SYSTEMS DYNAMICS AND HETEROGENEITY - THE KEY TO UNLOCKING WEST AFRICA'S POTENTIAL? THE CASE OF MAIZE IN NIGERIA

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The enormity of the food security challenge in West Africa is well documented. In Nigeria, for example, which is better off than many countries in the region because of its oil wealth, the average supply of calories, in 1988, was 12% less than the minimum requirement for a healthy life, in spite of per capita food production having increased by 6% between 1980 and 1990 (Cleaver, 1993). Since the 1970s maize has achieved one of the highest production growth rates for food crops. Maize is also believed to have the greatest potential for technological breakthroughs. This paper investigates the potential role of maize in West Africa by focusing on Nigeria, which occupies 34% of the land area in West Africa, and produces 43% of the maize grown in this region.

The results show that the Green Revolution approach, in which the primary focus is on the development of high yielding varieties, does not lead to sustainable systems in West Africa. An alternative approach which exploits the dynamics and heterogeneity of West African agricultural systems is applied to the case of maize.Results show that high yielding fertilizer responsive maize can make a major contribution, but only in limited areas. Varietal

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improvement is shown to be one component in a holistic strategy for attaining sustainable development through technological and policy interventions.This dynamic approach to exploiting heterogeneity may be the key to closing West Africa's food gap.

Maize in the Nigerian economy

Oil revenues have had a major impact on government policy in Nigeria. We distinguish, therefore, between the oil bonanza period (mid 1970s to early 1980s), and the period after 1982 when oil revenues declined. During the first period, inspite of an overvalued exchange rate and soaring food imports, intersectoral terms of trade moved strongly in favor of the food sector.The price of food relative to non-food commodities was 80% higher in the early 1980s relative to the mid 1970s (Lele et al, 1989a).Fertilizer was subdized, usually at rates above 80% throughout this period, and until the mid 1990s. In spite of these incentives, food availability per capita declined. In the case of maize, production declined at an average annual rate of 6.7% between 1973 and 1982[5]. This occurred because of high rates of rural-urban migration, induced by the increasing gap between urban and rural wages.Maize prices fluctuated widely, but remained well above the 1976 level throughout the first period. In the second period, starting in 1982, maize production started responding to the favorable terms of trade. As shown later, this response was made possible by improved transport infrastructure and fertilizer responsive maize varieties. In addition, declining oil prices reduced urban job opportunities, and return migration to rural areas occurred. Incentives for maize production were at their peak in the early 1980s, with benefit: cost ratios mainly over 5 (World Bank, 1993). Production increases during this period together with currency devaluation in 1986 led to sharp decreases in the real price of maize, which in 1987 was less than half the 1976 level (Lele et al, 1989a).Maize prices recovered at the end of the 1980s in response to a ban on cereal imports, but input costs rose because of currency devaluation.The net result was that benefit: cost ratios declined to under 4 in 1991 (World Bank, 1993), but maize remained highly profitable due to the fertilizer subsidy. As a result the second period was characterized by a major turnaround in maize production, with output increasing at an annual rate of 5.3% (CIMMYT, 1994).

Food production and consumption in Nigeria is extremely varied. Traditional non-tradeable root crops such as cassava and yams, account for 38% of national calorie consumption, predominantly in the south. Rice and wheat, which constitute about 10% of calorie intake, is consumed mainly among higher income groups in urban areas. Staple foods in the north are traditional cereals (sorghum and millet) and increasingly maize. Per capita maize consumption at the national level is relatively low (16 kg/year). Wide differences in food self sufficiency within different parts of Nigeria are found, In general the northern states have food surpluses, while the south has deficits. Projections of food requirements under alternative population and income scenarios indicate that a 4.5% annual increase in maize production will be required. If non food uses of maize increase, higher production growth rates may be required. This indicates that the growth rate during the 1980s, when area increases accounted for the bulk of the increase, will at least have to be maintained. Since Domestic Resource Cost (DRC) analysis indicates that maize appears to have a comparative advantage, i.e. that domestic maize production saves foreign exhange, it would be worthwhile producing required amounts of maize nationally, rather than resorting to imports (Lele et al, 1989a).

THE ROLE OF MAIZE IN WEST AFRICAN AGRICULTURAL SYSTEMS

A forward looking strategy for technological and policy interventions requires an understanding of the factors behind the current role of maize in West African systems. This can be used to develop a vision for the future role of maize, and the identification of entry points for realizing the vision. A framework for analyzing the role of maize in West Africa is developed and applied in broad qualitative terms, with specific reference to Nigeria.

The role of a crop is the result of complex interactions between the biophysical and socioeconomic characteristics of the crop on the one hand, and those of the environment on the other. West African systems are characterized by a high degree of heterogeneity in both biophysical and socioeconomic terms. At first sight this may appear to imply that technological requirements are site-specific, leaving a very limited role for strategic technology generation. Analysis of changes in agricultural systems over time reveal however, that it is possible to identify broad based distinctions in the trajectories of agricultural systems, from which differences in the role of maize, its constraints, and technological and policy requirements can be derived. Thus,heterogeneity in agricultural systems is exploited to provide a characterization of the evolutionary path followed by systems. A broad based characterization of this nature is undoubtedly simplistic. However, as shown later, it can be a powerful tool for orienting technology generation towards the differential requirements of the diversity of systems in West Africa.

Climatically, 4 major zones can be differentiated in humid and sub-humid West Africa. Going from north to south they are the Northern and Southern Guinea Savanna (NGS and SGS), the Forest-Savanna transitional zone, also called the Derived Savanna (DS), and the Humid Forest (HF). The humid zone (DS and HF) occupies over half the land area in West Africa, while the sub-humid zone (NGS and SGS)accounts for about 40%.The pattern of distribution is broadly the same in Nigeria (Figure 1)[6]. In the sub-humid zone, with growing periods of 5 to 7 months and low rainfall, bases and nutrients are not easily leached, and alfisols predominate. In the humid zone, as season length extends to 7 to 9 months, and precipitation increases, the risk of leaching is also greater, resulting in low-base-status and acid Ultisols and Oxisols. About a quarter of the land area in humid and sub-humid West Africa has inherent soil characteristics suitable for crop production.

In West Africa the humid zone in general has better transport infrastructure than the north. Sixty eight percent of the humid zone has a road density greater than 15 km/100

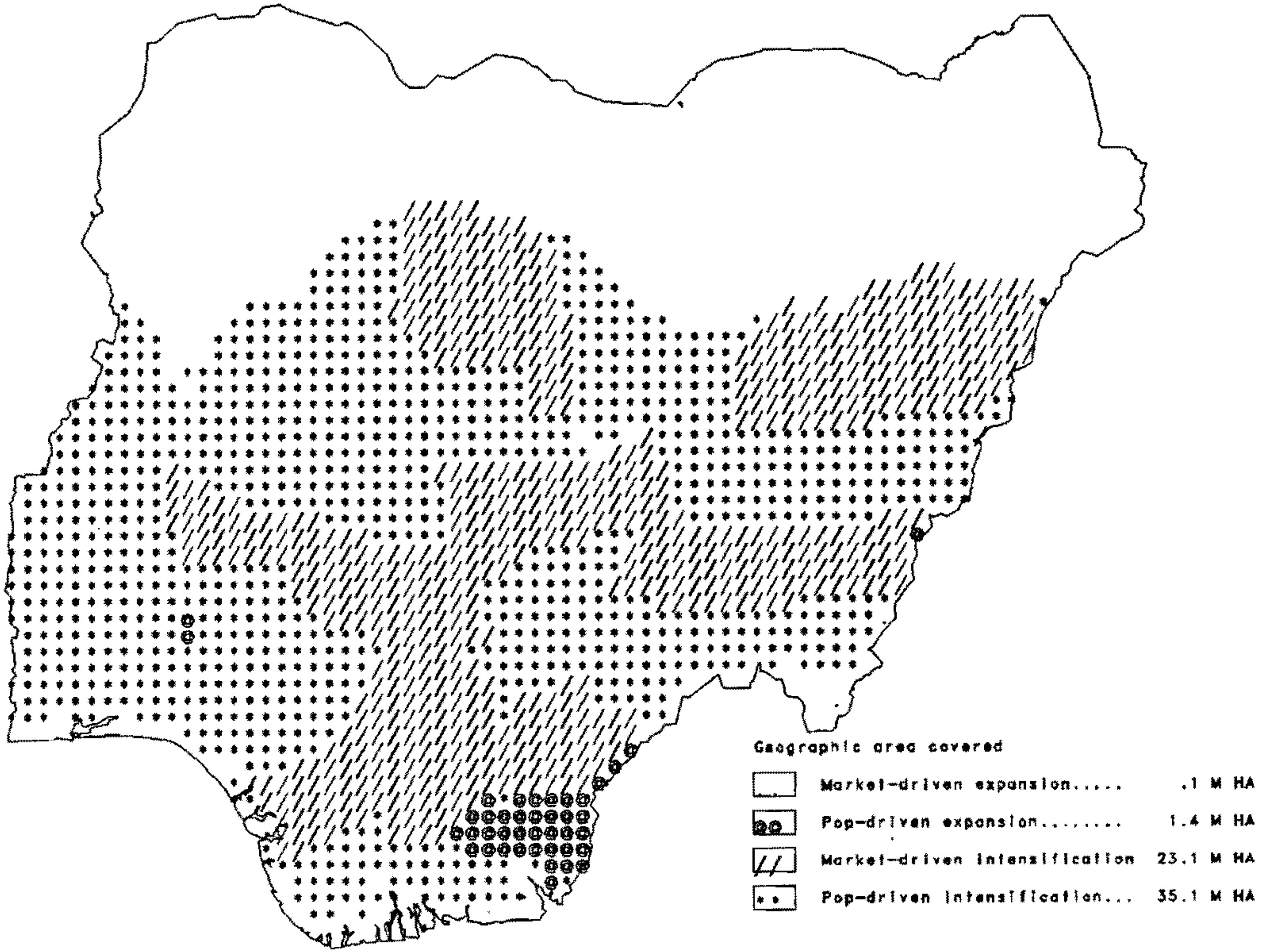

FIGURE I.
Status of agricultural systems in humid and sub-humid area of Nigeria

Macro-characterization of agric. systems in West Africa (Manyong et als 1994)
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sq.km., compared to 53% in the NGS (Manyong et al., in press). Moreover the humid zone contains the major population centers, and is located close to the sea ports. Nigeria has the best road density in West Africa (29 km/100 sq.km). The density of all weather rural roads is about 4% higher in the south than in the north (Gavira et al, 1989). Thus input/output price ratios should be lower in the south, which would favor nutrient responsive crops such as maize. As shown below, however, biophysical factors favor maize in the north.

Synthesizing the heterogeneity of agricultural systems in West Africa, Smith and Weber (1994) have distinguished two different trajectories: a subsistence oriented path driven primarily by population increase, and a market - driven path driven primarily by opportunities for cash cropping. A multi-period simulation analysis in the NGS by Freeman and Smith (1994) shows that pre-conditions for the market - driven path are good transport infrastructure, which reduces input/output price ratios, and the existence of technology that enables the system to profitably produce commodities for which it has a natural comparative advantage. Within each path, land use intensity increases over time. The early phase where soil fertility is restored through long fallows, is described as the expansion phase, and the later stages of bush fallow and permanent cropping are designated the intensification phase. The nature of the intensification process is markedly different between the population - and market - driven trajectories[7]. As land use intensifies over time, both trajectories are characterized by increasing labor/land ratios, and increasingly secure, privatized land rights. Market - driven systems, at all stages however, are distinguished from population - driven systems by a greater facility for adopting land saving, input using technologies, because of lower marketing margins. Data show that the average marketing margin[8] for cereals in a market - driven area in the NGS was 7 to 12 %, while in a population - driven area it was 34% (Freeman et al, 1994). As a result, input - intensive cash cropping is a distinguishing characteristic of market - driven systems. Fertilizer subsidies do not appear to be primarily responsible for this, because

PDI and MDI systems do not differ in this respect. Population driven systems in the intensification phase (PDI) favor crops that give the highest calorie output per unit land area, with minimal use of purchased inputs. Market-driven systems in the intensification stage (MDI) seek food and cash crops that can utilize purchased inputs to give high returns to land. Labor saving food crop production is the chief objective in systems in the expansion phase. Crop-livestock interactions are more likely in the market-driven trajectory, the high cost of cattle inhibiting their acquisition in PDI and PDE[9] (Table 1).

Table 1. Distinguishing characteristics of agricultural systems in humid and sub-humid areas of 9 West Africa countries.

Population - driven		Market-Driven
Expansion phase (PDE)	**Intensification phase (PDI)**	**Intensification phase (MDI)**
Shifting cultivation (Mean R=0.23)[a]	Bush Fallow Continuous cropping (Mean R=0.58)[a]	Bush Fallow Continuous cropping (Mean R=0.61)[a]
Land Abundance	Land Scarcity	Land Scarcity
Labor Scarcity	Abundant family labor	Abundant family and hired labor
No fertilizer subsidy (94% of systems)	Some subsidization of fertilizer (27% of systems)	Some susidization of fertilizer (26% of systems)
Minimal purchased inputs (No fertilizer use in 79% of systems)	Minimal purchased inputs (No fertilizer use in 61% of systems)	High levels of purchased inputs (Fertilizer used in 78% of systems)
Poor infrastructure	Poor infrastructure	Good infrastructure
Minimal cash cropping, Labor saving food crops (crops vary according to food preferences)	Minimal cash cropping. Land saving, low purchased input food crops (eg cassava)	Input - intensive food and cash crops (eg maize, cotton, cocoa)
Minimal crop - livestock interaction (non-existent in 72% of systems)	Minimal crop - livestock interaction (non existent in 71% of systems)	Crop - livestock interactions in 61% of systems

Source: Smith and Weber, 1994; Manyong et al., (in press); Manyong et al., 1995.

[a] $R = \dfrac{\text{Years of cultivation}}{\text{Years of cultivation + years of fallow}}$

Discriminant analysis applied to geo-referenced key informant interviews and secondary data from 9 West African countries[10] reveals that although population -driven areas predominate, market - driven systems occupy a substantial portion (34%) of West Africa, contrary to what is widely believed. Market - driven systems are more prevalent in the NGS and HF (41% and 39% of area) than in the other agroecologies (Manyong et al, in press; Mnayong, et al, 1995). About half the total area consists of PDI, just under a third is in MDI. Only 15% is in the expansion phase, almost all being part of the population - driven trajectory (PDE). Almost all of Nigeria is in the intensification phase, with the market - driven area (MDI) covering 39%, ie somewhat more than the West African average, while PDI systems occupy 59%[11] (Figure 1). Thus West Africa's heterogeneity can be broadly captured by 3 major types of agricultural systems (PDE, PDI and MDI), occurring in each of 4 major agro-ecological zones (NGS, SGS, DS and HF), giving rise to 12 major categories of systems. Within each category, modifications occur due to factors such as government policy or soil characteristics.

The role of a crop in a system can broadly be characterized as:

a) a lead crop, ie a crop that can best convert biophysical and socioeconomic resources into products that meet farmers' objectives. The production system tends to be organized around the needs of the lead crop.

b) a niche crop, ie a crop that can exploit spatial or temporal niches in the cropping system, to fulfill particular aspects of farmers' needs. Production practices on niche crops are dominated by the requirements of the lead crop.

c) regenerating crops, ie those whose primary role is to regenerate the resource base for the lead crop. These are mainly nitrogen fixing legumes. Their importance is greatest in PDI where soil fertility is declining and the resources for using corrective fertilizers are not available.

The NGS is climatically considered to have a comparative advantage in maize production because of high solar radiation and low night temperatures (Kassam et al, 1975). It is also the area where the season length (150 to 180 days) most closely matches that of maize and therefore enables it to use water and nutrient supply most effectively. Longer growing seasons, further south, can be more effectively converted into useful products by day-sensitive sorghum or millet varieties and roots and tubers in the SGS, and semi-perennial or perennial shrub and tree crops such as cassava, banana and cocoa in the DS and HF. In these agroecologies with longer growing periods sole cropping of maize would result in severe leaching of soil bases and nutrients, unless intercropped with semi-perennial or perennial plants[12]. Only deep rooting shrubs and trees can contribute to effective nutrient cycling, while grass fallows or annual legume cover crops are less effective (Jaiyebo and Moore, 1964; Kang, 1986).Thus, from the ecological point of view, only the NGS (occupying 17% of West Africa) is appropriate for intensive maize production, while in the more humid environments maize should be a niche crop in shrub or tree based systems.

As systems move from the expansion to the intensification phase, over time, fallow periods are reduced and inherent soil fertility declines. This reduces the yield of maize relative to less nutrient demanding crops such as cassava and traditional sorghum and millet. A comparison of maize yield across sites in Togo, Niger and Nigeria showed that in the absence of inorganic fertilizer, yield is higher in the humid tropics (2550 kg/ha), than in the subhumid zone (1350 kg/ha), most likely because of higher organic matter mineralization. With fertilizer application, the linear response to applied N reaches about 30 kg grain per kg N in the subhumid zone, while only half the response is achieved in the humid zone. As fertilizer application increases, maize yield in the subhumid zone approaches and finally out yields the humid zone at a N-rate of about 80 to 100 kg/ha. (Mughogho et al, 1986).Thus fertilizer response to maize declines from the north to the south. Traditional millet and sorghum achieve at most half the response of maize in the subhumid zone (Mudahar, 1986).This shows that in

MDI, characterized by a greater facility for adopting high input technologies, maize in the subhumid zone (NGS and SGS)is likely to out yield competing crops, as well as maize from the humid zone (DS/HF), and can therefore be a lead crop. In PDI however, where the use of purchased inputs is generally at low levels, maize is likely to be out yielded by competing crops in all agroecologies[13]. Here its role is that of a niche crop. In the expansion phase when inherent soil fertility is high, maize in the subhumid zone would out yield other less nutrient responsive crops, as well as maize from the humid zone. Whether or not maize becomes a lead crop, in the expansion phase, would depend on food preferences. The earlier advent of the rains in the humid zone provides a market for maize from this zone at a time when stocks from the subhumid zone are low. The bimodal rainfall pattern in the humid zone permits a second crop of maize. This crop however has to compete with the northern harvest, which as shown earlier is likely to out yield maize from the south. As a result, in countries with transport systems,across agroecologies, and with market - driven systems in the NGS, there is likely to be little incentive for second season maize.

In summary, therefore, matching the characteristics of maize, in broad terms, to the diversity of biophysical and socioeconomic environments in West Africa shows that in the expansion phase the role of maize is likely to be determined by food preferences. As land use intensity increases over time, and bush fallow and continuous cultivation systems become prevalent, maize is likely to become a lead crop in market - driven areas of the subhumid zones, with greater importance in the NGS than in the SGS. In other areas, maize is likely to be a niche crop where appropriate niches exist, with its prevalence in PD systems declining from south to north. The better the transport infrastructure between agroecological zones, and the degree of technical progress in lead crops of all agroecologies, the greater is the likely importance of maize in MD systems of the NGS relative to other areas (Table 2).

Table 2. Predicted role of maize in West African agricultural systems.

Agroecology	Agricultural System		
	PDE	PDI	MDI
NGS	Role	Niche	Lead crop declining in importance
SGS	related to	crop declining	from North to South
	food preferences	in importance	
DS	and relative importance of	from South to	Niche crop
HF	biotic constraints	North	Niche crop

This concept of the role of maize is broadly consistent with data from Manyong et al's (in press) characterization survey of West Africa. The data show that maize is widely grown in all agroecologies in West Africa, featuring in the farming systems of 72% of the cropped area, with its prevalence highest in the NGS (92% of area), and lowest in the HF (57% of area). Maize is one of the two most important crops in about 30% to 40% of the subhumid zone. In the HF it is mainly a minor crop. A substantial part of the maize growing area in the subhumid zone is market - driven (36% to 43%). By contrast, in the DS and HF, maize growing areas are overwhelmingly population - driven, whereas yam and tree crops dominate the market - driven areas.

The Nigerian case

In addition to the broad biophysical and socioeconomic factors analyzed above, the role of maize depends on technology, and country specific factors, among which the most important are government policy, and food preferences. The modifying effect of these factors is now illustrated with survey data from Nigeria.

Within a decade Nigeria experienced major changes in the regional shares of maize production. In 1972-73 the south produced 60% of Nigerian maize, the middle belt 24%, while the north was a minor producer (16% of national share). In 1983-84 the north was the largest producing area (54%), the south's share having fallen to 23% (Lele et al, 1989a). The precondition for this phenomenal increase in the north was the construction of transport systems linking the NGS to the population centers of the south. Between 1975 and 1980 about 1700 km of road works (either new roads or improvements) were carried out on the main thoroughfares linking Lagos to Kaduna, Katsina, Bauchi, and to a lesser extent Sokoto states. Road mileage within the northern states also increased more than five fold between 1967 to 1980. Subsidies on fertilizer and fuel, and good extension services by the Agricultural Development Projects (ADPs), in selected enclaves, aided the transformation process, but the crucial driving force was a technological breakthrough in the form of an improved maize variety (TZB), which, in the economic conditions of the early 1980s, gave dramatically higher returns to land: six times as much as the traditional staples (sorghum and millet) and seven times as much as cotton, the traditional cash crop (Balcet and Candler, 1981).These high returns were due to TZB's high yield (21% to 115% over local varieties in farmers' fields with moderate fertilizer: IITA, 1976).These high yields were achieved by selection for yield potential, prolificacy, and resistance to rust, blight, high soil temperatures and root lodging. The fertilizer responsiveness of TZB also contributed to its high returns, because the existence of a fertilizer subsidy of around 85% resulted in nitrogen - maize price ratios as low as 0.9 to 1.9. These factors enabled maize to capitalize on its natural comparative advantage in the NGS, and catalyze the conversion of the system to the market - driven trajectory (Smith et al, 1994a).

Maize also became a major food in the north, where sorghum and millet had been the traditional staples. The high yield of maize enabled farmers to meet food requirements from a smaller area, thus releasing land for cash crop cultivation. The grain quality of TZB contributed to its development as a food crop. TZB had been selected by breeders for pure white color, improved husk cover, and ear rot resistance, and therefore gave a whiter color to the local dish (tuwo) which had traditionally been made from sorghum. Maize's dual role as a food and cash crop was repeatedly stressed by farmers as a reason for its importance. In a situation of highly variable prices (cv = 27.8%during 1976-1987: Lele et al, 1989a), maize could be stored for consumption purposes when prices were unattractive. This illustrates that, in areas of land scarcity, food habits can shift towards crops which give high returns to land. It also illustrates the importance of grain quality in areas of high price variability. In this context it is worth noting that cotton, which as shown later gives higher returns to land than maize, is a lead crop in the NGS of West Africa only in areas with guaranteed marketing.

Village level group interviews from 27 randomly selected NGS villages show that whereas maize had been a minor backyard crop up to the mid 1970s (Norman et al, 1982), in 1989 it was the lead crop in 90% to 100% of surveyed villages in Kaduna and Katsina states in the NGS. Fertilized improved maize was grown by virtually all farmers in every village, with local varieties having been completely replaced in 60% to 100% of villages (Table 3). Survey data from five villages in Kaduna and Katsina states in 1991, show that the system is highly cereal dominated, with cereals occupying 77% of the cultivated area. Maize and sorghum are the two most widely grown crops, with each occupying about a third of the planted area. While sorghum is almost entirely for home consumption, maize is both consumed and sold, with 61% of farmers claiming that maize is the major source of cash for crop production inputs. Thus maize is the lynchpin of the market - driven system. Calculation of the returns to maize production show that maize gives higher returns to land, labor and cash than competing crops (Table 4). The only exception is cotton, which in spite of its high returns remains a minor crop because of market uncertainties. Day length sensitive sorghum is widely cultivated although it gives low returns, because it is the traditional staple, and because of its high stover yield.

Table 3. Increased importance of maize in the NGS, Nigeria; group interviews, 1989 [a].

	All Villages	States			
		Northern Kaduna	Southern Katsina	Bauchi	South eastern Sokoto
1989	(27)	(10)	(5)	(9)	(3)
Major food crop	96	100	100	89	100
Major cash crop	70	80	100	33	100
Most important food or cash crop	59	90	100	22	0
Improved maize grown	100	100	100	100	100
Minimal or no local varieties	52	60	100	22	33
Fertilizer adoption by all/ almost all farmers	81	100	100	56	67
Mid 1970s					
Major food crop	33	30	20	33	67
Major cash crop	0	0	0	0	0

[a] Data are percent of villages. Numbers in parentheses in each column are Ns.
Source: Smith et al, 1994a.

The expansion of maize in Kaduna and Katsina is primarily responsible for the turnaround in maize production , from major declines in the 1970s to a high growth rate in the 1980s. It is also responsible for the shift in the major maize producing area from the south to the north. The NGS now makes a major contribution to food supplies both in the traditional maize growing area in the humid zone, as well as in the Sahelian countries. The adoption of improved maize, and the consequent transformation of the system is significantly lower in other areas of the NGS such as Bauchi and Sokoto states, where soils and rainfall are less favorable, and feeder roads are less developed. Thus the northern Nigerian experience illustrates that high yielding fertilizer responsive crop varieties do have a vital role to play in

West Africa. In order to catalyse a dramatic transformation, as in northern Nigeria, they should be targeted to agroecologies in which the crop has a natural comparative advantage, and where good transport systems link the area to markets in other agroecologies (Smith et al, 1994a).

Table 4. **Returns to resources for major crops in an area of market- driven intensification in the NGS of Nigeria: survey data from 5 villages in Kaduna and Katsina states, 1991.**

	Maize	Sorghum	Millet	Cowpea	Cotton	Rice
Grain yield (kg/ha)	2536	1365	899	396	831	1794
Stover yield (kg/ha)[a]	3901	5671	2816	1188	531	2378
Returns to land (Naira/ha)[b]	2544	657	426	954	2622	2517
Returns to preharvest labor	6.26	2.16	2.05	3.62	7.18	5.28
Returns to cash	4.28	1.67	1.97	4.26	6.95	4.14
Water requirements	Mod	Mod-Low	Mod-Low	Low	Mod-Low	High
Fertility requirements	High	Mod	Low	Low	Mod	Mod-High

[a] Not valued in costs and returns analysis.
[b] \$1 = Naira 9.87 (1991)
Source: Weber et al (in press).

We turn now to a contrasting situation in the Nigerian Derived Savanna (DS) in the humid zone. This is an area with fairly good road connections to major markets. The system however remains population-driven because of insufficient technical progress in the crops in which it has a comparative advantage. Survey data from three villages in the area show that tree crops (cocoa and oilpalm) occupy the bulk of the cultivated area (49%). Non - tree crops occupy just under a third of the area (31%), within which the dominant enterprise (81% of area) is intercropped maize and cassava. Farmers emphasize the dominant role of cassava over maize. Cassava is valued as providing food and cash throughout the year, whereas maize is ridiculed as a "three month visitor". Data from farmer - managed trials show that certified seed of the improved variety (TZSR) exceed the yield of farmers' varieties by 28%, maintaining this advantage over the whole range of site mean yields (Mutsaers and Walker, 1990). Farm level data on improved variety adoption are not available, but in a survey of 45 villages across the cocoa belt of the DS in Nigeria, farmers in 41% of villages planted seeds purchased in the local market. As the bulk of the maize in the south at that time of the year is from the NGS, where improved variety adoption is universal, the implication is that while a moderate degree of adoption has occurred in the south, maize yield could be further increased through the adoption of improved varieties. Maize is however unlikely to expand into a major crop, because of the natural comparative advantage of tree crops in the area. The returns to land on established tree crop fields, containing intercropped cocoa and oilpalm, were 64% higher than the returns to intercropped maize and cassava in 1988. The early development of maize complemented the slower growth and longer duration of cassava. Thus fields containing both crops gave substantially higher returns than fields where one or the other was missing (Table 5). Cash flow analysis over the year showed that tree crops dominated cash income from agriculture. Cash income from maize, however made a key contribution to liquidity, as the maize haravest took place at a period following five months of negative cash income from agriculture. Although maize is not a major staple in the area, it was appreciated by farmers for providing early food, often in the form of green cobs, during the "hungry period" created by off-season prices being often 2-3 times higher than post-harvest prices (Lele et al, 1989a). Thus a niche for maize was created by the complementary nature of its morphology and phenology to cassava, and by maize's ability to contribute food and cash during critical periods. In spite of this contribution, production practices on maize/cassava fields were oriented towards the needs of the dominant crop: cassava. Only 31% of the non - tree crop area was fertilized, the average application rate being 30 kg nutrients/ha.

Second season maize had practically disappeared from the area, because of extremely low yields due to unreliable rainfall and stem borer damage. Although on-farm trials show that the development of early maturing stem borer resistant varieties could raise yields to about the level of the first season (Mutsaers, 1991), this is unlikelyto be able to make a substantial contribution to the food production problem, because of competition from the simultaneous harvest of the NGS, and late maize from the SGS.Cassava, however, could make a major contribution in this area, if improved post-harvest technologies are developed (Nweke et al, 1994).

Table 5. Returns to land: DS, Nigeria, 1988.

	Crop enterprises			
	Sole Maize	Sole Cassava	Cassava with maize	Cocoa with[a] oil palm
Maize yield (t/ha)	1.0	0	1.4	0
Cassava yield (t/ha)	0	19.0	18.0	0
Annual returns to land[b] (Naira/ha)[c]	1041	2629	3085	5052

[a] Cassava returns over 20 months of land use, others over one year.
[b] Excludes establishment cost.
[c] $1 = Naira 4.54 (1988)

We turn next to the SGS, which represents an intermediate case between the NGS and the humid zone. Data from a rapid rural appraisal in 16 villages in the Shaki area of northern Oyo state show that yam was the lead crop, grown for both food and cash. Maize was the major cash crop, early maize relayed with sorghum, being planted before the yam harvest, and late maize being grown after yam was harvested. Cassava was grown on older plots of declining fertility, often combined with cowpea. Fertilizer was applied to maize, though not to yam, in spite of very poor feeder roads. This was probably because the area was an important focus of the Agricultural Development Projects (ADP), and an input supply center had been set up in the area supplying farmers with subsidized fertilizer, at a nitrogen - maize ratio as low as 0.45 to 1.1 (Oputa et al 1983).

The results from the above surveys are broadly consistent with the results of Manyong et al's (in press) survey of key informants in all agroecologies in Nigeria. Maize area was reported to be increasing in most parts of the NGS, declining in the DS, and without any clear trend in the SGS. The majority of farmers in all areas of the subhumid zone were reported to be using improved varieties, while adoption by the majority of farmers was reported to have occurred in 63% of the DS, and 15% of the HF (Table 6). A similar pattern, at lower adoption rates was reported for West Africa as a whole. Synthesizing conclusions from surveys in the various agroecologies of Nigeria therefore basically confirms that maize has the greatest potential to make a contribution to the food crisis in the market - driven areas of the sub - humid zone, with the NGS having greater potential than the SGS. The relative importance of the NGS is likely to be greater where good transport infrastructure across agroecologies exists, and where high levels of technological progress in lead crops have occurred. In the humid zone, maize is likely to remain a minor niche crop, serving a useful purpose, but unlikely to be able to contribute to the food crisis.

Table 6. Adoption of improved maize, West Africa and Nigeria[a].

	West Africa	Nigeria
NGS	45	100
SGS	42	100
DS	36	63
HF	15	15

[a] Percent maize growing area where > 50% of farmers use improved varieties.
Source: Manyong et al (in press).

SUSTAINABILITY OF MAIZE BASED SYSTEMS

The development of sustainable systems requires an understanding of the factors driving the evolution of the constraints to sustained productivity. Thus future high risk systems can be anticipated, and interventions targeted to the driving forces can be identified. This forward looking approach aims to prevent, in addition to reversing resource degradation (Smith and Weber, 1994).

Changes in the incidence and severity of abiotic and biotic constraints are influenced by the physical environment, management practices, and evolutionary phenomena. As land use intensifies, regeneration of soil organic matter through land fallowing is no longer possible. Degradation of organic matter content is particularly severe in MDI areas of intensified cereal cropping, where high levels of fertilizer use lead to the elimination of fallow periods, high level of biomass export, and reduced interest in legumes. These systems are also particularly susceptible to soil acidification and micro nutrient deficiencies, due to the use of high concentration fertilizers, which are cheaper to transport. Nitrogen deficiency is more likely to occur in PDI where fertilizer use is likely to be minimal (Weber et al, 1995a). Of the insects and diseases affecting maize yields, some, such as Maize Streak Virus and Striga have been new encounters between pest and host in Africa. Integrated pest management approaches for those pests have to be identified in Africa, because their incidence depends on the frequency of encounter with the native host (Weber et al, 1995b). Others such as rust disease and the larger grain borer have co-evolved with maize in the Americas in the area of crop origin, and have subsequently been introduced into Africa. For some of these pests, as happened in the case of Rust, it may be possible to transfer sources of resistance or biological control agents from the Americas. Weeds remain by far the most important biotic constraint, particularly in PDI where land use intensity is high, and cash for weeding labor is scarce (Weber et al, in press). High humidity in the DS and HF leads to severe problems with Downy Mildew in isolated areas, while streak and stem borers may severely affect late planted maize in the humid zone (Bosque-Perez and Mareck, 1990). In subhumid areas, Striga becomes a severe problem in PDI with frequent sorghum cropping, and nematodes become severe in intensified maize based systems in MDI. Tables 7 and 8 synthesize the effect of biophysical and socioeconomic factors to identify high risk systems for biotic and abiotic constraints. The analysis is broadly validated by data from key informant interviews for West Africa, and from village interviews in Nigeria (Manyong et al., in press, and Fakorede et al., 1995).

Sustainability of maize in market - driven areas of the NGS in Nigeria

The agricultural transformation of the Nigerian NGS was undoubtedly aided by a fertilizer subsidy of around 85%. The fiscal cost of this subsidy has been high: 32% of federal government agricultural expenditure, and 3.7% of total government expenditure (Lele et al, 1989b). In addition, the existence of the subsidy has led to severe shortages of fertilizer in the NGS, because supplies have been smuggled out of the country. As a result farmers in the NGS payed prices well above the subsidized price, but still well below the unsubsidized price.

The fertilizer subsidy has also reduced the use of legumes as regenerating crops, and resulted in a highly intensive cereal dominated system. In the mid 1960s legumes occupied 22% of the cultivated area, while cereals were planted in just over half the area (Norman et al., 1982). In 1991 legumes had declined to 11%, and cereals had increased to 77%. The regenerating role of legumes had been taken over by fertilizzer, the average rate being as high as 216 kg nutrients/ha. Intensive farm monitoring shows that threats to the sustainability of the system are closely linked to cereal dominance. Organic carbon, for instance, appears to decline with intensive, continuous cereal cropping, being 0.47% in Katsina state where intensive maize moved in 15-20 years ago, 0.69% in Kaduna state where maize moved in 10-15 years ago, and highest in Bauchi (0.83%) where maize is less important, and short fallows exist. Data also reveal a negative nutrient balance for potassium and micro nutrient, in spite of high levels of fertilizer application, indicating soil mining and a high probability of medium term deficiencies (Figure 2). The severity of cereal parasitic nematodes was also found to be associated with the frequency of maize cropping (Weber et al, 1995c). On the positive side, intensively managed maize based systems were found to be suppressive to striga, and to be impeding its adaptation to maize (Weber et al, 1995b). While the evolution of constraints in the NGS do not pose an immediate threat to the system, their cumulative effect over time could be serious. Moreover, the impact of these problems on yields appears to be masked by high levels of fertilizer, because 61% of farmers claim that yields have increased over the last 5 years, while 19% say yields have remained constant. Therefore farmers are not taking corrective measures to counteract the build-up of constraints.

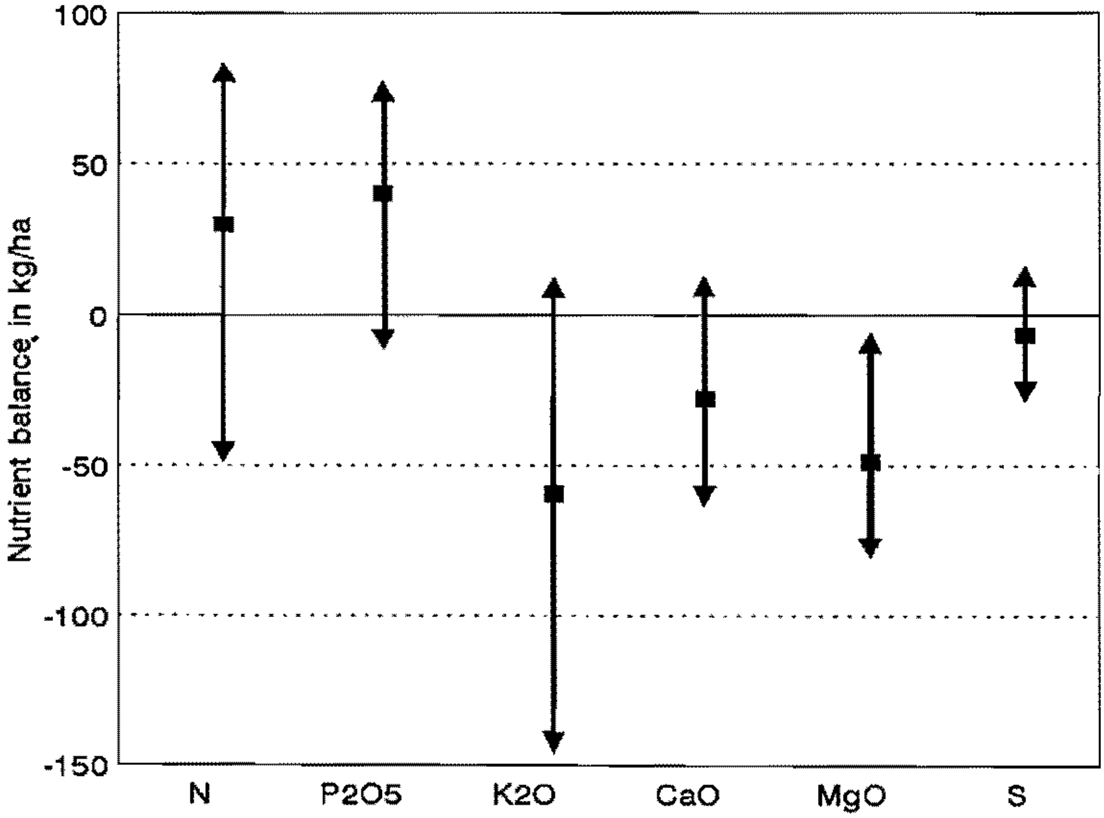

Figure 2. Nutrient balance on farmers' fields: Northern Guinea Savanna, Nigeria.

Table 7. Abiotic constraints of maize production in different agroecological zones in West Africa.

Constraint	Differentiation based on physical resource base[a]	Effect of increasing land use intensity	Effect of improving market access
N-deficiency	Sandy soils most affected, leaching increases from SGS to HF, N-loss through erosion in MAS	Deficiency less if livestock integrated (NGS, MAS), residue managed (all), tree crops (SGS, DS, HF, MAS)	Reduced deficiency through increased use of fertilizer on cash crops, best response to N in NGS and MAS; Reduced interest in legumes for soil fertility
P-deficiency	Sandy soils of low pH most affected	Deficiency less if livestock integrated (NGS, MAS), residue managed (all), P- recycling by deep rooted trees (all)	Reduced deficiency through fertilizer on cash crops; P applied often not sufficient if high concentration fertilizers are used, i.e. urea and CAN for N
K-deficiency	Sandy soils affected; harmattan winds contribute K to NGS and part of SGS	Most soils relatively rich in K; biomass export in areas of high intensity increases K-depletion	K applied often not sufficient to prevent depletion of soil if biomass is exported and high concentration fertilizer is used
Micro-nutrient problems	Low Zn- and S-reserves in most sandy soils	Deficiency of S less in OM-rich soils, residue and fallow burning increases Zn	Increased as higher export; Compound fertilizer with Zn and S rarely available; trend to high concentration fertilizer increases problem
Soil acidity	Inherently acidic soil on granite and quartzite after leaching of bases (SGS, DS, HF)	May increase with OM-loss (all) and increased leaching	Acidification under N-fertilizer use, in particular ammonium sulfate
Erosion	Hillsides (MAS) and sloping land (all) with loamy soils most affected	Increased but at high land use intensity erosion control technologies may be adopted	Effect unknown, but higher land values may encourage adoption of erosion control measures.

[a] Column 2 assumes a traditional maize based system; Column 3 presents the impact of a shift from the expansion to the intensification phase; Column 4 presents the impact of moving from a population - driven to a market-driven system.

Table 8. Some biotic constraints of maize in West Africa.

Constraint	Effects of the physical environment	Effect of increasing land use intensity	Effect of improving market access
Maize Streak Virus	Increased risk in areas of bimodal rainfall (DS, part of SGS, HF, MAS), in areas of off-season cropping (all)	Increased risk with frequent maize cropping, increased incidence of grasses, double cropping	Access to improved resistant germplasm reduces importance
Rust	Increased risk with increasing rainfall for lowland (SGS, DS, HF) and highland (MAS) rust		Access to improved resistant germplasm reduces importance
Downy mildew	Increased risk in areas of high humidity (DS, HF)	Increased risk with frequent maize cropping and off-season cropping	Access to improved resistant germplasm reduces risk
Striga spp.	High risk in areas with pronounced dry season (NGS, SGS, part of MAS)	Increased risk with frequent sorghum cropping; intensive maize management reduces risk, extensive one increases risk	Access to fertilizer and labour for intensive maize management reduces risk
Pratylenchus nematodes	High risk in areas of sandy and loamy soil, in particular if shallow in all zones	Increased risk with frequent cereal cropping in resource domains of low OM; maize suffers most	Intensive maize cropping increases risk
Weeds	Natural vegetation more vigorous with increasing rainfall, species composition depends on climate and soil	Shift from perennial fallow species to noxious annual weeds; increase of grasses; species composition depends on cropping system	Access to hired labour reduces losses from weeds, weeds best adapted to intensive maize management predominate

The analysis in Tables 7 and 8, and the empirical data presented for the Nigerian NGS illustrate the complexity of the dynamic interactions between systems characteristics and the evolution of constraints. The implication is that it is not possible to make categoric statements about the impact of intensification and market opportunities on system sustainability. Certain constraints, such as striga and N deficiency are ameliorated in MDI systems, giving an outcome similar to the Machakos case presented by Tiffen et. al. (1993). Others, such as nematodes and soil acidification are exacerbated in MDI systems. As shown in Tables 7 and 8, differences in characteristics of the physical resource base also affect the outcome.

Recently the Nigerian government has removed the fertilizer subsidy, and partially privatized distribution. Preliminary results from group interviews with farmers in the SGS after subsidy removal show that maize is declining in 39% of sample villages. No villages reported increases in maize area. The decline was reported to be due to the high cost and unavailability of fertilizers and to striga infestation. Maize is being replaced by sorghum in the drier part of the SGS and by cassava and rice in the more humid areas. Field data on the impact of subsidy removal in the NGS are not available. Simulation of the effect of removing the fertilizer subsidy was carried out by using a social accounting matrix (SAM) based on a farm household model integrating production and consumption decisions (Freeman et al, 1994). Results given in Table 9 show that there would be reductions in maize out put for all farmers, and in sorghum output for better off farmers, due to the fertilizer intensiveness of these crops. Production of all other crops also declines because maize sales finance farming inputs, the decline being sharpest for poorer farmers. Marketed surplus of maize declines by just over 20%, and farm incomes decline by 10% to 17% leading to reductions in the consumption of food, purchased commodities and leisure. This indicates that the removal of the subsidy would reduce maize's contribution to national food production, and farmer welfare. If however, the removal of the subsidy is accompanied by technical progress which increases maize yield by

10%, reduction in marketed surplus is substantially reduced. While production of cereals and legumes still decline, production of other crops such as cotton increase, resulting in minimal effects on farm income and consumption. These results imply that increases in maize productivity can compensate for the negative effects of subsidy removal, while at the same time improving fiscal balance, and reducing the inefficiencies and rent seeking activities stimulated by the subsidy.

Table 9. Effect of removing fertilizer subsidy, NGS, Nigeria: Simulation results.

	Subsidy Removal		Subsidy Removal and 10% maize yield increase	
	Better off farmers	Poor farmers	Better off farmers	Poor farmers
	% change from base			
Production				
Maize	-21	-33	-5	-13
Sorghum	-38	-10	-23	-9
Legumes	-11	-24	-19	-9
Cotton	-10	-21	16	67
Other	-10	-8	20	23
Marketed surplus: maize	-23	-20	-6	-14
Full Income	-11	-17	-2	-4

Source: Freeman et al, 1994.

Analysis of farm and experimental data show, that the negative effects of subsidy removal on farmer incomes, could be overcome by the adoption of maize hybrids. Currently there is minimal adoption of hybrids (5% of maize area). Probit analysis shows that this is due to uncertainties in fertilizer supply, and farmers' perceptions (based on extension messages) that hybrids require higher rates of fertilizer than open pollinated varieties (OPV). Fertilizer response data show that the maximum yield advantage of hybrids over OPVs occurs at moderate fertilizer rates of around 60 kg N/ha., which is substantially below the rates applied by farmers under the fertilizer subsidy (80 to 100 kg N/ha). At a fertilizer rate of 60 kg N/ha, hybrids with a yield advantage of 25% over OPVs are capable of providing returns to resources which should be acceptable to small scale farmers (Table 10). Data from breeders' trials show that the currently available hybrids can out yield OPVs by 33% to 45%. Further improvements in the consistency of the yield advantage are however required. Achievement of these improvements in hybrid technology, accompanied by reliable fertilizer supplies and correct extension messages could catalyze the expansion of market - driven systems to other areas of good infrastructure in the NGS. In current market - driven areas it could compensate for the negative impact of subsidy removal on farmer income and consumption (Smith et al, 1994b).

Table 10. Ex-ante analysis of on-farm performance of hybrid and OPV maize at unsubsidized fertilizer prices, based on survey data from 60 plots in two villages in the Northern Guinea Savanna, Nigeria, 1990.

	Hybrid[a]		OPV	Hybrid vs. OPV (%)	
	Y1	Y2		Y1	Y2
Maize yield (kg/ha)[a]	2219	2035	1530	45	33
Returns to land (Naira/ha)[b]	1668	1413	933	79	51
Returns to pre-harvest labor expenditure (Naira)[b]	3.47	3.09	2.38	46	30
MRR on investment (%)[c]	OPV to hybrid			331	216
MRR (%) at yield advantage of 25%	OPV to hybrid		139		

[a] Y1assumes hybrid yield advantage of 45%; Y2 assumes hybrid yield advantage of 33%, based on breeders' trials in the NGS at 60 kg N/ha.
[b] $1 = Naira 8.04 (1990)
[c] MRR = $\frac{\text{Returns to land: Hybrid - OPV}}{\text{Variable cost: Hybrid - OPV}}$

Source: Smith et al, 1994b.

Hybrid maize on its own would not however lead to sustainable sytems.The higher returns to hybrids would most likely increase the dominance of cereals in the system and thus exacerbate the threats to sustainability. Subsidy removal could make some contribution to the reduction of cereal dominance, but the effect is small (Table 9).The implication is that focusing on the lead crop alone is unlikely to lead to sustainable increases in food production.This is because West African systems are highly complex and heterogeneous, and require diversity in their cropping systems in order to be sustainable. In this region, therefore, the emphasis should be on analyzing the driving forces behind system change and the evolution of constraints. As shown earlier, this can be done by exploiting the heterogeneity and dynamics of systems.Policy and technological interventions for attaining sustainable systems can then be qualitatively targeted to appropriate systems based on compatability with farmers' biophysical and socioeconomic environment. Details of this approach, and results of applying it to the NGS are given in Smith and Weber (1994), Weber et. al. (in press), and Weber and Smith (1995). These results form the basis for the priority research issues presented in the next section.

ISSUES FOR RESEARCH

We start by reviewing the history of maize research in Nigeria. Maize breeding activities started in 1952 when the West African Rust Research Unit was established at Moor plantation in Ibadan.Maize improvement by the Federal Department of Agricultural Research commenced in 1956, followed by Joint Project 26, established by the Organization for African Unity in 1966. These programs developed 2 heterotic maize populations, Nigerian Composites A and B, which have been important base populations for maize improvement by the International Institute of Tropical Agriculture (IITA), which commenced in 1970. IITA's maize improvement strategy is based on 3 principles: increasing the yield potential of tropical maize, breeding for durable resistance to pests and diseases, and the development of distinct germplasm complexes for different ecosystems (IITA, 1992). Nigerian composites A and B were the parents of TZB, the variety which catalyzed the dramatic transformation in the NGS, while TZPB, a variety adapted to the humid zone, was basically selected out of Latin American material, viz. the International Maize and Wheat Improvement Center's (CIMMYT) Planta Baja.

Since the early 1970s, the Nigerian Breeding Program at Moor Plantation, now belonging to the Institute of Agricultural Research and Training (IAR&T), and IITA have collaborated in the development and release of a wide range of Streak-resistant and Downy Mildew resistant varieties.Research on hybrid maize was started by breeders at national research institutes in the early 1970s and by IITA in 1979 with strong support from the Nigerian government. By 1984 the first hybrids were available for on-farm trials, and IITA assisted the Nigerian government in setting up the first private seed company in West Africa.

The potential of maize in the NGS was first identified by the Institute of Agricultural Research (IAR), Zaria in the 1970s (Kassam at al., 1975). Although this is now the prime maize growing area in West Africa, no maize breeding work in the NGS has been initiated in Nigeria, except the evaluation of advanced populations. In 1982, based on earlier work by Norman et al. (1982), a Farming Systems Research Program was initiated at IAR, which linked on-station and on-farm work with extension through monthly meetings with the ADPs. IITA, which had a farming systems orientation since its establishment in 1968, initially focused its resource management activities in the humid zone. Systems research in the main maize growing area. the NGS, started in 1989, in collaboration with IAR.

Turning next to the adoption of available technologies, earlier we discussed the widespread adoption of improved OPV maize, and the limited adoption of maize hybrids. The adoption of other maize related technologies in Nigeria is given in Table 11. As is commonly observed in most parts of the world, the adoption of improved cereal varieties and fertilizer has been most widespread. What is encouraging however, is that there is some evidence that legume adoption, which as shown earlier, could make a multifaceted contribution to resource conservation, is now beginning to occur. Tephrosia has reportedly been adopted in the Nigerian mid altitude ecology. Creation of a market for soybean has stimulated its widespread adoption in Benue state in the SGS (Smith, et al, 1993), and soybeans are now moving into the MD areas of the NGS as well, where they could play a crucial role in the sustainability of the system. Adoption of Mucuna (Velvet bean), for Imperata control and soil fertility improvement, has occurred in PDI areas of Benin Republic (Versteeg and Koudokpon, 1993), and efforts are now being made to target it to appropriate systems in other parts of West Africa. A methodology for targeting legumes has been developed (COMBS, 1992), and is being applied, and a legume data base has been developed by COMBS, a maize based research group of national scientists from West and Central Africa (COMBS, 1994). These legume targeting efforts are part of the approach formulated in Smith and Weber (1994). Another out come of this approach has been its impact on the development of Striga technologies. The analysis has demonstrated that Striga control measures that are likely to be effective and adoptable in PDI, are very different from those that should be targeted to MDI. As a result, seed treatments and striga tolerant maize (Kim and Winslow, 1991) are being developed for MDI, while simultaneously sorghum transplanting is being tested in PDI areas, thus ensuring that control measures appropriate for the diversity of high risk systems are being developed.The analysis has also highlighted technological approaches which should be de-emphasized because thet are unsustainable, or unlikely to be adopted. Examples are tolerant sorghum and herbicides. These examples indicate that the analysis of dynamics and heterogeneity can be a powerful tool for orienting technology generation. They also indicate that new optimism about resource management technologies, and legumes and striga in particular, may now be warranted.

Turning now to future research priorities, some of the most important research issues identified by us , and the systems for which they are relevant, are given in Table 12. The focus is primarily on the NGS, because this is the zone where results from both broad based and detailed system characterization are available at the present time. The results show that although MDI systems in the NGS have captured the imagination of maize technology developers, there are a some important issues in PDI areas, which should not be neglected because of their equity implications. Among them are maize varieties for compound fields in PDI, which though small in area, could contribute towards food security in these systems. Hybrid vigor captured through apomixis (non-sexual seed production) is one possible approach, as are improvements in the N-use efficiency of maize, through better synchronization of maize N-demand with inherent N-release from soils. Another notable feature of Table 12 is that only a few items (N-use efficient maize, striga tolerant maize, apomixis and hybrids) relate to maize improvement. The others relate to other crops, resource management and policies, but many contribute to the productivity and sustainability of maize in the NGS.This illustrates the inadequacy of a research effort focused on the fertilzer responsiveness of the lead crop. As the NGS experience shows, dramatic improvements in the yield potential of the lead crop have a vital role to play, but if the benefit is to be sustainable, these technologies should be developed and targeted within the context of a holistic future vision of systems in the mandate area. Moreover, given the heterogeneity of West African systems, a diversity of strategies are required. In spite of the heterogeneity, however, the analysis demonstrates that broad based issues for strategic research can be identified.

CONCLUSIONS

Our analysis of the dynamics and heterogeneity of agricultural systems in West Africa, and particularly in Nigeria, shows that maize can make a major contribution to the food crisis, but only in limited areas, primarily the market - driven areas of the northern Guinea Savanna (approximately 11.3 m ha or 6.5% of West Africa, and 4.5 m ha or 7.6% of Nigeria). To a lesser extent, maize can also contribute to national food production in the market - driven areas of the southern Guinea Savanna which, together with target areas in the NGS, cover approximately 15% of West Africa. Most of West Africa (66%) is population - driven and subsistence oriented. Given the high cost of purchased food in these areas, food security must come from the production of major staples, which in the case of Nigeria are cassava and yam in the south, and sorghum in the north. Even in countries where maize is an important staple, yield increase in population - driven areas, should be through nitrogen use efficiency, apromixis, early maturity and pest and disease resistance, rather than increased fertilizer response, in view of the limited capability of farmers in these areas to use purchased inputs.

Technologies which dramatically improve the yield potential of the lead crop, do have a key role to play, but they should be targeted to appropriate areas, ie areas where good transport infrastructure across agroecological zones exists, and where the crop has a natural comparative advantage. The neglect of these technologies could deprive West Africa of a major opportunity to overcome the food crisis. Staple food crops like maize have a particular advantage in this respect, when compared to non edible cash crops like cotton, as their dual role as food and cash crops is highly attractive to farmers in West Africa where output price variability is high. Therefore attention to grain quality is important, and the Nigerian experience shows that food preferences can change towards crops that give high returns to land.

Our analysis shows that West African production systems, even intensive ones, require diversity in order to be sustainable. Therefore a strategy which focuses on the fertilizer response of the lead crop is inadequate, even in high potential areas. Technological priorities need to be developed within the context of a holistic vision of systems in the mandate area, and their policy and technological requirements, most of which will be outside the domain of the lead crop. This requires characterization of the heterogeneity of systems, an understanding of their dynamics, and how these dynamics interact with the evolution of threats to sustainability. In the maize based system in the northern Guinea Savanna of Nigeria, for example, we have shown that cereal dominance could drive the system to unsustainability. Further increase in the fertilizer responsiveness of maize alone would worsen the situation. With complementary technologies and policies derived from an understanding of systems dynamics, however, we believe that hybrid maize, could make a valuable contribution.

Table 11. Some maize production technologies and an assessment of their adoption in Nigeria.

Technology[1]	Problems of adoption	Process of adoption	Assessment of impact
Rust resistant maize varieties (Moor Plantation) 1950-1960	Varieties with lower storage and processing quality; limited seed supply	Direct adoption minor; farmers selected in 1950s moderately resistant material out of locals and local/improved mixed cropping	Most farmers varieties are now moderately resistant
Streak resistant maize varieties (IITA, IAR&T, IAR) 1975-1985	Epidemics of disease are unpredictable	Adoption in areas of epidemics (HF, DS); Spread in areas of increased yield potential and where maize was expanding as a new crop (NGS, SGS)	Resistance wide spread in farmers' germplasm; transport of maize from NGS (mainly resistant) to markets in HF has contributed to spread of resistance in HF
Downy mildew resistant maize varieties (IITA, IAR&T) 1980-1990	Farmers rarely store seed in HF, limited seed supply	Repeated multiplication and supply of seed to farmers in affected areas	Lasting effect limited as farmers do not maintain variety
Inorganic fertilizers (IAR&T, IAR) 1970-1980	Inefficient distribution, poor infrastructure	Introduction of fertilizer responsive improved maize in savannas and improvement of road infrastructure	Wide-spread
Less acidifying N-fertilizer (IAR) 1975-1985		Change in official fertilizer recommendations and in production, importation and release	Ammonium sulfate replaced by urea and CAN
Micronutrient additions to fertilizers (IAR, IITA, IAR&T) 1980-1990	Farmers are not aware of problems	Incorporation of Zn and S into compound fertilizers	New fertilizer blends on market

Table 11. ...contd.

Technology	Problems of adoption	Process of adoption	Assessment of impact
Integration of legumes (many institutes and NGOs; soybean: IITA, NCRI,IAR) 1960-1990	Labour and land demand of technology reduces farmers' interest	Adoption occured in areas where legume characteristics fit farmers' needs	Tephrosia provides firewood, soil N and erosion control (Mbila plateau, MAS); soybean provides cash from market (Benue, SGS)
Animal traction (development institutions)	Tse-Tse fly in HF, DS and part of SGS; fallow vegetation and trees in areas of extensive land use, lack of fodder in areas of intensive land use, sloping land in MAS	Adoption in areas of moderate land use intensity, often first by settled pastoralists	Widespread in NGS, market for renting service of oxen ridging developed
Herbicides for weed control (IAR, IITA) 1965-1980	Uneconomical on small farms; selectivity of herbicides for intercropping		Restricted to large commercial farms
Minimum tillage (IITA) 1970-1980	Need for herbicides; indigenous no-till planting in some areas (NGS)		Little adoption of researcher-designed technology; indigenous method not wide spread
Tied ridging (SAFGRAD, IAR) 1975-1985	Labour demand for tying ridges; risk of water logging	Indigenous method in areas of sloping land, sandy soils and frequent drought stress	Common in certain areas (drier parts of MAS; sandy soils in NGS); little spread from areas of indigenous use

[1] Including major organizations and time of research on technology in Nigeria
IAR - Institute for Agricultural Research, Zaria
IAR&T - Institute for Agricultural Research and Training, Moor Plantation, Ibadan
IITA - International Institute of Tropical Agriculture, Ibadan
SAFGRAD - Semi-arid Food Grain Research and Development Project, Ouagadougou
NCRI - National Cereals Research Institute, Badeggi
NGO - Non-governmental organizations

Table 12. Some strategic research issues: NGS.

- ❑ Policies and technologies to stimulate conversion to market-driven sytems (Infrastructure, hybrid maize, fertilizer policy): PDE, PDI.
- ❑ Policies and technologies to stimulate land intensification in land abundant areas (stop penetration roads in virgin areas, improve infrastructure in established areas, improved fallow, tree crops, land titling, conversion to market-driven system): PDE.
- ❑ N-use efficient maize: MDI, PDE, PDI (compound fields)
- ❑ Hybrid vigor captured through apomixis: PDI compound fields
- ❑ Striga resistant sorghum (appropriate grain quality and stover characteristics).
- ❑ Striga tolerant maize: MDI
- ❑ Impediments to crop-livestock integration (particularly fattening): MDI
- ❑ **Legumes:** Rotation with cash crop legumes to improve quality/quantity of organic matter, trap crop for cereal pests: MDI.
  Rotation with food legumes to reduce nitrogen deficiency, trap crop for cereal pests: PDI, PDE.
  Intercropped non-food legumes to reduce weed infestation and reduce nitrogen deficiency: PDI.
- ❑ Sweet cassava, sweet potato adapted to NGS: PDI
- ❑ Alectra resistant groundnut, cowpea: PDI
- ❑ Cereal seed treatments: MDI
- ❑ Biocontrol: all agricultural systems
- ❑ Sorghum transplanting for Striga control: PDI

Source: Adapted from Weber and Smith (1994).

Fertilizer subsidies for jump starting Green Revolutions have led to fiscal problems, inefficiencies and rent seeking behavior, and over domination of cereals, which as shown earlier, is unsustainable. Without the subsidy, the agricultural transformation of the Nigerian Northern Guinea Savanna would probably have been less spectacular, but more sustainable. Government expenditure on agricultural research and infrastructure, rather than on subsidized fertilizer, is likely to yield better returns. The transformation in the Nigerian Northern Guinea

Savanna could not have taken place without outstanding maize varieties. Nor could it have occurred without good roads linking the area with a comparative advantage in maize, to markets in the south. Transport systems across agroecological zones, and feeder roads connecting farms to local markets are essential for West Africa's agricultural development. While threats to the sustainability of the NGS phenomenon have been uncovered, we have demonstrated that we have a strategy for overcoming these problems, and that the impact of this approach is beginning to be felt. We believe West Africa's potential can be unlocked. But a very different approach from what worked in favorable, homogeneous areas of Asia and Latin America will be required. Maize, and its fertilizer responsiveness, have a key role to play, but if sustainability is to be achieved, maize improvement must be developed within the framework of a holistic strategy, based on an understanding of the dynamics and heterogeneity of West African systems.

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FOOTNOTES:

[5] Production figures from Nigeria should be treated with caution due to their unreliability (Lele et al, 1989a).

[6] A fifth zone, the Mid-Altitude Savanna (MAS) occupies about 2% of West Africa, and is mainly excluded from the analysis.

[7] This is contrary to Binswanger and McIntire's (1987) framework in which ncreases in population and market opportunities lead to similar patterns of intensification.

[8] Defined as the difference between farm gate prices and retail prices in rural markets.

[9] Pingali et al. (1987) and McIntire et al (1992) show that crop-livestock interactions increase with intensification, but do not distinguish between population - and market - driven systems.

[10] Benin Republic, Burkina Faso, Côte d'Ivore, Ghana, Guinea Conakry, Mali, Nigeria, Sierra Leone, Togo: humid and subhumid areas only.

[11] Market - driven systems in the expansion phase (MDE) occupy only 3% of the area in West Africa, and are virtually non-existent in Nigeria. MDE systems are therefore excluded from the rest of the analysis.

[12] This could be overcome by the development of long season maize, if an appropriate deep rooted legume intercrop can be identified.

[13] Even in PDI maize can be grown on compound fields near the homestead by exploiting the niche created by household refuse to these fields.