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Review of soil fertility management for yam-based systems in west africa

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Abstract

The project *Poverty Alleviation and Enhanced Food Availability in West Africa through Improved Yam Technologies* proposed to improve yam production in five West African countries (Nigeria, Bénin, Togo, Ghana, Côte d'Ivoire) during the period from 2000 to 2003. A recognized need for productive, stable yam-based systems is the maintenance of soil fertility. Trials were initiated in each country on the fertilizer needs of yam and in several countries on improved fallows or leguminous intercrops. A review of information was also recommended with the objective of guiding future research. A search of all available literature was agreed, including sources with poor accessibility (grey literature) that might be available in NARS libraries.

Background

As background to this review, we assume that we are targeting intensified yam production systems. It is generally known that yam cannot be grown continuously on the same piece of land. It is commonly known that yam should be grown in the first year after clearing fallow vegetation. Gigou (1987) says that this is to avoid weed competition for nutrients, moisture, and light. This is a major problem during the first 3 months of yam growth, which is slow. In addition, most writers imply that yam is the first crop after fallow because of nutritional requirements. "Yams are considered a demanding crop, so they come first in the rotation cycle in most traditional yam-based farming systems. They are thus the first to benefit from the restoration of the soil's fertility" (Degras 1993). But before drawing firm conclusions we must first be clear on what we mean by soil fertility in the case of yam. Soil fertility for yam in this review is taken to mean:

i. Adequate nutrient supply to the growing plant
ii. Adequate soil moisture retention
iii. A loose soil structure for good root expansion

A first point at which to learn about sustainable yam production is to document yields in continuous yam production trials. For example, in the savanna zone of southern Burkina Faso, Somé et al (1995) observed that the yield decline from one year to the next was dramatic (Table 1) in spite of the fact that the second year had better rainfall. Also Odurukwe and Oji (1981) observed that the fresh tuber yield at Umudike in southeastern Nigeria declined even with high organic and inorganic nutrient amendments. This suggests that an important cause of yield decline is not related to soil fertility but may be due to pests and weeds. Yeboua (1990) demonstrated that yield decline could be partially prevented by the application of fertilizers.

The effect of the duration of previous fallow on yam yield also suggests that yam depends on undegraded soil conditions. Watson and Goldsworthy (1964) grew yam after several durations of fallow and observed a strong positive correlation between the length of fallow and yam yield (Table 2). Unfortunately there are few studies of this kind that have been documented. Another indicator of yam's dependence on good soil conditions is the effect of the duration of continuous cropping on yam yield. Djokoto and Stephens (1961a) found that average yields of yam at Ejura were 9.1 t/ha in the first two years of continuous cropping and 7.2 t/ha in the third and fourth years. In contrast, average yam yields in Tamale and Nyankpala were higher, 7 to 9 years after fallow, than in the first years. This is probably due to the soil improving effects of the mineral and organic fertilizers applied. Similar information can be gathered from studies of the effect of the length of previous fallow periods.

Degras (1993) states that the length of cropping and fallow periods depends on the inherent soil fertility and nutrient amendments that are available. For example, alluvial soils allow more years of yam cropping before a switch to other crops or fallow. Also, fertilizer use may allow more years of cultivation before fallow is needed.

This review focuses on issues to be taken into account in recommending fertilizer applications and organic matter maintenance systems for sustainable yam cropping. The collaborators agreed on elements of an outline that are reflected in the contents of this document. They looked for relevant information from their countries. For further information, all country reports are available from IITA.

Fertilizer issues

Current use of fertilizer on yam in the different countries. There is little information on fertilizer use in yam production. Fertilizer use was heavily promoted in Nigeria in the 1970s and therefore it can be expected that fertilizer use is highest there. In a survey conducted in 1981 by Unama et al (1985) in southeastern Nigeria, 55% of farmers surveyed applied fertilizers to their crops. Of those farmers, about 78% applied the recommended rates. Major crops fertilized were cassava (96% of the farmers who used fertilizer), maize (72%), yam (64%), and vegetables (42%). Thus approximately 35% of farmers surveyed applied fertilizer to yam. At the same time in the middle belt of Nigeria, there was virtually no fertilizer application in yam production. It is not mentioned at all in a comprehensive survey by Diehl and Winch (1979).

A more recent survey in the western middle belt of Nigeria was conducted in the mid-1990s by Manyong et al (2001). They found that inorganic fertilizer was used on 27% on men's yam fields and on 34% of women's yam fields. Thus, the results of the two surveys are similar. There appears to be slightly less use of fertilizer in the middle belt because human population density is much lower there and land is not as scarce as in southeastern Nigeria. Organic amendments were applied to 11% of men's fields and 19% of women's fields in the middle belt study.

Another recent survey in the East-Central section of the yam-producing belt in Nigeria by Amegbeto et al (2003) found that 60% of farmers use fertilizer for yam production. The survey went further to examine the intensity of use by those farmers. It provided evidence of intensification and sedentarization of yam cultivation by older farmers. Other variables that were closely linked to fertilizer use were the size of the farmer's yam area, the number of other crops on which fertilizer is used, and whether or not some yam is sold (market orientation).

Fertilizer use for yam in Bénin appears to be extremely low. It was not mentioned in studies of yams production in Bénin by Dumont (1985), Bruntrup and Kougba (1991), Vernier (2001) found that only 4% of yam producers applied fertilizer directly to their yam in a survey of several villages in Bénin. However, most farmers applied fertilizer to their maize and cotton, which were grown in rotation with yam.

Current fertilizer recommendations for yam in each country. There are many publications of fertilizer response trials, especially from Nigeria. Almost every trial resulted in a new recommendation for yam fertilizer application. A summary of these trials and recommendations is included (Annex 1). Some of them are based on a soil type and others purport to be valid for an agroecological zone. But important information such as field history, dominant fallow vegetation, and soil properties are rarely included in the reports.

In Bénin and Togo, there is one blanket recommendation for yam. This is a dangerous situation, which may cause some farmers to lose money. In Côte d'lvoire, there are different recommendations for different species (Annex 2), but the recommendations are again country-wide. In Nigeria, there are many recommendations. Sometimes, this is justified in the case of different ecological zones or soil types. But sometimes different recommendations are given, even for the same zones. This suggests that the trials were conducted under variable conditions by different authors and those conditions were not very well described. Also, some of these recommendations emanate from a limited number of trials on a limited number of sites in a limited number of years. Thus, they are only approximations. Field history is rarely mentioned in the reports, but field history can change drastically the recommendation for a given crop on a given type of soil. For example, yam grown on a field that is recently cleared from fallow is not likely to respond to fertilizer because soil organic matter is high and adequate nutrients may be stored in the mineral and organic fractions of the soil. After several years of cropping, the same cultivar may respond to

N applications.

In modem agriculture, fertilizer amendments are based on soil testing or on field history combined with soil type. But soil properties are mentioned in few of the reports of fertilizer response. Another method of calculating fertilizer needs may be to estimate the exports of nutrients in harvested yam tubers. In addition, the appearance of deficiency symptoms can guide investment in fertilizer.

Nutrient deficiency symptoms on yam. It is recognized that images of nutrient deficiency symptoms could be used to guide decisions on where and when to apply fertilizer. Descriptions of nutrient deficiencies were recorded for *D. rotundata* by Gaztambide and Cibes (1975) and are presented below as taken from Degras (1993). O'Sullivan et al (no date) have also described deficiency symptoms in *D. alata*.

Nitrogen: Very small leaves, light green or yellowish at first, then drying out from the tip to the edges before falling off. The leaves that grow back are thin, translucent, contain anthocyanins and do not fall.
Phosphorus: Purple or violet leaves when young, and dark, shiny green leaves when mature; senescence is marked by scattered yellow to light brown then dark brown leaf areas, then the area between becomes yellow; the leaves fall starting from the bottom to the top.

Potassium: Small, round, brownish spots appear, then the leaves roll up, afterwards, the spots coalesce especially at the margins; they appear burnt and necrotic, with a yellow background; leaf abscission.

Calcium: The leaf is small and leathery, the older ones are mottled and yellow; at the end they become necrotic along the main vein on the underside of the leaf.

Systematic images of symptoms do not yet exist for yam although the paper by Gaztambide and Cibes (1975) includes some images. It is clear that images of nutrient deficiencies should be made available to development projects. In the absence of this, maize nutrient deficiency symptoms are very clear (Figure 1) and can be used to indicate the nutrient status of soil for the eventual application of fertilizer to yam.

Most commonly limiting nutrients. Researchers should attempt to clarify the nutrient elements that are most often limiting to the yam yield. This knowledge can be used by farmers to economise on fertilizer. For example, if yam rarely responds to nitrogen (N) additions, and the applied N leaches from the soil before a crop can be grown after yam, then the investment in N fertilizer will have been wasted. Identification of limiting nutrients can best be done by using missing nutrient techniques or factorial experiments in which the effects of single nutrient applications can be isolated. The application of combined fertilizers can not help to achieve this. These trials can be done in nutrient solution, in pots, or in the field. Each kind of trial has its advantages and disadvantages.

The most limiting nutrient for yam growth in nutrient solution was shown by Gaztambide and Cibes (1975) to be N. Biomass of tubers and aerial apparatus without N was less than 1% of biomass with a complete nutrient solution. Phosphorus (10%) followed N, calcium (15%), potassium (25%), and sulfur (30%). This may not necessarily be the case in the field because the soil provides some part of the required nutrition.

Experience from many years ago gave useful indications of fertilizer responses. For example, trials in eastern Nigeria from 1947 to 1951 showed a consistently positive effect of N application and a lesser response to K (Irving 1956). The same author found that response to P was rare and occurred only when the previous fallow was dominated by grasses. Unfortunately, soil nutrient characteristics are not included in the paper. The results of a large fertilizer experiment conducted in Ghana also suggested that P and K were not needed in the savanna, but only in the forest. For Togo, Ghana, and western Nigeria, the FFHC (1965) confirmed the need for N in all cases, while the need for P and K was less clear. A relatively minor attempt to assess yam yield response to individual nutrients was synthesized by Djokoto and Stephens (1961a; 1961b) in central and northern Ghana. The highest frequency of yam yield response was achieved from P application. There was never a response to K. However, it must be noted that the results were confounded by rotation effects with other crops. In Côte d'Ivoire, Chabalier (1980) observed a clear response to N but it is not clear how the trial was conducted and where.

More recent studies give a bit more clarity, especially where soil properties are also reported. Kayode (1985) worked in four different fields over a 4-year period in southwestern Nigeria and found that *D. rotundata* did not respond to N in the environments where soil organic matter (SOM) was 4.6 or 5.6% (Table 3). But in the environments where SOM was 1.7 and 0.9%, a significant yield increase of 12.5% was observed with 35 kg N/ha. In those trials, there was no effect of P and K application where P was 8 mg/kg or more and exchangeable K was 0.15 meq/100 g or more (Table 4). These results can give an idea of critical nutrient levels. In northern Ghana, Koli (1973) observed substantial responses of yam to N application on fields where SOM was 0.8% or below (Table 3). Exchangeable K was 0.29 meq/100 g and there was no response to K additions. Available P was 13.7 mg/kg and response to P was substantial.

In a trial at IITA in southwestern Nigeria, Kpeglo et al (1981) achieved a maximum yield of 42.6 t/ha with 45 kg N/ha and 30 kg K/ha. The same fertilizer rate gave the highest marketable tuber yield of 38.4 t/ha. Yield reduction was 7.5 t/ha from withholding N and 7.9 t/ha from withholding K. Soil properties were not reported in the paper. Lyonga (1981) also recorded significant responses in the highlands of Cameroon to N alone, K alone, NP and NK. The ratio of extra return to cost averaged 5.2 for N alone, 5.0 for K alone, 3.5 for NP, and 3.7 for NK. The soil properties are not given.

In Togo, there was little research on soil fertility for yam before 1988. One trial was conducted in 1990 and 1991 by the Institut National des Cultures Vivrières (INCV) at Sotouboua on a *sol ferrugineux tropical*. There was no response to N in these trials in which yield potential seems to be limited to approximately 12 t/ha. Application of K increased yield and application of P increased tuber size and commercial yield (tubers larger than 1.5 kg). Based on this and the good food quality (for pounded yam), the author recommended 50 kg P_20_5 and 60 kg K_2O/ha. But this was not validated in other years or at other sites.

In summary, there is substantial variability in the results over time and space. It is expected that over time, the probability of the response of yam to fertilizer will increase as soils become more depleted. This was noted by Irving (1956) and illustrated by the results of Kayode (1985). Since dominant vegetation is an indicator of soil quality, this could also be used. Other trends may be related to soil types on different parent material. For example, in Ghana and Nigeria, the predominant soils are from sedimentary rocks in forested regions and from igneous and metamorphic rocks in the savanna regions, which usually contain adequate K. So response to K would be less likely in the savanna regions.

Strategy for the development of fertilizer recommendations. The strategy for fertilizer recommendations is to generate the maximum economic return. Economic return depends on the cost of the fertilizer and the value of the increased yield. The problem faced by the farmer is to foresee the response (yield increase) from the application of a given amount of fertilizer. Certain tools can be used to guide a farmer's fertilization program. Tools for guiding fertilisation include the following.

- Nutrient deficiency symptoms: If nutrient deficiency symptoms are observed, then it is highly probable that there will be an economically justifiable response to fertilizer application. However, if they are not observed, there may still be an economic response to nutrient additions. So the lack of symptoms does not indicate that supplemenatary nutrients are not needed.
- Correlations between soil types and nutrient deficiencies: Some soil types are known to be deficient in certain nutrients. For example, the sedimentary soils of the rainforest zone of southern and eastern Nigeria (Obigbesan, 1981) and southern Bénin and Togo are known to be low in K and responses to K are more likely. On the other hand, the soils of the Guinea savanna zone of West Africa generally have adequate K reserves and therefore a low probability of response to K unless the soils have been continuously cropped over a long period. Soils of semi-arid zones are known to be low in SOM and hence in N. They would be expected to respond to N application.
- Fertilizer response trials: If a crop responds to the addition of a nutrient, this tells us that the nutrient is limiting yield under the conditions of the trial. But it does not mean that this nutrient will be required under all conditions. From this result we need to judge how far to extrapolate the need to apply fertilizer. A large number of response trials are needed over years with varying weather conditions and on different sites that are well described.
- Correlations between field history or dominant vegetation and fertilizer response: The probablility of a response increases with the duration of cropping. For example, fields recently brought out of forest fallow are not likely to respond to N. But crops may respond

to N after grass fallow in the forest or in the savanna zone. Fallow may not bring the soil fertility to a level that is sufficient for high yam yields and the quality of the fallow vegetation can be linked to fertilizer response. Irving (1956) noted that a response to P was observed only when the fallow vegetation was dominated by grasses. He also noted that response to K was more likely where the bush cover was poor. Therefore, fertilizer response trials should be conducted on field sites with different cropping or fallow histories and the results must be synthesized, taking into account the different histories. Fallow vegetation is a good indicator of the fertility of the soil. The major type of vegetation (trees, bushes, grasses) should be described, as well as the dominant species if there are only one or two of them (for example, *Chromolaena odorata*, *Imperata cylindrica*, *Andropogon guyanensis*, etc.)

- Correlations between soil characteristics and fertilizer response: The response of a crop to fertilizer addition also depends on the nutrient levels in the soil. If there are sufficient nutrients in the soil to achieve potential yield, then there will be no response to fertilizer. For a farmer, it would be an ideal situation to know the nutrient status of the soil. However, fertilizer recommendations based on soil testing are not currently used in tropical Africa, as soil testing is very expensive and there are insufficient fertilizer trials in which soil properties are known. In many places, fertilizer application is guided by soil nutrient concentrations compared with the critical level, which can be defined as the soil nutrient level above which the crop is not likely to respond to the addition of that particular nutrient.
- Yield potential: Higher yield potential (due to high solar radiation, adequate rainfall, irrigation, good protection from pests and diseases, etc.) increases the probability of a response to fertilizer. This is because, if yield potential is high, then the soil may not be able to supply sufficient nutrients as rapidly as they are required by the crop. For example, in Trinidad, Van der Zaag et al. (1980) showed that varieties (and species) with higher potential yield have a higher demand for P. If yield potential is low for some reason other than nutrient limitations, then the yield of a crop is not likely to be increased by fertilizer. Yield potential is most influenced by climate (solar radiation, drought, flooding). In root or tuber crops such as yam, the response is also influenced by the soil's physical properties. For example, Kang and Wilson (1981) found that the response of *D. rotundata* to fertilizer depended on the mound size. With large mounds (30 cm in height) the response to fertilizer was 16%. Much smaller responses were obtained with mound heights of 24 cm (6%) and 13 cm (7%). Without mounding, the response to fertilizer was slightly negative.

Clearly, there are several tools for the development of fertilizer recommendations. Each requires information of different kinds. In the absence of observed nutrient deficiencies and adequate fertilizer response studies, there are some simple approaches:

- Replace nutrients exported in harvest: This approach is biologically sustainable in the long term but it may not be justified in the short term if the soil actually supplies all of the nutrients needed by the crop.
- Underestimate fertilizer needs: This approach reduces risk. As shown in Figure 1 (scenario 'C'), the greatest response of crops to fertilizer is generally to the first increment. Thus, a solution in the absence of clear information is to apply small amounts carefully near the plant at a time when the plant can absorb the nutrients.

Lack of response by a crop to an added nutrient generally has two causes. The first is that the nutrient is supplied in sufficient quantity and rapidly enough to satisfy the crop (shown as scenario 'A' in Figure 1). This explains why yam grown immediately after a long forest fallow is not likely to respond to fertilizer. Onwueme and Charles (1994) suggest that yam rarely responds to P because the soils on which yam is grown are rich in P, but also because mycorrhizae associated with yam roots facilitate the absorption of P.

The second case is where the soil's physical properties are highly degraded and the plant cannot take advantage of the additional nutrients. This is shown in Figure 1 as scenario 'B'. The crop roots cannot effectively absorb the fertilizer that is supplied.

Nutrient exports in yam yields. In the absence of clear production functions, due to a dearth of well characterized nutrient response trials, approximations can be made by combining information on the nutrient contents of tubers, average yields or target yields, internal nutrient requirements of the yam crop, and estimates of nutrient supply from the soil. The nutrient content of tubers can be used to estimate the amounts of nutrients exported in the harvest. One possible strategy for nutrient management is for additions to replace exported nutrients. The results of several studies are collated in Table 5. Note that the estimates in fresh tubers can be compared to those from dry tubers by multiplying by 3, assuming 33% moisture in tubers. A synthesis of the data reveals that exports per tonne of fresh tubers are typically 3 to 5 kg N, 0.3 to 0.5 kg P, and 3 to 5 kg K.

Using the approach of replacing exported nutrients, a farmer would multiply the yield by the nutrient content. For example, the export of N by a 10 t/ha tuber yield can be estimated at 40 kg/ha (80 kg/ha for 20 t/ha; 120 kg/ha for 30 t/ha). This does not take into account other losses of N during the growing season. The major cause of loss of N would be leaching and would occur during heavy rains when the soil is saturated. This would be aggravated if the crop is not yet well established.

Some improvement in the estimated need for fertilizer can be achieved if the internal requirement is known. The internal nutrient requirement is the amount of nutrient in the entire crop biomass, which produces a particular harvestable product. Sanchez (1976) has compiled this information for many crops, but not for yam. The internal requirement includes the nutrient content of the harvested product (tubers in this case) and the rest of the plant. It is used to estimate nutrient balances and nutrient needs. Estimates of aboveground yam biomass are rarely collected and estimates of litter fall before tuber harvest do not exist. One study that can contribute to information on the internal nutrient requirements of yam was reported by Irizarry and Rivera (1985) from Puerto Rico (Table 6). It shows that the harvest index of dry matter and most nutrients is around 65 to 85% except for calcium, which is around 20%. The N harvest index was 71.4%. This means that for a harvest of 30 t/ha, there would be 120 kg N in the tubers and 120 / 0.714 = 168 kg N/ha in the entire crop. There should be more estimates of the nutrient harvest index in yam. Practices that influence the source and sink relationships (e.g., staking, soil preparation) can influence the partitioning of nutrients in the plant and change the nutrient harvest index.

In addition to internal crop requirements, it is necessary to have an estimate of the supply of nutrient by the soil. The difference is the amount that should be absorbed by the crop from fertilizer. However, it should be noted that not all fertilizer is absorbed by a crop. The exact estimate of fertilizer addition takes into the fraction of nutrient that is taken up by the crop. This is often called fertilizer recovery or nutrient uptake efficiency.

Soil and plant critical nutrient levels. Leaf and soil nutrient levels are used to guide fertilizer applications to crops in many countries. For leaf critical levels it is first necessary to know which plant organs to sample and when to sample them. This is based on intensive research to study nutrient concentrations in different plant parts over time. Ideally, this is also related to crop yield and it is done in many environments. The data of lrizarry and Rivera (1985) suggest that the most appropriate time to determine the nutritional status of yam is about 5 months after planting when near maximum growth rates of leaves and vines occur. In one study in southwestern Nigeria, the nutrient content of *D. rotundata* lamina was found to be 3.20-3.45% N, 0.28-0.30% P, 2.20-2.50% K, 0.45-0.70% Ca, and 0.27-0.37% Mg at the peak period of nutrient supply (Obigbesan and Agboola 1978). The authors suggested that the leaf lamina is more appropriate for N and P diagnosis while the petiole is more satisfactory for diagnosis of K deficiency. This was based on their observation of high concentrations and rapid changes during the season. However, it was not based on comparison amongst differentially fertilized plots. They further suggest the use of fully mature but not senescent top leaves on the fourth branch on each main stem and that sampling should be at about 10 a.m. Janine (1985) observed a strong correlation between leaf K concentration and yam yield in southern Côte d'lvoire. Budelman (1989a) also observed a strong correlation at Adiopodoume, near Abidjan.

Regarding soil critical levels, various authors emphasize that responses are likely on soils containing less than 0.1% N, less than 10 ppm available P (Bray-1) and less than 0.15 meq/100 g of exchangeable K. The critical K level for cassava is also approximately 0.15 meq/100 g (Howeler; Kang). On Alfisols at Otobi in the southern Guinea savanna, Ohiri (1990) obtained the highest tuber yield consistently in 1985 and 1989 with the application of 90 kg N, 10 kg P and P (<15 mg/kg) but medium in K (0.20-0.30 mg/100g).

Fertilizer management for yam production. The key to good fertilizer management is making the maximum amount of nutrients available to the crop. Possible loss of nutrients must be avoided and this is best done with the appropriate timing of application.

The time of application depends how susceptible the nutrient is to loss. P is immobile and can be applied any time before the plant is established. N is very mobile and and is rapidly leached during heavy rains when the soil is saturated. K is less mobile but can be managed like N. These nutrients should be applied a few weeks before the period of maximum growth (Obigbesan 1981). It may be worthwhile to apply part of the N and K at emergence and the rest when the plant is growing vigorously, but the return on this added labour is not known.

In addition to the time of application, the placement of fertilizer is very important. Because P is immobile, it should ideally be incorporated into the soil at the time of mounding so that it comes into contact with many roots. But N and K should be applied close enough to the plant to provide good accessibility to the roots. However, one must be aware that spot or band placement too close to the plant can result in high concentrations that can damage plant tissues. Onwueme and Charles (1994) summarized the usual recommendations for fertilizer placement as follows. On mounds: Most authors apply the fertilizer in a circle 15 cm from the yam plant at a depth of 3 to 5 cm. But it could also be spot placed.

On ridges: The fertilizer is applied in a band 10 cm from the centre of the ridge.

In addition to the above considerations, the number of fertilizer application operations that are needed must be taken into account. On very small plots, it would be justified to apply P while mounding and to apply N and K after emergence and during vigorous growth (i.e., three different operations), but this might not be justified on a large-scale farm where multiple applications would be too costly. Applied P also continues to have an important effect in subsequent years. Therefore, as a compromise solution, complex fertilizer can be applied after germination. This is reasonable because P is rarely the limiting nutrient.

Researchers have studied the effect of the date of application with respect to the date of planting. For example, Chebalier (1980) found that N application 3 months after planting resulted in a higher yield than application 1.5 months after planting. However, fertilizer should be applied only to mounds on which plants are growing. And it is only by observing the plants' growth that one can judge if the plant is nearing its period of rapid nutrient uptake. The INRAB fiche technique recommends that fertilizer be applied one month after germination and this appears to be a reasonable recommendation.

Effect of fertilizer application on yam quality. Farmers often do not apply fertilizer to yam because they perceive that it will result in tubers of reduced quality for storage and for consumption. For example, the INRAB (1995) technical guide states that excess N results in tubers with high water content that do not store well. The use of inorganic fertilizer is strongly believed by farmers to be a major factor causing the rot of yam tubers in storage (Chukwu et al 2000, unpublished draft). As a consequence, some yam farmers refuse to use inorganic fertilizer in the production of seed yams or those meant to be stored beyond 6 months after harvest (Chukwu et al, 2000, unpublished draft). According to Vernier et al (2000) the problem of fertilizer application reducing quality appears to be true for the first harvest of early, double harvest types but it is not true for the second harvest of the double harvest types, or for late varieties, or for *D. alata*.

Starch content: Results from a fertilizer trial on Alfisols of southwestern Nigeria using a factorial combination of N, P, and K (Kayode 1985) revealed that neither nutrient had any significant effect on the starch content of yam. Umanah (1973) and Adeniji (1998) found the same negative effect. For Treche and Guion (1983), the ratio of amylase to amylopectin increases with N application but the significance of this finding is not obvious. Some authors observe that N application increases starch content, especially in the first harvest (Okpon and Aduayi, 1988). Obigbesan (1973) found increased starch contents of yam tuber with K fertilizer. Maximum starch content for *D. esculenta* were obtained with 40 kg N/ha and 120 kg K_20/ha (Singh et al. 1973).

Dry matter: According to Vernier et al (2000) and Obigbesan (1973), excess N appears to increase tuber water content while K appears to reduce water content and improve storage. This is fairly well documented for tuber crops in general (Treche, thesis). However, Kayode (1985) demonstrated slight increases in tuber dry matter from N application and slight decreases from P and K application for Enyi (1972), Hedge (1981) and Singh et al. (1973). Contrary to this, Treche and Guion (1983) found dry matter to decrease with N application. Adeniji (1998) observed no effect of fertilization on the dry matter content of yam.

Browning: Etereje et al (1990) found that the browning potential of the surfaces of cut tubers of *D. rotundata* has been observed to be significantly higher in yam tubers produced under fertilizer application. This browning was supposed to be non-enzymatic.

Weight loss in storage: Kpeglo et al (1985) found no effect of fertilizer rates on weight loss in storage. Umanah (1973) and Azih (1976) had similar results. There are two kinds of loss in storage. One is the loss from damage during harvest and transport and the other is physological loss (respiration). A trial conducted in Côte d'lvoire assessed the influence of chemical fertilization with NPK (75-54-94) on storage losses of different varieties of yam (two *D. alata* and one belonging to *D. cayenensis-rotundata*) (Dumont et al 1997). The authors observed that fertilisation resulted in more storage loss from both mechanisms. They also note that the importance is probably underestimated because farmers select out damaged tubers before storing. Physiological losses were greater for *D. cayenensis-rotundata* than for *D. alata*.

Sprouting: Kpeglo et al (1981) found that N application increased sprouting in storage and high K application reduced sprouting. The same results were noted by Obigbesan and Adesiyan (1981). However, the statistical treatment of the data is not clearly described and the fertilizer effects were significant only in one out of two years of observation.

Quality of pounded yam: Obigbesan (1993) reported that farmers in the Kabba area of southwestern Nigeria complained that yam grown with 125 kg/ha of ammonium sulphate fertilizer darkens on cooking. As a consequence, many farmers were reported to refuse to apply this fertilizer to yam for fear that it would impair the quality of pounded yam. In a survey of the root crop belt of Nigeria (Ohiri et al. 1996) reported that the majority of farmers (70%) interviewed in southwestern Nigeria, believed that fertilizer reduced the pounding quality of yam. Vernier et al. (2000) found that fertilizer application (200 kg/ha of 14-23-14-5-1 N-P-K-S-B) had a negative effect on the elasticity and on the taste of 'Baniwoure' (*D. rotundata*; late maturing) and no effect on 'Singo' (*D. rotundata*; late maturing; many small tubers). Adeniji (1998) found that N fertilizer alone reduced the acceptability of pounded yam from a *D. rotundata* variety while NPK slightly improved it. Adeniji (1998) found that fertilizer application affected the color and elasticity of pounded yam but not the taste.

Because of the concern for yam quality, Hydrochem in Bénin has already proposed a fertilizer formulation for cassava and yam in which K_2O concentration is twice that of N concentration, stating that this is done to reduce the risk of root rots. The formulation is 13-9-27-5S-4MgO.

Effect of fertilizer application on nematode infestation. It is known that nematode populations are affected by soil properties (Cadet and Thioulouse, 1998). Therefore, it might be expected that fertilizer application would influence nematode populations. Several studies have been conducted on the effect of fertilizer on nematode populations, especially *Scutellonema bradys* (Steiner & Lehew) Andrassy For example, a reduction of *S. bradys* was demonstrated by Adesiyan and Adeniji (1976) when yam was amended with a high level of N-P-K fertilizer (Coyne and Baimey, personal communication, 2002). However, N alone on D. rotundata increased the fraction of infested tubers (Luc et al 1993). In the same study, P application mitigated the effect of N on tuber infestation. These results corroborate the observations by farmers recorded by Adesiyan and Adeniji (1976) (cited by Luc et al 1993). Obigbesan and Adesiyan (1981) also report that yam fertilizered with N alone without P and K produce poor quality tubers which accumulate a larger number of dry rot nematodes.

The application of N P K and Nemagon suppresed *S. bradys*, but Nemagon reduces significantly the yield of *D. alata* (Adeniji 1977). The use of organic manure gives higher yields and considerably reduces the density of nematodes. Wood ash increased yield but was ineffective in reducing nematode densities (Adeniji 1977).

Organic matter as sources of nutrients. Janine (1985) found good responses to organic fertilization but there are not enough details to know whether it was because of the nutrient supply or because of the improvement of soil properties with consequent moisture or nutrient retention.

Application of organic nutrient sources such as cow dung ensures a more balanced nutrition and less probability of the negative effects on quality. Ohiri and Chukwu (1991) found that application of 4.0 t/ha of cow dung could replace 50% of the inorganic fertilizer requirements for yam.

Organic matter management

Soil organic matter levels needed for yam production. A limited review of research results led Degras (1993) to postulate a total N concentration of 0.1% as sufficient to render forest soils adequately fertile for yam cultivation. This corresponds to about 1.2 to 1.5% organic carbon and 2 to 2.5% SOM. Djokoto and Stephens (1961) found yam yield to be positively correlated with soil organic carbon (r=0.81) in five sites in Ghana. Kayode (1985) also observed the response of yam to N fertilizer to be correlated with SOM content (Figure 2).

Assuming a target of 2% SOM, how can this be achieved? de Ridder and van Keulen (1990) give guidelines for simple calculations of organic matter (OM). First, it is necessary to calculate the amount of OM/ha so that it can be compared with the amounts available in various fallow or cropping systems. For example, assuming an SOM content of 1% and a soil bulk density of 1.4 g/cc, one hectare to 30 cm depth contains 42 t (1 g SOM/100 g soil x 30 cm x 10,000 cm x 10,000 cm x 1.4 g/cm x 1 tonne/I ,000,000 g) of SOM. Then, it is necessary to calculate the amount of additional OM needed to compensate for the decomposition of the initial SOM content. Assuming an annual rate of loss of SOM of 4%/year, 1.68 t/ha must be added just to maintain SOM. Finally, it is possible to estimate in a similar manner that in order to increase SOM from 1% to 2%, 42 t/ha of OM would be needed.

Once the target SOM content is achieved, a similar calculation suggests that annual additions of 3.36 t/ha (2 x 1.68 t/ha) would be needed to maintain this level.

Potential of improved fallow systems to contribute to soil organic matter. A suggestion for yam research and development by Degras (1993) was to experiment with legumes in yam production systems as soil conditioners, sources of N, organic matter, and for weed control (p.347). The most studied systems of organic matter production using legumes are based on herbaceous legumes and woody perennials. We consider *Gliricida sepium* as one candidate woody system and *Mucuna* and *Pueraria* as herbaceous legume systems.

Gliricidia sepium live staking system. The *Gliricidia sepium* live staking system is one promising niche for agroforestry because yam responds well to staking and requires OM inputs. Furthermore, *Gliricidia* has a canopy that allows more light transmission than most other trees because of its 'open architecture' (Budelman 1990). There are several studies of alley cropping with *Gliricidia* in various sites in humid and subhumid West and Central Africa that can provide estimates of *Gliricida* pruning dry matter (Table 7). In some trials, total prunings were measured, while in others, leaf and stem biomass were measured separately. Kang and Van den Beldt (1990) reported production of total dry matter of *Gliricidia* prunings of 5.5 Mg/ha from five prunings of trees spaced 4 x 0.5 m (5 000 trees/ha) on an Alfisol in southwestern Nigeria. Otu and Agboola (1994) estimated pruning dry matter of 8.5 Mg/ha with three prunings in the second year after *G. sepium* planting in southwestern Nigeria at a density of 2500 plants/ha.

Since most of the nutrients are found in the leaves, we tried to find estimates of the proportions of leaves and stems in prunings of *G. sepium*. Small stems are sometimes measured with the leaves since they are also applied as mulch, while large stems are often taken away for firewood. However, some researchers may strip leaves from the small stems and weigh the latter together with large stems. Fagbola et al (1995) found that one-third of the dry matter from prunings of *G. sepium* was composed of leaves and two- thirds consisted of stems. Tossah et al. (1995) reported a relation of approximately 60% leaves and 40% stems. Their objective was to identify tree species for the production of mulch and firewood and small stems were weighed together with leaves, thus explaining their high estimate of leaf production. It appears that leaves and twigs form approximately 50% of *Gliricidia* prunings dry matter. From all of the results we can estimate average production of *G. sepium* mulch (leaves and twigs) of 3 Mg/ha, with a range of 1.5 to 4.5 Mg/ha (Table 7).

Herbaceous legume rotation systems. For *Mucuna*, a typical dry matter accumulation is approximately 5 to 6 t/ha (Table 8) although it can range from 1 to 12 t/ha depending on soil properties, drought, and waterlogging. This dry matter must be protected from fire and from bowsing animals if it is to contribute to SOM. Amounts of *Pueraria* dry matter are similar. Tian et al. (1999) measured 7.6 t/ha above ground and and 9.2 t/ha including roots. In the same trial, *Chomolaena odorata* accumulated 7.8 and 8.8 t/ha, respectively. In southern Côte d'lvoire, Autfray and Gbaka Tchetche (1998) found that *Pueraria* fallow usually produced more than 10 t/ha of mulch, slightly more than *Chromolaena odorata*.

The use of *Pueraria* has been particularly attractive after the experience in central Côte d'lvoire of Charpentier et al (1999) in which yam yield without soil tillage was approximately 17 t/ha after one year of *Pueraria* fallow compared with 8.9 t/ha on mounds after natural fallow, In the next cycle, yam after *Pueraria* without mounds produced 3.5 t/ha and the control produced no yield, due to unfavorable rainfall. Measurements of water infiltration under analogous conditions showed that the rate was doubled by a 1-year *Pueraria* fallow (Charpentier et al. 1999). A trial in the forest zone (Tene 1997) confirmed that yield of yam without tillage was slightly increased (13%) for Dcr 'Bete Bete' and substantially increased (56 %) for Da 'Florido' (Autfray and Gbaka Tchetche 1998). At a different site (Gabia, 1997), the same authors observed a decrease in bulk density under 18 months of *Pueraria* fallow of approximately 13%.

Table 1. Yield of yam in the same field over time in West Africa.

Source	AEZ; country	Year 1	Year 2	Year 3	Year 4
1	Humid; Nigeria	23.6	16.0	5.9	13.0
2	Humid; Côte d'lvoire; + fertilizer	15.7	-	-	11.1
2	Humid; Côte d'lvoire; - fertilizer	17.6	-	-	7.6
3	Sub-humid; Burkina Faso	13.0	7.2		

Sources: 1 = Odurukwe and Oji (1981); 2 = Yeboua (1990); 3 = Somé et al (1995)

Table 2. Yield of yam as a function of length of previous fallow period in central Nigeria.

Fallow length (years)	Fresh tuber yield (t/ha)
1-2	5.7
3	9.7
4	10.8

Table 3. Response of yam to N application and soil organic matter concentration.

Author	Year	Yield without fert	Response (t/ha)	SOM (%)
Kayode (1985)	1978	15.95	0.37	5.6
	1979	17.0	0.96	4.6
	1980	15.6	1.83	1.7
	1981	16.5	3.52	0.9
Koli (1973)	1970	13.8	2.7	0.72
	1971	20.8	2.3	0.83

Table 4. Response of yam to P application and available P (Bray-1) concentration

Author	Year	Yield without fert	Response (t/ha)	Bray-1 P
Kayode (1985)	1978	16.0	0.22	7.0
	1979	17.8	None	8.0
	1980	17.7	None	10.1
	1981	19.2	None	11.5
Koli (1973)	1970	13.5	1.6	13.7
	1971	20.8	1.3	13.7

Table 5. Range of nutrients in kg/Mg in dry and fresh yam tubers.

Estimate	State of tubers	N	P	K
Obigbesan and Agboola (1978)	Dry	14.2	1.9	17.9
Ferguson et al (1980)	Dry	13.7	1.3	11.6
Budelman (1989)	Dry	10.2	1.4	9.6
Sobulo (1972)	Fresh	4.6	0.33	2.9
Le Buanec (1972)	Fresh	3.8	0.39	4.2
Rodriguez et al (1989)	Fresh	4.0	1.1	5.9
Degras (1993)	Fresh	3.1-4.1	0.38-0.51	4.0-4.8

Table 6. Percentage in plant at harvest (8 months) of D. rotundata.

	DM	N	P	K	Ca	Mg
Tubers	83.7	71.4	84	74.4	18.7	66.7
Stems	6.5	3.7	4	6.5	19.8	5.6
Leaves	9.8	24.9	16	25.6	81.3	33.4

From Irizarry, H. and E. Rivera (1985)

Table 7. Dry weight (Mg/ha/yr) of G. sepium prunings after the establishment year in several studies in the savanna zone of West and Central Africa.

Estimate	Prunings	Leaf	Stem
Kang and Van den Beldt (1990)	5.5	--	--
Otu and Agboola (1994)	8.5	--	--
Fagbola et al (1995)	4.6-8.4	1.6-2.4	3.0-6.1
Tossah et al (1995) Ultisol	3.2	1.7	1.5
Tossah et al (1995) Alfisol	8.0	4.6	3.4

Note: Fagbola et al. (1995) included all woody parts in the stem sample while Tossah et al. (1995) included twigs in the leaf sample.

Table 8. Above ground dry weight (Mg/ha) and N content (kg/ha) of M pruriens var. utilis in several studies in the savanna zone of West and Central Africa.

Estimate	Leaf + Vine	N content	Time
Hauser and Nolte (2002)	3.3-6.7	63-144	25
Chikoye and Ekeleme (2001)	1.8-3.6	--	16
Vanlauwe et al (2000)	6.1-6.9	115-145	18
Houngnandan et al (2000)	4.4-6.0	63-94	20
Carsky et al (1999)	3.4-6.2	85-154	16
Becker et al (1998)	1.0-12.7	20-160	20
Segda and Hien (1998)	8.5-9.0	193-211	20
Ibewiro et al (1998)	6.4	290	13
Muhr et al (1998)	4.2-6.0	--	36
Sanginga et al (1996)	7.7	325	12

Recommendations for development

- Generally, the application of more than approximately 40 kg N, 40 kg P_20_5 and 40 kg K_20 is rarely justified. This is because the largest effect of fertilizer occurs with the first increments in conditions responsive to fertilizer. Under conditions of poor response to fertilizer (for whatever the reason), small doses will result in less waste.
- Under conditions of low yield potential due to, for example, late planting, small mounds or ridges, small sett size, etc., high fertilizer recommendations are difficult to justify. The above recommendation can be considered as a maximum.
- Residual effects should be taken into effect. Fields that have received P fertilizer in the last 5 years do not normally need P fertilizer application.
- High value yams for pounded yam, such as Kpouna (Puna, Kponan) and Laboko, are those that most require high levels of OM. Cropping/fallow systems to provide OM to the soil should be acceptable to farmers who have a wholistic view of costs and benefits. Only high value yam may justify: 1) the high labor cost of transporting OM, 2) occupying the field for a year with a cover crop, or 3) the reduction of planting density and the increased labor involved in using the live staking agroforestry system.

Recommendations for research

- Residual effects of K fertilizer should be determined.
- Total nutrient uptake in the yam crop should be estimated in a limited number of trials.
- Yam systems that require OM and those that can benefit from small amounts of fertilizer need to be identified.

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Annexes

Annex 1. Fertilizer recommendations for yam in West Africa. Irving (1956) reported on a major project of fertilizer trials in southeastern Nigeria from 1947 to 1951. There was a marked response to N application and a lesser response to K, while a response to P was rare. The fertilizer recommendation for yam in eastern Nigeria in the 1950s was 50g of N-P_2O_5-K_2O 12-12-18 per hill (Coursey, 1967). Since then, there have been many recommendations for fertilizer for yam in Nigeria.

- 200 kg/ha of 10-10-20 in southwest Nigeria (Ojo 1969),
- 12-12-18 in southeast Nigeria (Mann 1963),

- 125-250 kg/ha of ammonium sulfate in Nigeria (Onwueme and Charles 1994),
- 72 kg of N as urea, 22 kg of P and 72 kg of K per hectare at Umudike in southeast
  Nigeria (Enwezor et al. 1988).

More recently in Nigeria, Obigbesan (1981), recommended:

- in the north : 25 kg ha"1 of ammonium sulfate,
- in the southeast: 400 to 600 kg ha1 of NPK (12-12-17) with a supplement of Mg,
- in the southwest on acid soils : 300 kg ha1 of NPK (12-12-17) + Mg;
- in the southwest on other soils: 50 kg ha1 of N and 60 kg ha1 of K^2O.

On Ultisols at Umudike in the degraded humid forest ecology with total N of 0.09% N, exchangeable K of 0.08 mg/100g and available P of 20-25 mg/kg, optimum yield of yam was obtained when fertilizer rates of 90 kg N, 0 kg P and 75 kg K/ha were applied. A recent review of chemical conditions favorable to yam production in Nigeria. (Ohiri 1995) recommended 81-90 kg N, 0-20 kg P and 0-62 kg/ha based on soil tests and calibration studies to maximize tuber yield with reference to compound fertilizer NKP 15.15.15, The application of 200 kg/ha was recommended in the southwest. In the Southeast zone, recommended 600 kg/ha. Under yam/cassava/maize intercrop, recommended the application of 800 kg/ha to be applied at 8 weeks after planting.

The technical bulletin published by INRAB (1995) in Benin calls for an unspecified amount of TSP and 100 kg/ha of KCl. The recommendation in Togo is 50 kg of P_2O_5 and 60 kg of K_2O but this is based on 2 years of observation at one site in the savanna zone. Trials conducted in Côte d'lvoire show that application of 14 g NPK/plant (10-18-18) and 7 g /plant of urea give yield increases of 9 to 121% (Dumont and Tokpa 1989).

Annex 2.

Fiche technique pour la fertilisation de l'igname en Côte d'lvoire (Technical bulletin for yam fertilization in Côte d'lvoire)

- L'igname est exigeante en azote et en potasse. Les besoins en phosphore sont modestes. Le calcium et le magnésium sont nécessaires pour obtenir des rendements élevés. L'expérimentation a montré qu'il est bénéfique de fractionner la fertilisation. Ceci est surtout vrai pour 1'azote.
- La fertilisation de l'igname ne peut être définie de façon simple. Elle doit être modulée en fonction des situations très diverses qui peuvent se présenter.
- Après une très longue jachère, la fertilisation peut ne pas être rentable. Quand 1'igname est introduite dans un système permanent d'agriculture, les quantités d'engrais à apporter dépendent de plusieurs facteurs dont le niveau d'intensification pratiqué et le type

d'igname utilisé.

Fiches techniques

Dioscorea cayenensis à deux récolte: la fertilisation
Derrière une vieille jachère, la fertilisation n'est pas nécessaire. Quand les conditions de fertilité sont moins bonnes ou encore dans les zones très sèches, on apportera la fumure suivante (par butte):
-après la levée (stade 8-10 feuilles), 20 g d'engrais coton (10.18.18) ou 20 g d'engrais ananas (8.4.20.4Mgo);
-40 à 50 jours après la levée (début de la tubérisation), 10 g d'urée et 10 g de chlorure de potasse. L'engrais doit être apporté en couronne, au niveau du tiers inférieur de la butte. La production de seconde récolte (semenceaux) peut-être sensiblement augmentée (+ 50%) en apportant, immédiatement après la première récolte, 50 g par butte d'un mélange comprenant 150 kg d'engrais coton (10.18.18) et 50 kg d'urée.

Dioscorea cayenensis à une récolte: la fertilisation.
Derrière une jachère la fertilisation n'est pas nécessaire.
Dans les auties cas, on apportera la fumure suivante (par plante):
-après la levée (stade 8-10 feuilles), 13 g d'engrais coton (10.18.18) ou 13 g d'engrais ananas (8.24.20.4Mgo);
-50 à 60 jours après la levée (début de la tubérisation), 6,5 g d'urée et 6,5 g de chlorure de potasse.
En culture mécanisée, on peut procéder de la façon différente:
-avant le billonnage, 100 kg/ha d'engrais coton ou d'engrais ananas et 50 kg/ha de chlorure de potasse;
-50 a 60 jours apres la levee, on apportera 6.5 g d'uree par plante.
Lorsque 1'engrais est apporte sur billon, il faut Ie disposer en couronne autour de la plante. Il faut eviter de mettre 1'uree en contact direct avec les tiges d'igname.

Dioscorea alata: fertilisation
Derrière une vieille jachere, la fertilisation n'est pas necessaire. Dans un système intensif d'agriculture, il faut d'abord veiller a ce que L'igname ne soil pas introduite sur un sol acide. Au cas echeant, 1'acidite doit etre corrigée par un amendement calcaire (500 g de dolomie a 1'hectare au labour). Toujours dans un système intensifd'agriculture, la fertilisation preconisee pour Ie *D. alata* est la suivante: au labour, 200 kg/ha d'engrais colon (10.18.18) et au 70 ejour de vegetation, on apportera 100 kg d'uree/ha et 100 kg de chlorure de potasse/ha.

L'apport de 1'engrais, en cours de vegetation, doit se faire plante par plante en évitant le contact entre 1'engrais et la plante. La quantité d'engrais à apporter à chaque plante doit e é tre calcul é e en fonction de la densit é de plantation.