densities of 5,000, 10,000, 20,000 and 40,000 hills/ha with 3 plants/hill. In the adequate and good rainfall years there were dramatic positive responses to both increased densities and N application. In the very dry year there was *no* yield depression at higher densities but a slight depression when N fertilizer was also applied. Otherwise all effects were positive. In the adequate and good years the highest density doubled or more yields (from 500 to >1000 kg/ha) with increasing yields if N fertilizer was applied. Also stover yields were greatly increased (33-100% greater) with increasing density and N fertilization. Even in the dry year there was no advantage from using a low density. The additional benefit of greater weed control with higher densities was also mentioned. Their final conclusion for Niger is that a farmers will maximise yields if they use a spacing of 15-20 000 hills/ha and an dose of 30 kg N/ha in a split dose (with some P) to minimise risk (if there is an early season drought the second N dose can be reduced or eliminated). These researchers failed to answer their initial question: why do farmers not plant at higher densities if yield benefits are almost always assured? Perhaps seed supply is limiting or, alternatively, land is not limiting and farmers are concerned about competition. Perhaps farmers feel 5-10 plants/hill at a wide spacing will give similar yields to 3 plants/hill at a closer spacing with a lower labour requirement at planting. What is certain is that if the farmer is investing in fertilizers, manure, or other soil fertility inputs the millet crop will use these inputs more efficiently if a relatively high density is used. This is because leaching and erosion losses of applied inputs will be high early in the season as the crop stand is thin. Where few or no inputs are used plant density is less of an issue.

Researchers frequently use higher densities than farmers in their experiments: 10,000 hills/ha is common with millet in Nigerien research (usually 3 plants/hill); most DART work in Namibia uses a millet hill spacing of 28-33,000 hills/ha with 1 or 3 plants/hill depending on the aims of the work). This is again because the effects of SFM strategies are often small at lower densities when, particularly early in the season, the crop does not fully exploit the soil. The relationship between farmers' spacing and that used in the research should always be made clear, particularly in soil fertility research - there are, however, only a few reports of farmer millet spacings in the Namibian literature. Matanyaire, (1998) states that farmers in Kavango plant 12 000 - 18 000 hills per ha but a large number only plant 8000 hills per ha. Data from the KFSR/E project in Kavango (Bagnall-Oakely, personal communication) suggest farmer's field densities of 15-16,000 hills/ha. In NCR although the DART recommendations are for 30,000 hills/ha, farmers are thought to plant only 10,000 hills/ha. Thus recorded spacings range from 8,000 - 18,000 hills/ha, though there does appear sometimes to be confusion as to whether the available data refer to hills or plants (there may be 3-10 plants/hill).

Azam-ali et al. (1984 a & b) looked at the effect of planting density on root development and water uptake in pearl millet sole crops. They found that there was less tillering and some depression of dry weight accumulation with very high plant densities (115,000 hills/ha) but not at their low density treatments which were, in fact, rather dense at 29,000 [illegible] that planting at densities up to 20,000 hills/ha sole cropping. Much of the following discussion will focus on pearl millet/cowpea intercropping as a significant amount of research has been done in this area and much of it is relevant to northern Namibia.

3.3. Pearl millet/cowpea intercrops.

In the Sahel farmers intercrop to stabilize productivity, reduce risks of total crop failure and spread labour peaks - Namibian farmers probably intercrop for similar reasons and these advantages must not be lost with any proposed 'improvements'. Although both cowpea and millet are resistant to water stress, pearl millet is particularly sensitive to drought stress around mid-season, lasting about 45 days starting from 30-40 days after planting - the time of stem elongation and anthesis (Bationo, et al., 1990, Petrie and Hall, 1992). If there is drought stress at this time there may well be no response to N fertilizer and a negative response to high application rates due to excessive vegetative growth. Cowpea can survive soil water deficits more effectively than pearl millet and, when drought is extreme, can produce higher yields than millet. Thus there is a useful insurance element when growing these crops together. It shouldn't be forgotten, however, that millet is a much more important crop for the farmer, most years (Keyler, 1995).

Average cowpea yields when intercropped with millet on farmers fields in Niger are 200 kg/ha (Ntare, 1989). Pearl millet grain yields reported in the West African work range from 280 kg/ha in poor soils with no amendments (Bationo et al 1993) to 1000 -1600 kg/ha with various combinations of adequate rainfall, crop residues and fertilizer applications (Christianson et al, 1990, Bationo et al 1993). The millet crop duration is typically 90-110 days and local cowpea 120-150 days maturing at the end of the rainy season. In most years in the drier regions these long duration cowpea varieties produce little grain - only fodder. Cowpea is normally sown 2 weeks to a month after millet.

3.3.1. How important is competition between pearl millet and cowpea?

There is always likely to be some form of competition when two crops are grown together at the same time. This can be for one or more of the important resources: water, light or nutrients. For some reason farmers across West Africa and also farmers in Namibia are happy to intercrop cowpea, but not usually other legumes, with pearl millet. This is partly for the reasons of insurance mentioned above but also suggests competition between the crops may be limited. Some research also supports this. The two crops have different rooting patterns and the work of Petrie and Hall (glasshouse experiment, 1992) has suggested that, even when grown in very close proximity to each other, the two crops exploit different soil water reserves. This conclusion is supported by water balance studies of pearl millet/cowpea intercrops in Nigeria (Grema and Hess, 1994) where, albeit in a year of good rains, the authors believe the cowpea did not compete with the millet for either water or light but rather used water that would otherwise be lost to evaporation. It has been shown that soil evaporation can be considerable in low density millet crops (Wallace et al. 1993 in Grema and Hess, 1994). Work over 4 seasons by Reddy et al. (1992) in Niger supports the suggestion that millet suffers little from water or light competition when intercropped with cowpea. In this work millet was well fertilized and planted at 10,000 hills/ha with cowpea planted at 20,000 hills/ha (i.e. quite a dense stand). Over the 4 seasons with total season rainfall ranging from 454-616 mm in no year were there significant millet yield depressions in the intercrops when compared with millet sole crops. Their conclusion is, therefore, that the risks (to millet) of competition for water and light may be small in millet/cowpea intercrops. Competition for nutrients is more likely in dense stands (Grema and Hess, 1994), but this experiment was well fertilized. Cowpea yields were greatly reduced by intercropping in this work (approximately 50% of cowpea sole crop yields but still reasonable at 500-1400 kg grain/ha) but this is inevitable and greatly preferable to millet yield depression.

3.3.2. Planting density in intercrops

Farmers in West Africa normally sow cowpea at a very low density of 2-3,000 hills/ha (Ntare 1989) when it is intercropped with millet. Pearl millet is commonly also planted at rather a low density of 5-8,000 hills/ha (but 5-10 plants per hill). Ntare and Williams (1992) reported local cowpea densities of 1000-5000 plants/ha in intercrops with millet and, at these low densities competition problems are unlikely whatever the relative planting times or crop varieties. The situation may be similar in northern Namibia today.

intercrops almost always use these higher

A classification taken from Ntare (Ntare, 1989) which he used to describe a number of varieties in quite widely accepted and is presented in Table 2.

Table 2. Characteristics of some cowpea varieties used by Ntare (1989) in Niger

Variety	Habit	Duration in days	Duration classification	Photoperiod	Source
1	determinate, erect	60	extra early	insensitive	IITA[1] (improved)
2	determinate, erect	65	extra early	insensitive	IITA (improved)
3	Indeterminate, bush	70	early	insensitive	IITA (improved)
4	Indeterminate spreading	70	early	insensitive	IITA (improved)
5	Indeterminate spreading	70	early	insensitive	local selections
6	Indeterminate spreading	75	medium-maturing	insensitive	local selections
7	Indeterminate spreading	80	medium-maturing	insensitive	local selections
8	Indeterminate spreading	>90	late-maturing	sensitive	local fodder landrace

[1]International Institute for Tropical Agriculture, Nigeria

Most of the cowpea varieties around today can still be similarly grouped. *In general*, 'improved' varieties tend to be early maturing, often erect or bush type, insensitive to photoperiod (this allows them to be grown successfully across regions with different day-lengths) and produce relatively large amounts of grain and small amounts of residues. Local varieties are usually late-maturing, spreading, indeterminate, photoperiod sensitive and produce large amounts of residues.

Ntare's work (1989) suggested that the long-duration, indeterminate spreading cowpeas are more likely to seriously compete with the millet if planted at the same time, thus a week's delay is essential in W. Africa if these varieties are grown at moderate densities. More determinate, less vigorous or short duration varieties can probably be planted sooner after the millet and work from Nigeria (Grema and Hess, 1994) agrees, in this respect, with the ICRISAT findings in Niger. Over four seasons in Niger Reddy et al. (Reddy, et al., 1992) looked at millet/cowpea intercrops planted with relative delays of 1, 2 and 8 weeks. In the 8 week treatment cowpea performance was extremely poor. The legume performed best when planted only a week after the millet and there was no significant millet yield depression (compared with sole crop millet) in any of the treatments. Annual rainfall was from 454 - 616 in the four seasons and fertilizer (45 kg N and 9 kg P/ha) was applied to all millet crops. Thus a relatively narrow planting window of 7-10 days after millet planting is recommended for the cowpea in West Africa.

Ntare (1989, though work actually done in 1984) looked at competition between millet and 75 advanced cowpea breeding lines from IITA . The results (Table 3) give a useful indication of how likely competition is with particular cowpea types.

Table 3. Cowpea and millet yield reduction (%) for different cowpea plant types in 1995 and 1996 in Niger (taken from Ntare 1989)[1].

Cowpea plant type	number of varieties	1985			1986		
		cowpea grain	cowpea fodder	millet	cowpea grain	cowpea fodder	millet
Early erect, determinate	15	37	36	24	51	46	34
Early, semi-erect, indeterminate	36	33	33	42	47	34	47
Early spreading	17	31	34	32	49	42	34
Late spreading	7	21	23	54	32	22	50

[1]In this work the millet and cowpea crops were planted at the *same time*, millet spacing was 1 x 1 m, and the cowpea was planted between millet rows with an interrow spacing of 30 cm (i.e. density of 30,000 hills/ha).

... serious competition and millet yield depression can occur. In this

	bush		[illegible]	[illegible]	[illegible]	1200 (0)
4	Indeterminate spreading	early	400 (830)	200 (230)	1790 (20)	1100 (4)
5	Indeterminate spreading	early	620 (1340)	430 (500)	1550 (30)	1125 (1)
6	Indeterminate spreading	medium-maturing	420 (1060)	180 (460)	1600 (29)	1300 (0)
7	Indeterminate spreading	medium-maturing	600 (1300)	380 (770)	1860 (17)	1165 (0)

Again, characteristics such as indeterminate nature, spreading type and medium to late maturity seem to be associated with stronger competition. Table 3 also shows how much the cowpea yields were affected by competition with the millet and the short duration erect varieties are least able to compete and, even when planted at high densities at the same time as the millet do not produce much grain or fodder in this environment.

3.3.4. Relevance to northern Namibia

Cowpea is a crop with considerable potential in Namibia and is already liked by farmers. On farm planting densities are probably similar to those in Niger (5,000 hills/ha? - again, little data for Namibia). DART researchers are using higher densities in their work (28-33,000 hills/ha: e.g. Fleissner, 1997, Niitebu, 1997). If this crop is to accumulate significant quantities of biomass (e.g. 2 tonnes/ha) and nitrogen (e.g. 20-40 kg/ha) it needs to be planted at higher densities than farmers use and this raises the possibility of competition. We can see from Niger that within the cowpea species, it is possible to find varieties which are at one extreme unable to compete with millet in an intercrop and at the other in danger of over-competing if planted at the same time as the millet at moderate density. Unless the value of cowpea as a cash crop increases farmers are unlikely to accept the risk of more than a small millet yield reduction, say 10%. On the other hand, there is apparently little potential fodder or soil fertility benefit associated with growing short duration, erect, determinate cowpea varieties intercropped with millet. Following this argument, if the interest is in soil fertility, attention should be given to indeterminate medium-long duration varieties with focus on relative planting date and density. It would certainly be unwise to ignore the indeterminate varieties altogether as they have much to offer in rain-fed environments where they are able to respond to seasonal differences in rainfall. The relative planting gap should be sufficient to allow the millet to perform well in years of good rainfall with the cowpea able to recover after the millet harvest, increase its biomass and yield on residual soil moisture. Based on Nigerien work this planting gap should be approximately 7-10 days.

In a year of bad rains the cowpea should be able do as well as possible. Short duration determinate varieties (and other short duration legume species) will be better able to yield grain (very important if the millet harvest fails) and medium to longer duration indeterminate varieties are likely to produce some fodder - responding to rainy periods when they occur, but little grain. This raises possibility of sowing *mixtures* of short and long duration cowpea varieties as a risk management strategy. If it was possible to predict the likely pattern of rain at the start of the season then cowpea seed mixtures dominated by either long-duration indeterminate varieties or short duration determinate varieties and species could be planted but such prediction is not yet possible. The implication here is the farmers should have access to a number of different varieties (and species) of legume. The trend towards shorter duration millet varieties (e.g. Okashana) can only be good for reducing risk of millet failure in poor rainfall years and also gives indeterminate cowpeas a better chance of performing well on residual moisture after millet harvest.

3.4. Forage cowpea and other forage legumes

The role of forage cowpea (and perhaps other forage legumes) is being looked at by some livestock projects in northern Namibia (e.g. NNRDP, NOLIDEP) and needs to be seriously addressed. In northern Namibia cattle are presently or are becoming a very important component of the farming system. Communal grazing areas area dwindling in size and crop residues are already very important as dry season grazing supplements as needs are not being met by available pasture. This demand on crop residues is likely to increase and this is another reason to put emphasis on producing large quantities of high quality crop residues.

calcium ammonium nitrate (CAN) over 3 years in Niger. P and K fertilizer were applied to all treatments so this was an experiment primarily comparing N fertilizer type and rate. They found that, in general, N fertilizer recovery was low at 20 - 37% of that applied. Leaching losses were small with ammonia volatilization thought to be the main mechanism of loss. Urea is more susceptible to volatilization losses particularly with banding or point application (usual in widely spaced millet cropping) with losses exacerbated by lack of moisture. CAN was thought (in theory) to be a better N fertilizer as half the N is soluble nitrate: not susceptible to volatilization and will wash down (but not leach in this climate) and so be available to crops when upper soil layers are dry. In adequate or good rainfall years there was approximately a 15 kg millet grain yield benefit for each kg N applied at application rates of 30 kg N/ha. They also predict a 50% increase in straw yield with 30 kg N in adequate or good rainfall years.

Ntare and Bationo (1992) looked at the response of several varieties of cowpea in pearl millet intercrops to different P applications (0, 8, 16 kg P as SSP). Responses were significant and considerable in most cases. One local, indeterminate, photoperiod sensitive variety did not respond particularly well (though had high yields anyway) the other local and improved varieties responded well with 8 kg P/ha giving approx. 30-80% grain and fodder increases.

Again in Niger Bationo et al., (1992) undertook three years of on farm farmer managed experiments in which farmers applied P (15 kg P/ha) and N (30 kgN/ha) to their millet using their own spacing. This was interesting work looking at the interaction between fertilizer response and millet spacing and including an economic assessment of fertilizer use. Farmers chose their plant spacing and planted at densities of 2,000 - 12,000 hills/ha (nationally recommended density is 10,000/ha). Response to fertilizer additions were strong with mean overall grain yield increases of 125% in response to the 15 kg P. When 30 kg N was also applied the increase was 181%. Over the range of densities used P fertilizer gave a yield increase of 16.3 kg grain/kg P_2O_5 . A strong message from this work is that response to fertilizer is greatly affected by the cropping density chosen by the farmer. Below 3500 hills/ha yields were low (317 kg/ha) and there was little response to fertilizer. Each 1500 increase in hill number/ha resulted in a 200 kg/ha increase in yield.

Another interesting effect of the fertilizer (again probably more the P) was in improving seedling survival. Each farmer planted at the same densities in their control and fertilized plots but at harvest plant densities were, on average, 49% higher in the fertilized plots as compared with the control plots. This indicates the early advantage fertilization gives when there is early drought stress. A significant residual affect from P fertilizer was also measured in this experiment.

Christianson et al. (1990) looked at methods of fertilizer application and, interestingly, found that the effects of P fertilizer (SSP 0-45 kg P_2O_5 /ha) were the same when incorporated or just broadcast (normal practice in Niger). We can not assume this will also be true in Namibia as, in this Nigerien work P application was not until 2-3 weeks after germination (a bit late for P - it is very important for early crop growth) and other work has suggested incorporation to be important (particularly for rock P). An important issue as it is a lot easier to broadcast than point place fertilizer. Point placement of CAN (calcium ammonium nitrate) has, however, been shown to improve uptake compared with simple broadcasting.

3.5.1. Mineral fertilizer research in northern Namibia

It is not clear how much standard FAO type fertilizer response work there has been in Namibia. In 1995 several studies looked at response to N and P fertilizers in millet in the north (Lenhardt, 1995, Lenhardt, 1995, Matanyaire, 1995, Matanyaire, 1995, Matanyaire, 1995). The findings are summarised below:

- In Omusati, Oshana and Kavango there were positive millet grain yield responses to both N (linear response to 40 kg/ha) and P (linear to 20 kg P/ha though one or two anomalies). The researchers tried both researcher- and farmer-managed trials and found positive effects in both (no rainfall data given). There was no economic analysis of this work but conclusions were that, in both NCR and Kavango, mineral fertilizer applications of 10 kg P and 20 kg N/ha can double millet yields or more (presumably in adequate or good rainfall years on soil with average to low fertility).

work was continued beyond 1996 but no reports have been seen. To determine whether deficiencies of N, P, or other nutrients are likely to be as important in northern Namibia as in W. Africa it helps to look at some soil analyses results from the region. There is no test for soil fertility more reliable than growing a crop. However, lab analysis of nitrogen, phosphorus, organic matter content, pH, CEC and amounts of nutrient cations tell us something, and there are recognised ranges for soil nutrient concentrations which can help in judging whether deficiencies in the crop are likely. Some of these are given in Table 5.

Table 5. Critical concentrations for CEC and some nutrient cations in agricultural soils (taken from Landon, (1991).

Nutrient	High values		Medium values		low values		Notes
	me/100 g	ppm	me/100g	ppm	me/100g	ppm	
N (total)		(0.5%)		(0.2-0.5%)		(<0.1%)	linked to organic matter content
P[1]		> 15		5 - 15		< 5	general ranges
K	0.8 - 0.4	150 - 300	0.2 - 0.4	80 -150	0.2 - 0.3	55 - 80	based on Malawian soils
Mg	> 0.5	> 60	0.2 - 0.5	30 - 60	< 0.2	< 30	
CEC	> 40		15 - 25		5-8		

[1] Figures for Olsen method of P extraction - best suited to neutral and alkali soils. Figures may be higher for similar categories if acid extraction methods (e.g. Bray) are used.

Phosphorus

The KFSR/E project carried out some analysis on soils form Kavango (KFSR/E, 1996).

They did not report the method of analysis but the topsoil available P contents were 3 ppm (Muheke sand and Ndombeheke) to 4 ppm (Ndombe loamy sand) in the 3 samples they analysed. In NCR Alweendo (1997) reported some analyses for soils from Okashana and Ogongo with available P values ranging from 3-14 ppm (again, method not specified). More analyses results from farmers fields are needed but these two reports suggest very low P levels in Kavango and more variable P levels in NCR (less than 5 ppm suggests low soil P, table 4). This is in line with reports indicating that a wide range of soil types occur in NCR (Rigourd, 1998). In both areas but Kavango particularly, a strong P response is likely in millet. P fixation is unlikely to be a problem in most soils in northern Namibia and therefore relatively modest applications of P fertilizer (10-15 kg P/ha/yr) would probably be sufficient for moderate production (Buresh et al. 1997). Less than this would be required if manure applications are possible in some years, depending on the P concentration of the manure. it can be said with some confidence however, that, if sustainable increases in crop yields are to be posible in northern Namibia these modest applications of mineral P fertilizer will probably be necessary.

Nitrogen

Available or mineral N measurements are possible in soil but not particularly useful as the amounts vary greatly across even a small field and are strongly linked to the moisture status and temperature of the soil. Total nitrogen measurements are slightly more useful and can be estimated roughly from the soil organic carbon as the C:N ratios in most soils is about 10:1. The three samples analysed by KFSR/E had between 0.3% (Muheke sand and Ndombe loamy sand) and 0.8% (Ndombe loamy sand) organic carbon and are likely to have 0.03 -0.08% total nitrogen contents. Of this no more than a few percent (2-5%) is likely to become available in any one year or, perhaps 20-35 kg N/ha in the poorer soils . If utilization efficiencies by the crop are as good as the best measured by Christianson et al. (1990) for fertilizer N in W. Africa then up to 50% might be taken up by the crop. Pearl millet is a particularly N demanding crop with approximately 20 kg N required for one tonne of grain and the same for the associated residues so, to produce a tonne of grain around 40 kg N is required (Bationo, 1993, Rebafka 1994). Based on these rough calculations from these few Namibia soil analyses the maximum N supply from the poor sandy soils in Northern Namibia, with no other inputs, is sufficient to produce 200 - 450 kg grain/ha in a good year when moisture and other nutrients are not limiting and weeds are controlled (they will compete for the N). If the rains fail some of this N may remain in the soil and the supply may be a little higher the next year but much of the N may also be lost to denitrification, even in sandy soils (Ganry, et al., 1978). Total %N values of around if exchangeable K levels are more than 0.1-0.5 meq/100g (40 ppm). In Kavango, one of the 3 soil samples analysed by KFSR/E (Muheke sand, 1996) had 38 ppm K suggesting that K deficiency could be a problem in some areas here, though more analyses are needed. DART has been involved in long term soil fertility and plant nutrition trials in NCR (Alweendo, 1997). None of the study soils seems to exhibit K deficiency (67-500 ppm) and yet the results from the 1996-7 season suggest a greater response to K fertiliser applied alone to soyabean than N or P fertilizer. Before accepting this result, however, a closer look is required at the design, methodology and management of this work as, in some cases, largely negative responses are found with fertilizer application (to millet at Hardap), in others N and P fertilizers give a bigger response than K (maize at Hardap and Ogongo) and harvested plot yields seem to be unbelievable small (e.g. 0.999-3.688 g grain/plot for maize at Ogongo).

Sulphur

It is difficult to make meaningful measurements of sulphur in the soil. Deficiencies can occur in semi-arid areas, particularly after an extended period of continuous production without use of sulphur containing mineral fertilizers (ammonium sulphate, SSP). As with K, deficiencies in other nutrients will be more pressing in northern Namibia but, long term, the sulphur balance in the cropping systems will be important.

Magnesium and Calcium

In the Kavango soils and the soils form NCR analyzed my KFSR/E and DART respectively there seemed to be few problems with magnesium or calcium except perhaps in the sandy soil sample from Kavango (Muheke sand) where concentrations bordered on deficiency. Again, this interpretation is based on a small number of analyses. In any event the reserves of these nutrients are unlikely to be large in most soils and, although there may not be currently limiting in most soils they will be depleted in the medium to long term if production increases. In any areas with acid soils magnesium and Calcium levels are already likely to be low.

3.5.3. Sources of plant nutrients (other than chemical fertilizers)

Sources of phosphorus

A millet crop producing a tonne of grain and two tonnes of residue will remove approximately 4 kg P, three-quarters of which is in the grain (calculated from Bationo, 1993). P is not a mobile nutrient, however, and utilization efficiencies for organic or inorganic P applications are typically very low. This is why 12-15 kg P fertilizer /ha is usually recommended to get a response. Legumes or other plant material may have the capacity to supply some N (see below) but are not able to supply P in the amounts required by crops. Some researchers have looked at this: in order to supply 10 kg P/ha to a maize crop in Kenya Jama et al. (Jama, et al., 1997) needed to apply 7.7 t/ha *Calliandra calothyrsus* residues to a plot - a totally unrealistic amount likely to cause other nutrient balance problems such as over supply (and losses) of N. Probert et al. (1995) reviewed P concentrations in cattle manure in the African literature and found P concentrations in FYM to range from 0.6 to 5.7 g/kg. Thus, in order to supply the minimum 10 kg P/ha or so required for a good crop response it can be necessary to apply from to 1.7 t (just about possible in some areas) to 16.7 t manure/ha (wholly unrealistic). P is less susceptible than N to management losses but it can be washed out of manure if left uncovered for long periods. The most significant reason for low P concentrations in FYM, however, is that it is usually mixed with soil to varying degrees. For example the manure analysed by KFSR/E (1996) may have been largely soil as its P concentration was only 0.14 g/kg (over 70 tonnes of this material would be required to supply 10 kg P).

Rock P is a cheap option for countries possessing accessible deposits of good quality (high solubility) material relatively close to their agricultural areas. Much larger applications are necessary than with processed P fertilizers (TSP, SSP) and distribution costs will be high if deposits are remote from agricultural areas. Rock P deposits occur in most African countries. There are several known rock P deposits in Namibia, igneous deposits at Empembe (NCR) and Kalkfield and an offshore sedimentary deposit (Buresh et al. 1997). Igneous deposits, however, are usually quite low in activity and require some acidulation before they can be used. There may be some undiscovered sedimentary deposits in northern Namibia but this would be a little unusual as most of the sedimentary combined with manure.

Legumes are also put forward as having significant potential for supplying nitrogen to cereals in low input systems. Hence the potential importance of the millet/cowpea system and the issue of crop residue use dealt with below.

3.5.4. Economics of fertilizer use analysis

Bationo et al. (1992) performed a relatively simple analysis of the economics of fertilizer use on pearl millet in Niger and concluded that, essentially, it paid farmers to use chemical fertilizers. But they didn't consider the impact of rain failure in their analysis (occurs in 50% of years in NCR, 40% of years in Kavango). The risk of millet failure in poor rainfall years underlies the reluctance of many farmers in semi-arid areas to use nitrogen fertilizer and this risk needs to be considered in any economic analysis. P fertilizer applied in a year with poor rains should have some effect the following year but any investment in N fertilizer will be lost. The risk can be reduced a little by applying the N fertilizer as a split dose (50% at planting and the rest later if rains are adequate) but, for most farmers in northern Namibia, it is too risky to recommend investment in N fertilizer.

3.5.5. Summary of relevant points concerning fertilizer use in northern Namibia

- Pearl millet responses to P and N fertilizer can be expected in adequate and good rainfall years, though N response will be less predictable and is more reliant then P on their being good rainfall.

- N use efficiencies of applied fertilizers are likely to be modest at 20-40% of applied N.

- The responses will be both in increased grain and increased straw production - both are important.

- Most cowpea varieties will respond to increased P supply. Some local indeterminate varieties may not and this may be because they are particularly efficient at accessing soil P.

- Moderate planting densities are required for dood responses to increased nutrient supply.

- Early P supply is particularly important for millet establishment and in ensuring a good plant stand

- At moderate plant densities broadcasting of P fertilizer is likely to be as efficient as point placement.

- Some form of P fertilization will probably be required for sustainable yield increases.

- Cost effective rock P sources are unlikely to be available in Namibia

- The rainfall environment is too risky to recommend use of chemical N fertilizers to poor farmers and this conclusion focuses attention on increasing legume and manure N inputs to these systems and increasing the efficiency of N cycling.

3.6. Crop Residues

Many researchers have looked at the use of crop residues as soil amendments. Although it is possible to find residues across the whole spectrum of possible compositions workers often speak of high and low quality residues with the following characteristics:

low quality residues (e.g. maize, millet, C:N ratios > 30) decompose relatively slowly (over more than one year), immobilise nitrogen for a variable period after incorporation (frequently several months) and can potentially contribute to long-term soil organic matter build up with the associated improvements in soil physical characteristics (improved water-holding capacity, increased CEC, amelioration of Al toxicity). For beneficial effects, frequent (annual) applications required.

conclusion from this study was that the use cowpea and millet residues as amendments is superior to cowpea green manures. This is a reasonable conclusion to come to from their work but they make no attempt to discuss whether or not this is a realistic practice within the Nigerien farming system. In the research the residues were bought from a local market and applied at the start of the growing season - they had not survived in the field through the dry season so for a farmer to apply this management practice he would need to remove, store and reapply residues after the dry season. Farmers may collect, store or buy residues for feeding to cattle or for building materials but would they return them to the soil? If not, and many think this is too much to expect a farmer to do, then the nutrient input from the legume drops to whatever is released from decay of roots and nodules and any leaves falling before harvest. Few researchers have measured below ground legume residue N but there are reports of 15-20% plant N present in below ground structures. Franzluebbers et al. (1994) stated that 32% of the N in 44 day-old cowpea plants was present in below ground biomass and therefore would remain in the soil even if residues are removed. Total N accumulation in a good cowpea monocrop (1 t/ha grain, 1.5 t/ha residue) might be around 70 kg N/ha (assuming N concentrations of 1.8 % and 4.5 % in residue and grain respectively) or 30-40 kg in a cowpea cereal intercrop with the cowpea performing well. From these figures we can calculate a below ground input of 22 and 11 kg N (monocrop and intercrop) from the cowpea if we assume 32% of the total plant N to be below ground at harvest. These figures drop to 14 and 7 kg N/ha if we assume only 20 % of the N remains below ground - more likely as there is normally partitioning of N from all plant parts into the grain in later stages of crop growth and most root nodules will have senesced by harvest. If we apply the common N utilization efficiencies from residues of say 30%, then we can expect 2 and 4 kg N from the sole and intercropped cowpea crops respectively to be taken up by a following cereal crop and only 40-80% of this will be fixed from the atmosphere and represent a new input into the system - the remainder will be recycled soil derived N.

One tonne of pearl millet grain (and associated residue: 3.5 t) extracts approximately 40 kg N (Bationo et al., 1992). From the above calculations it would be reasonable to predict that, if only the below ground parts of the cowpea crop remain, even after a productive cowpea monocrop, one could not expect a millet yield response of more than 100 kg/ha. This would be less in a dry year and is likely to be difficult to show experimentally in farmers fields given the heterogeneity of the production environment.

From a nutrient balance perspective, the true picture is likely to be still more depressing as a substantial amount of the N removed in the legume grain and residue (probably at least 25%) will have come from the soil. Thus, if legume residues are removed, even if N_2-fixation rates are high, the crop will almost certainly have a net mining effect on soil nitrogen. The effects of this on long term nitrogen balances and sustainability of the system will be negative. Reddy et al. (1992) looked at productivity of cowpea/pearl millet intercrops over 4 years in Niger removing residues and, even in a cowpea sole crop treatment performing well (grain yields of 1360-2850 kg/ha) soil N declined during the experiment.

Calculations like this illustrate the importance of returning nutrients to the system, even when there is a substantial legume component. The fate of the legume residues is critical and, in systems with important cattle components such as Namibia, one of the first questions to ask is: "Is it realistic is it to expect farmers to use some or all of their high quality residues for soil amendments?"

If the answer is an unequivocal "no" then it should be accepted that the plant available N needed for the increase or maintenance of cereal productivity will not come directly from legumes and attention should be focused on other potential sources, the two most significant of which are:

- animal manures (and so indirectly in part from legumes if the cattle are feeding on the legume residues).

- mineral fertilizers (see above)

If the answer is "yes" then some of the above calculations can perhaps be recalculated more favourably. Using the same cowpea production figures as above an extra 27 kg N comes into the soil with the residues, 8 kg of which might be taken up by the pearl millet leading to a 200 kg/ha increase in millet grain yield or perhaps double this in the long term if millet residues are also returned to the soil. In this case, as long as the % N_2-fixation is higher than the legume N harvest index, the legume will be making a net and S will be lost in gasses. Thus there are usually short term positive effects from burning due to weed control and a flush of P and K but the long term effect on the N balance is negative, particularly so with pearl millet which seems contains more N in its residues than most other cereal crops.

In northern Namibia the "burn or incorporate?" question has some relevance in Kavango still where relatively low cattle ownership and availability of good grazing areas means that crop residues are not always removed from the land. In NCR, however, fodder demands mean that few residues remain for burning or incorporation. The "open frontier" in many parts of Kavango (Behnke, 1998) allows farmers to open new land when production drops in old fields and this will always be a more preferable option to incorporation of residues or mineral fertilizer inputs. There is little new land in NCR however and continuous cropping is the norm. Farmers may feel that the labour savings and the partial (P and S) nutrient benefits of burning are preferable to the drawbacks of incorporating residues. This means that the long term N budget will need to be redressed in some other way and. Without some form of N input production cannot be lifted from the few hundred kg/ha/year possible relying on N released from the soil.

3.6.3. Other residue management options

An alternative to residue incorporation before planting is incorporation after harvest - difficult in the dry season but perhaps possible in sandy soils and with the advantage that draught animals may be in better condition at the start than at the end of the dry season. Through suppression of weeds some water may be conserved (but not much: Klaij and Ntare, 1995) and cultivation should not be required again before planting after the rains begin. This does, however, require commitment and investment from the farmers and they would need to be convinced of the benefits. Both crops would have to be incorporated as selective removal of millet residues from the field is an unrealistic expectation. Incorporation would also have to be thorough if grazing animals were not to uncover the residues.

Powell et al. (1991) looked at N and P concentrations in different fractions of sorghum stover and found significantly higher nutrient concentrations in the upper plant parts thus recommended these should be left in the soil. Others would argue that the upper parts of the stover should be allocated for fodder as their nutritional value is greater. Either way is it realistic to manage different residue components in different ways?

3.6.4. N immobilization with millet residues

Nitrogen imobilization problems have been quite widely reported associated with incorporating low quality residues into the soil and planting a crop soon after [Williams, 1968 #949; Sims, 1970 #856]. This has often deterred researchers and extensionists from recommending cereal residue incorporation as a practice to farmers and deserves some discussion here. Some research with pearl millet suggests immobilization might be less of a problem than with other cereals. Bationo, (1993), found positive yield responses in millet when millet residues were returned (4 tons residues/ha, no fertilizers) over four years, even in the first year of additions - it is quite surprising (though very encouraging) that there was no immobilization effect in this work as residues were applied only 2 weeks before planting. They were chopped (15 cm lengths) and this could have promoted rapid decomposition. Separate work from the same group also indicated no N immobilization effect in the field when millet residues were returned and a millet crop planted soon afterwards (Rebafka et al. 1994) though 40 kg N was applied in this study. This group clearly believes the beneficial nutrient supply effects of residues (K particularly) and positive rhizosphere effects (associative N_2-fixation , phyto-hormone production - see below) far outweigh any risk of N immobilization. Ganry (Ganry, et al., 1978), however, found substantial millet grain yield reductions (32%) over unattended controls when straw was incorporated at the rate of 7 t/ha, though this was a lysimeter study. This question clearly needs further attention.

One possible reason for the remarkable beneficial effect of millet residues in West African work may be explained by effects on aluminium concentrations in these acid soils. Whilst many parallels can be drawn between the W. African environment and systems and those in northern Namibia we need to be cautious when looking at some aspects of soil chemistry. The sandy soils with which ICRISAT is working in Niger are rather acid, with pH values commonly 4-5 (Hafner, et al., 1993). It is normal to find free Aluminium in soils with pH < 5 and, indeed Al toxicity and Al mediated effects on P availability are common problems in W. Africa. As has already been mentioned P is

Thus the large increases in P availability and linked improvements in millet production when residues are returned to the soil can not be expected. It may be that N immobilization effects of pearl millet residues were masked in the W. African work by the beneficial effects on P availability. This remains an unanswered research question in northern Namibia.

Although cereal residues do not contain much P or N (0.6 %) they do contain large amounts of potassium (1.3 % K in millet residues in Bationo and Christianson, 1993) so a direct K response is likely in K deficient soils after residue amendment and has been measured in Niger (Hafner, et al., 1993).

Rebafka et al. (1994) compared different millet residue management options: surface mulching, incorporation and burning. Burning gave positive P effects (release and also increased pH) and, in years when heavy rains did not cause leaching of soluble nutrients, gave similar benefits to other residue management practices but N fertilizer was used in this experiment and thus gaseous losses of N through burning would presumably not have been noticed. The benefits of residue application on millet yield were greater when residues were incorporated than when they were used as a surface mulch supporting the theory (promoted by the authors) that residues help root proliferation through their effect on soil processes such as phytohormone production and promotion of root growth.

3.6.5. Summary of relevant points concerning crop residue use for soil fertility in northern Namibia

- Whether or not legumes contribute directly to plant N supply in these systems hinges on how residues are managed. Some or all of the residues need to be returned to the soil for a direct benefit to occur.

- Even if Namibian farmers are able and willing to use millet residues as soil amendments it is not clear that they will benefit the system as they may imobilize nitrogen.

- If N immobilzation is likely when millet residues are incorporated then this cannot be recommended unless there are additional N inputs (e.g. legume residues, N fertilizers). Rather the residues should be grazed and emphasis placed on maximising N returned to the soil through the animal/manure route. If grazing is not an option then burning will, in most cases, be a better short term option than incorporation but the N losses associated with this will need to be somehow addressed.

- As dry season losses of legume and millet residues can be high due to grazing and wind erosion, farmers may need to invest some additional resources (fencing, end of season ploughing) to fully utilize these inputs.

If farmers cannot afford to use any crop residues as soil amendments then, no matter how much legume there is in the system, there will be substantial mining of nitrogen. If this mining is not balanced with inputs (manure, mineral fertilizers) the productivity will decline to a low and eventually uneconomic level leading to land abandonment. If , as seems to be the case in northern Namibia, an enforced fallow is occurring due to rain failure in 50% of the seasons the final stages of decline may take a long time, however. Klaij and Ntare (1995) found slightly higher millet grain yields when millet and cowpea were rotated, one crop a year, than when millet was monocropped, with residues of both crops removed in this work. The higher yields in the rotated plots were almost certainly due to an "N sparing effect" as the cowpea would have fixed much of its N and mined less from the soil than a pearl millet crop. It would be wrong, however, to interpret this as millet benefiting from cowpea N and this was implied in the work. Even though cowpea was relatively productive in some years, the total soil organic matter and N contents declined by over 60% across <u>all</u> treatments over the four years of the study.

Depending on the farmer and location in northern Namibia there may or may not be some interest in using some crop residues as soil amendments. Where the farmer has significant numbers of cattle he will probably be reluctant to give up legume residues as a dry season fodder supplement and farmers without cattle will probably somehow trade their legume residues. In NCR, therefore, it should be expected that, at current research but question of residue management needs to be handled carefully. The unlikelihood of direct N contributions from below ground parts and the difficulties with keeping residues on the land through the dry season have already been discussed.

3.7.1. Cowpea regeneration

An interesting feature noted in Tanzania and Namibia (personal observations and Fleissner, personal communication) is the ability of cowpea plants to regenerate after cutting. Interestingly erect determinate types as well as indeterminate varieties seem to show this property. If reliable there is potential for managing this behaviour in millet/ cowpea intercrops. Two suggestions are:

i) Short duration erect cowpea varieties could be sown initially with the millet (same planting date even) and the plants cut at harvest. Cowpea then may regenerate and produce a second harvest of fodder and, in years with good late rains, a second pod or grain harvest.

ii) Some cowpea varieties, particularly long duration ones likely to have deeper root systems, may be able to survive the dry season if cut low down at the start of the season. This may allow regeneration at the start of the next rains (faster than from seed as root system already developed) and improved biomass and grain production. Dry season grazing in farmers' fields may prevent survival and the danger of competition with the millet would be high if the cowpea did survive but survival of indeterminate creeping plants at low density could benefit the system. If early biomass production was good plants could be cut mid-season and biomass used as a green manure or fodder.

These or other strategies depend on a high regeneration rate after cutting - at least 50% and are worth pursuing as lines of research

3.7.2. Other grain legumes

So far only cowpea has been discussed in this review as it has much potential and is already known by farmers in northern Namibia. Clusterbean (guar, *Cyamopsis tetragonoloba*), horse gram (*Dolichos biflorus*) and moth bean (*Phaseolus aconitifolius*) are small seeded legumes known in India but not found much elsewhere. Moth bean is the most widely grown legume with pearl millet in India. most of the breeding and agronomy work on these species has been done in India. In a rather rough paper Yadav (1994) looked at the effect of different legume/millet planting configurations in fertilized experiments. He looked at moth bean and cluster bean sown with pearl millet in 1:1, 2:1 and 2:2 legume:millet row arrangements and found the 2:2 arrangement to give the best yields and land equivalent ratios (LERs). Methodological details rather unclear and application of recommended fertilizers would have reduced competition.

Groundnut and Bambarra nut are also known by farmers in Namibia and lablab has been recently grown on station in NCR and been shown to grow well. Researchers are also working with some interesting forage and tree species. An exhaustive discussion of the potential benefits of all these legumes to soil fertility in northern Namibia is not needed here but some summary remarks can be made:

- Short duration (<70 days), small-seeded legumes offer a high quality diet supplement and improve food security in dry years. These legumes are unlikely, however, to produce residues in quantities large enough to have a big impact as a soil amendment or source of fodder.

- Groundnut and Bambarra nut can both produce large quantities of good quality residues with potential as soil amendments or fodder supplements. Farmers rarely intercrop these legumes with cereals however, except at low densities, and this is likely to be because the effects of competition are unacceptably large on one or both of the crops. These species do have potential in rotations, however, with either an N sparing effect or a direct N supply effect (N released from decomposing residues) benefiting a millet crop following the legume. As with millet/cowpea intercrops (see above) the success of such a system relies partly on reducing dry season residue losses (grazing, erosion).

- From a soil fertility perspective some legume green manure species are attractive. These can grow rapidly, accumulating moderate quantities of biomass and N in a relatively short time (e.g. 45 days). They do not provide harvestable grain, however, mechanisms by which nitrogen fixation might benefit a cereal crop. N-transfer is the term given to the transfer of n from a legume crop in association with another crop while both are growing together. Almost all published studies suggest that there is no significant N transfer between legume/cereal intercrops. Redmon et al. (1995) describe a glasshouse pot experiment which they believe indicate a transfer of 32-34% pearl millet N from associated cowpea. The methodology is flawed however and the results are most likely artefacts.

Some believe that N_2-fixation carried out by free-living micro-organisms in the rhizosphere of cereals (i.e. not the rhizobia associated with legumes) are capable of contributing significant quantities of N to the system. Keuk-Ki et al. (1994) used the acetylene reduction assay to look for significant nitrogen fixation associated with the roots of pearl millet and sorghum. They didn't find any. Hafner et al. (1993) calculated Nitrogen balances over 6 years with sole crop pearl millet with and without crop residues and fertilizer applications. They come up with positive balances in all the treatments where either crop residues or fertilizers or both were added and invoke associative fixation to explain this. However, their positive balance calculations can be explained by their high estimates of N leaching losses (150 kg/ha) and although they try hard to justify these estimates they are probably too high. This is important as were the leaching estimates lower, the final balance would be smaller or negative. There is no evidence which would lead us to depart from the conventional view on legume to cereal N transfer and associative N_2-fixation, i.e. that the amounts involved are very small to negligible.

There are, however, clearly a number of people who strongly believe part of the beneficial effect of incorporating millet residues on yields of succeeding crops results from stimulation of phyto-hormone producing and nitrogen- fixing bacteria (e.g. Hafner, et al., 1993, Rebafka, et al., 1994). In a zero external input system these small inputs and other rhizosphere effects such as phytohormone production (Hafner, et al., 1993) might be of some importance but are unlikely to really lift production. If any of these effects are there then they lend support to the strategy of incorporating residues but hard evidence is still lacking.

3.9. Animal manures (discussion deals with cattle mostly)

3.9.1. Amount produced

The cattle of the Maasai around Nairobi were estimated to produce only 300 kg DM/yr. Goats and sheep produce much less - estimated at 30 kg DM/yr (Bayer and Pietrowicz, 1986), only 50% of which is collectable.

3.9.2. Composition

The usual characteristics of animal manures place them somewhere between the high and low quality residues described above. research has shown that over time and after repeated applications they can contribute to long term organic mater build up (with associated soil physical and chemical benefits) and can also supply plant nutrients if applied in large enough quantities. Table 6 gives some typical nutrient concentrations in African manure. From these data it seems 0.8%N, 0.2%P, 1.0% K are likely nutrient concentrations in Namibian kraal manure (though there was much less P in the sample from Kavango). Some workers have suggested around 30% of the manure N is available in the first year (Bayer and Pietrowicz, 1986) and this would mean around 12 kg N would be available from a manure application of 5 tonnes. Less than 30% of the P is likely to become available in the first year but still a fertility effect could be expected with application rates of 5 t/ha. Residual effects from a one off application of manure at rates of 5 t/ha are not likely to be large as much of the N remaining in the material after the first season is in forms resistant to decomposition. When considering application rates which are more realistic, however, their major positive effects are on soil physical properties, CEC, reduction of Al toxicity and supply of nutrients other than N.

0.95	0.13	1.04				Open boma, Malawi	Bayer (1986)
0.6	0.15					Open boma, Nigeria, end of dry season	Bayer (1986)
0.4	0.2	0.1					Borowski (1983)
1.4						Well fed Zimbabwe cattle	Swift (1989)
1						Poorly fed Zimbabwe cattle	Swift (1989)
	0.014	1.29				kraal manure, Namibia	(KFSR/E, 1996)

3.9.3. Nutrient supply and losses from manure

As already mentioned, unless more than 5 tonnes dry manure/ha is applied annually there is unlikely to be a noticeable soil fertility benefit to cropped land. Transport difficulties aside, these amounts are simply not available in northern Namibia (Matanyaire, 1998) or, usually, in other semi-arid tropical areas [Swift, 1989 #1193]. Part of the problem is that, although cattle can excrete significant quantities of N, P, and K these nutrients, particularly N, are subject to severe losses often exacerbated by local manure management techniques. Bayer cites work indicating that during drying and rotting of manure N losses may be 20-60%. P up to 10% and K up to 20%. Stangel (1995) mentions that losses of N and K from poorly managed manures can be 30-80% and 90% respectively.

A typical cow living in northern Namibia (relatively unproductive by Western standards) would be expected to take in feed containing approximately 40 kg N in a year. Of this only 3.2 kg would be retained for growth and the remaining 36 kg N excreted (de Wit et al. 1997). Approximately 50% of this N would be in the urine and, if deposited in a kraal where temperatures, pH and ammonium concentrations in the manure are all high, practically all of this will be volatilzed as ammonia soon after excretion. This means that if the animal is grazing on crop residues then, almost immediately, over 50% of the N in these residues is lost from the system, even if all the manure is later returned to the land. If the animal is grazing on pastures outside the cultivated area then this still represents a loss of potentially imported nitrogen which might otherwise help to balance the system.

3.9.4. Improved management

There are several improved manure management options well known but little used by farmers. Covering kraals will reduce runoff and leaching losses, also the high temperatures which increase N volatilization. The addition of low quality residues to the manure (e.g. millet straw, bedding) will help to capture (immobilize) some of the ammonium before it volatilizes. Table 7 summarises the results of some of these practices

					prepared manure
Kenya/ cattle	2.72	0.50	2.92		
(Pietrowicz, 1984)					
Rwanda/cattle	1-2	0.35	2.2	0.8	Stable, abundant bedding
Rwanda/cattle	<1.6	0.6	1	<1.6	Composted boma manure
Rwanda/goats	2.4	0.26	3.4	0.83	stable with bedding
Rwanda/sheep	2.0	0.43	4.1	1.17	stable with bedding
(Powell, 1984)					
Nigeria/cattle	1.55	0.26			early dry season
Nigeria/cattle	0.6	0.15			late dry season
Nigeria/cattle	1.87	0.27			early wet season

To minimize losses during application manure should not be spread thinly on the surface (hot and dry - leads to N volatilization). N Volatilization can be reduced by 40% or more by incorporating the manure into the soil (De Wit, 1997). The animals should spend as much time as possible on the crop land. Cattle generally produce a little more manure during the day (eating, moving) than the night (sleeping) though almost half is still deposited during the night time in kraals where many of the above losses occur. In order to reduce nutrient losses, cattle should be kraaled on crop land during the dry season and moved at intervals. Despite the likely advantages of this practice, security concerns of farmers and the labour required to move kraals will probably prevent most farmers changing from their system of semi-permanent kraals near to the family dwelling.

The most realistic approach to using manure in small-holder systems in semi-arid Africa is to apply as much as possible, broadcast or placed depending on farmer preference Jama et al. (1997) found no advantage of spot placement of manure over broadcast though, perhaps because of their generally wide spacings, farmers often prefer to spot place manure. It is probably easier in management (transport) terms to apply relatively large amounts to a field every 3 or 4 years than to try to apply small amounts every year thus farmers should rely on the residual effect of manure - beneficial effects for 3-5 years after addition. If possible contamination with soil should be reduced as this will improve the nutrient status. It will probably be necessary to supplement manure additions with inorganic P (SSP) applications and organic/inorganic N in some years if moderate production levels are to be sustained. In western Kenya such integrated mineral/organic fertilizer additions stand up well to an economic analysis (Jama et al. 1997) but with maize rather than millet as the main crop. When applied with manure there may be more of a residual effect in later years from an inorganic P application applied with manure (Jama et al. 1997)

There has been some DART research looking at the effects of cattle manure and crop residues on millet production in northern Namibia (Lenhardt, 1995a&b, Matanyaire, 1995a-c, 1998). They were looking at the use of cattle manure (2-8 t/ha/yr) and their main findings were:

- On some soils millet yields are very poor, e.g. 25-100 kg/ha (unlikely to be economic for a farmer). Control treatment yields of around 250-300 kg millet grain/ha give an indication of what farmers are harvesting on average to low fertility fields.

- Manure (8 t/ha) and millet residues (4 t/ha, method of application not stated) increased millet yields at Mashare from 25 - 50 kg/ha on a very poor soil.

- In some work response to kraal manure was low e.g. 9% and 15% grain yield increase after applications of 4 and 8 tonnes of manure/ha respectively. This was on a soil with from outside. It is always risky to making sweeping statements about soil, farming systems and farmers in heterogenous environments but, if based on sound facts, such statements can be useful and help guide future work and research emphasis.

- Pearl millet is and will remain the most important staple food crop in most of NCR and Kavango.

- Phosphorus and nitrogen are limiting in cultivated soils across Kavango and in most of the soils in NCR (particularly central areas). These are the two main nutrients limiting agricultural production at the moment and SFM strategies should aim to meet the P and N needs for moderate millet yields (800 kg/ha). Supplying just one of these nutrients (particularly just N) is unlikely to lead to medium or long term increases in production.

- Pearl millet/cowpea intercropping systems, in particular, deserve to be looked at with research emphasis on density of both crops, cowpea varietal choice and relative planting date.

- Modest N (20-30 kg N/ha) and P (10-15 kg P /ha) fertilizer application will <u>dramatically</u> improve yields in adequate and good rainfall years. The likelihood of rain failure in at least 50 % of the years means N fertilizer application to millet cannot be recommended. The greater potential for a residual effect with P fertilizer if rains fail, combined with the fact there is <u>no other source</u> of P in the system (particularly in NCR where there are few trees) means modest chemical P applications should not be ruled out.

- Incorporation of cowpea or other good quality residues before planting millet will improve millet yields in adequate or good rainfall years as 20-25% of the residue N will become available to the millet. BUT:

- Legumes will only contribute directly to soil fertility if their residues are incorporated and this conflicts with the use of legume residues as fodder. More legume residues are required and research is needed to find the best legume varieties (cowpea particularly) for intercropping and rotating with pearl millet and the optimum plant densities and spacings.

- Some research is required looking into the efects of incorporating millet residues into the soil as there is a danger of negative effects (immobilization) on the plant nitrogen supply. Problems of disease carry over and management due to the woody nature of much of the residues need to be addressed.

- Burning millet residues offers some short term benefit to the farmer (small P and moderate K flush, weed control, ease of management) but N deficiency problems will soon occur if not otherwise addressed. Any benefit to the soil, associated with incorporation of organic matter (e.g. increase in CEC, improved soil water holding capacity, amelioration of acidity or aluminum problems) will also be lost.

- Manure applied in amounts realistic when considering production (perhaps 2 tonnes/ha) will have little soil fertility benefit but may have a longer term benefit on soil physical properties and ameliorate long term negative effects of mineral fertilizer application (acidification, depletion of minor nutrients). These effects are important and mean that if any chemical fertilizers are applied to these soils they need to be combined with some organic inputs, manure particularly.

- Improved manure management options (in situ kraaling, covering, straw additions) need to be explored with farmers. Also new ways of increasing the legume component of the system (new species combinations and mixes) require attention.

The challenge for researchers is to take this knowledge to farmers, combine it with indigenous knowledge and together design practical management strategies which make the most of this information. Farmers and researchers need to know the implications of particular management decisions e.g.

What are the implications of no chemical fertilizer use in these systems?

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