IITA High Rainfall Station: Twenty Years of Research for Sustainable Agriculture in the West African Humid Forest

In response to current food shortages, the International Institute of Tropical Agriculture (IITA) seeks to increase the quantity and improve the quality of food production in sub-Saharan Africa. IITA aims to develop systems that conserve the land and other natural resources so that needs of future generations are not compromised. In addition, IITA seeks to strengthen the national agricultural research systems (NARS) of various African countries and to help develop indigenous human resources. Around 1500 staff are engaged in this endeavor, including 140 scientists and professionals from more than 40 countries.

In addition to its headquarters in Ibadan, IITA has stations at Onne (near Port Harcourt) and at Kano, plus additional testing sites, all in Nigeria. It has also established three stations outside Nigeria, one in the Benin Republic (Cotonou), another in Cameroon (Mbalmayo), and a third in Côte d'Ivoire (Ferkessedougou). Recently, with the cooperation of the National Agricultural Research Organization of Uganda, IITA has established the East and Southern Africa Regional Center for the Improvement of Cassava, Banana, and Plantain at the Namulonge Agricultural and Animal Production Research Institute near Kampala, Uganda. Countries throughout Africa and elsewhere have benefited in various ways from IITA's work.

IITA HIGH RAINFALL STATION AT ONNE

The IITA High Rainfall Station at Onne has played a major role in the implementation of research relevant to the humid lowland forest agroecology of West and Central Af-

rica. This station is located in southeastern Nigeria (7°E, 5°N; 10 m above mean sea level) in the densely populated Niger delta region of Rivers State (48 persons/km², locally rising to >100 persons/km²). Onne is the main work base for IITA's Plantain and Banana Improvement Program, which has achieved rapid success in the production of hybrid *Musa* cultivars resistant to the fungal leaf spot disease black sigatoka (*Mycosphaerella fijiensis* Morelet) (Vuylsteke et al., 1993a, 1993b, 1995). In addition, the Onne Station is an important test site for IITA's resource and crop management work, particularly for developing sustainable agroforestry systems for the humid lowlands. This station has fostered active collaboration with National Agricultural Research and Extension Systems (NARES). The station acts as a satellite of IITA, and collaborates with other research institutes, the agricultural development projects (ADPs), nongovernmental organizations (NGOs) sponsored by the major oil companies, and universities in this densely populated and economically important area.

SITE CHARACTERIZATION

The character of the site is to a large extent determined by human factors. The station is in an area with the highest population density in West Africa. Extreme population pressure on the land leads to rapid change in farming practices. Fallow periods traditionally exceeded 10 years, but in recent times these have shortened considerably to 4 years or less. IITA's work in this area is aimed particularly at the development of appropriate technologies to meet the changing circumstances and needs of a dynamic agricultural and socioeconomic environment.

The soil (Table 1) is representative of highly leached acid ultisols; it is a deep and freely drained Typic Paleudult of the coarse-loamy, siliceous, isohyperthermic family (Uyo Series). The parent material is plio-Pleistocene coastal sediment of marine origin (Niger Delta region). This soil has good physical properties, but is chemically poor, with nutrient deficiencies and soil acidity (pH 4.3 in 1:1 H₂O; upper 15 cm) limiting crop production. The soil is prone to compaction, thereby reducing drainage and causing waterlogging and erosion. A low-activity clay (kaolinite) is predominant, which indicates an advanced stage of weathering and desilication. The soil has low effective cation exchange capacity and low base saturation, but high extractable P, arising from marine depositional influences (Table 1). Unlike many acidic Ultisols, the Onne soil has low extractable Mn (Winslow, 1992).

The station is representative of the humid rainforest ecosystem with characteristically high rainfall. Onne has an average annual rainfall of 2400 mm that is distributed monomodally from February to December. Mean daily temperatures are high, averaging 27°C in the warmest months (February, March, and April) and 25°C in July, the coolest month. Relative humidity remains high throughout the year, with average values ranging from 78% in February to 89% in July and September. On average, there are only 4 h of direct sunshine each day. The range is from 2 h per day in September to 6 h in February. The monthly and annual summaries of weather data at Onne for 1995 are typical (Table 2).

FACTS ABOUT ONNE STATION

The strategic need for a high rainfall research site was recognized by IITA in 1974. That year, the government of Rivers State, Nigeria, made available 80 ha of land for IITA to establish the High Rainfall Station adjacent to the Rivers Institute of Agricultural Research and Training. The first research trials were planted in 1976. The Belgian Administration for Development Cooperation (BADC) provided funding for station development in 1978. The Arboretum was established in 1979. That same year, the majority of IITA's plantain and banana (*Musa* spp. L.) research was transferred to the High Rainfall Station from IITA headquarters at Ibadan.

By the end of the 1970s, research programs for rice (*Oryza sativa* L.), maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), and grain legume improvement made routine use of the high rainfall site. Research on cropping systems and soil management, including agroforestry, began in the early 1980s. The tissue culture laboratory was completed in 1983 and expanded with funds provided by the Nigerian AGIP Oil Company-Green Rivers Project in 1990. In 1991, an additional block of land was given by the state government, thereby expanding the station to 100 ha. Recently, an insect-proof greenhouse was constructed with funds provided by the World Bank/Common Fund for Commodities/Banana Improvement Project for virus research on *Musa*. Currently, five laboratories for plant tissue culture, plant pathology, postharvest research for enhanced utilization, molecular markers for diagnostics and selection, and basic plant/soil analyses are operational at Onne Station. A data processing center for analysis and archives, supported by minidesktop computers, became available in 1995.

On 18 Aug. 1995, the extension of the High Rainfall Station and other renovated/upgraded facilities were officially opened by the Ambassador of Belgium in Nigeria. A few weeks later, a regional workshop was held at Onne, using the new meeting room and accommodation facilities. During this meeting, IITA and West and Central African *Musa* scientists discussed current and future plantain and banana research in the region. The capital investment at the IITA High Rainfall Station cumulatively over 20 years amounts to about US \$2.5 million.

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Front cover: A sustainable agroforestry system with multispecies hedgerows for perennial plantain production has been developed at the Onne High Rainfall Station of IITA. This multispecies hedgerow system maintains crop productivity over extended periods of cultivation, and conserves plant diversity for bush fallows. About 120 species were identified in the hedgerows, which are coppiced regularly to provide mulch to the plantain.

Table 1. Original soil properties at the Onne Station, March 1975^a.

Soil property	Depth (cm)		
	0–15	15–30	30–45
pH (1:1, H ₂ O)	4.3	4.3	4.3
Physical components (%)			
Sand	67	74	67
Silt	15	6	5
Clay	18	20	28
Organic C	1.04	0.64	0.48
Total N	0.11	0.07	0.05
Effective CEC, meq/100g	2.86	2.67	2.54
Exchange cations, meq/100g			
Ca	0.26	0.16	0.15
Mg	0.09	0.02	0.02
K	0.02	0.02	0.02
Mn	0.02	0.01	0.01
Al	1.83	1.84	1.94
Bray 1 extractable P (mg·Kg ⁻¹)	26	34	33
Bulk density (g·cm ⁻³)	1.32	1.48	1.39
Total porosity (%)	49	45	48

^aMoisture content of soil surface (depth 0–15 cm) at field capacity (20 kPa) was 18%. Clay mineralogy: kaolinite (dominant), goethite (small amount), amorphous material (small amount). Vegetation at sampling site: 7-year-old thicket. Source: A.S.R. Juo, IITA, unp. results.

Since 1984, the station has hosted experiments of other international agricultural research centers, such as the International Centre for Research on Agroforestry (ICRAF, Kenya), International Livestock Research Institute (ILRI, Ethiopia–Kenya), International Rice Research Institute (IRRI, The Philippines), the West African Rice Development Association (WARDA, Cote d'Ivoire), and the Natural Resources Institute (United Kingdom), as well as other programs/research divisions of IITA (Root and Tuber Improvement Program of the Crop Improvement Division, Plant Health Management Division, and Resource and Crop Management Division).

Currently, six international scientists and 100 local support staff are based at Onne. The research mainly concerns plantain and banana in the following disciplines: taxonomy, germplasm enhancement, genetics, breeding, biotechnology (applied cell biology and molecular markers), crop protection (with emphasis on plant parasitic nematodes and viruses), morphophysiology (focusing on root systems), postharvest biology (palatability and durability), and crop-oriented agronomy. In addition, research continues on agroforestry, livestock, resource and crop management, and root and tuber improvement under the supervision of international scientists who periodically visit Onne.

RESEARCH ACHIEVEMENTS OF IITA HIGH RAINFALL STATION

Soil fertility. To maintain the productivity of the fragile soil, shifting cultivation and the related bush fallow systems have been practiced in the humid and subhumid tropics. However, with increasing population pressure, fallow periods have become too short for soil fertility to be restored. Improved systems for food crop production are needed. The success of these systems will depend on managing the soil in a way that fertility is maintained (Lal, 1987). Soil fertility problems of ultisols can be corrected by liming, appropriate fertilization, and appropriate agronomic practices. How-

ever, socioeconomic constraints often limit the application of these crop production technologies.

Results have shown that low applications of lime are sufficient to reduce toxic levels of Al and Mn. Modest amounts of fertilizer application combined with appropriate agronomic practices, including intercropping, agroforestry, and fallow management systems, can sustain high yields. Also, there are various processes by which soil productivity can be sustained with low external inputs (Kang et al., 1991). These are processes that contribute to the production and maintenance of in situ mulch, soil protection, and recycling of nutrients. Technology development at Onne Station seeks to couple biological processes with improved cropping systems to enhance the stability and increase the efficiency of resource use. Two main farming systems are being evaluated and improved: bush fallow management and agroforestry (Kang et al., 1990).

Cropping systems. A key feature of the design of a cropping system is to have one that is flexible and can be adapted to meet location-specific cultural and environmental needs. IITA's priority crops in the humid forest are cassava, maize, plantain, and yam (*Dioscorea* spp.), since they are important components of the cropping systems in this agroecozone. Other crops, such as cowpea [*Vigna unguiculata* (L.) Walp. ssp. *unguiculata*], are considered as part of the farming system where appropriate.

Cassava grows well in acid soils. Since it performs so well under such adverse conditions, cropping systems that are based on this important root crop are essential (Hullugalle et al., 1990). Such systems, which have been evaluated at Onne Station, include intercropping of cassava with maize and the rotation of cassava with leguminous species such as cowpea and pigeonpea [*Cajanus cajan* (L.) Millsp.] and other leguminous cover crops (e.g., *Pueraria phaseoloides* L.). Research on intercropping has quantified the productive potential of cassava-based mixtures and cereal-

legume combinations. Low-growing species such as egusi melon [*Citrullus lanatus* (Chumb.) Mats et Nakai], and white melon (*Cucumeropsis manii* Naud.) have been confirmed to have a favorable effect on soil conditions and weed control.

Agroforestry research. The use of perennial trees and shrubs in cropping systems has also been studied at Onne Station. In an agroforestry arboretum, maintained at the site since 1979, various perennial trees and shrub species have been evaluated for their adaptation to humid, tropical conditions. They are also evaluated for their potential use in alley cropping (an agroforestry system of growing food crops in alleys formed by hedgerows of trees or shrubs) and other cropping systems.

Substantial seed and live germplasm collections of indigenous and exotic multipurpose tree and shrub species have been established and are being screened for appropriate agroforestry use in collaboration with ICRAF and Oregon State Univ. Readily established species such as *Dactyladenia barteri* Hook. f. ex Oliv., *Alchornea cordifolia* Schum. & Thonn., *Senna siamea* (Lam.) Irvin & Barley, *Flemingia macrophylla* (Willd.) Merrill, and *Gmelina arborea* (Roxb.) have been widely tested in alley cropping systems (Ruhigwa et al., 1992). Such systems show great potential for maintaining soil fertility through the mulch and green manure provided from tree and shrub prunings. The mulch also protects the soil during intense rainfall and conserves soil moisture during the drier periods, in addition to suppressing weeds (Ruhigwa et al., 1993). Some of the prunings can also be used as browse or fodder for livestock. The trees or shrubs also provide staking material for food crop plants as well as firewood for the farm family. A further advantage of alley cropping is the recycling of nutrients from deep soil layers. However, the trees or shrubs need to be carefully selected for favorable characteristics, such as deep root systems, which do not compete with the roots of food crops for nutrients and moisture and that recycle nutrients from deep layers (Ruhigwa et al., 1992). These trees or shrubs should also have high biomass production of a high quality mulch that suppresses weeds, conserves soil water, and requires a low pruning frequency to minimize labor costs.

Prunings of *D. barteri* provide the most profitable mulch for plantain production (Ruhigwa et al., 1994). *D. barteri* has performed particularly well under this humid forest environment and has been recommended for on-farm testing. The system is being improved to include a nitrogen-fixing legume to enhance soil productivity.

Researchers at Onne Station have developed a fallow management strategy in which *Tephrosia candida* D.C. (a nitrogen-fixing shrub) is introduced in shifting cultivation or bush fallow systems at the beginning of the fallow cycle (Gichuru, 1991). *Tephrosia candida* enhances the soil regeneration process by increasing the nitrogen content of the surface soil, recycling nutrients from deeper layers, and improving soil physical properties in 1 or

2 years as opposed to the 6 or more years required by natural bush fallow (Gichuru, 1994).

A continuous maize/cowpea rotation has also been developed at Onne Station. In this system a maize monocrop is followed by a cowpea crop planted in the rainy season and harvested in the dry season. With an adequate supply of nutrients, low levels of liming, and recycling of all crop and weed residues, maize and cowpea yields can be maintained. However, cowpea is susceptible to pod sucking bugs (*Clavigralla tomentosicollis* Stal.), thrips [*Megalorhynchus sjostedti* (Trybom)], and the pod borer [*Maruca testuralis* (Geyer)], and therefore grain yields remain low without insecticides.

Plantain and banana improvement. IITA scientists based at Onne were able to rapidly develop improved plantain germplasm using a range of conventional and innovative approaches: interspecific hybridization, ploidy manipulation, embryo culture, rapid in vitro multiplication, field testing, and selection (Vuylsteke et al., 1997). This result is a noteworthy achievement, considering that programs elsewhere required decades of breeding before hybrid release (Ortiz et al., 1995). In 1994, IITA won the seventh King Baudouin Award of the Consultative Group on International Agricultural Research (CGIAR). This award for excellence in international agricultural research, named after the late King of Belgium, recognizes IITA's contributions to breeding plantains for black sigatoka resistance and advances in *Musa* genetics.

The potential impact of using black sigatoka-resistant plantains was assessed in comparison to the use of chemical fungicides in a rural southeastern Nigeria context (Ortiz and Vuylsteke, 1994). Host plant resistance had a cost-benefit advantage of 10:1 over fungicides during periods of adequate production. However, the advantage was reduced to 5.5:1 during periods of scarcity in plantain production, which dramatically influences the market price of plantain fruit. An attempt has also been made to calculate the potential im-

pact of IITA's improved plantain germplasm in African agriculture. The gross value of plantain production in Africa has been estimated at around US \$2.8 billion. A potential yield increase of 225% is achievable by using the black sigatoka-resistant tetraploid germplasm developed at IITA. This might have the impact of raising the annual gross value of plantain production to over US \$9 billion (Ortiz and Vuylsteke, 1994).

Other technologies developed at Onne Station. Cassava, sweetpotato [*Ipomoea batatas* (L.) Lam.], maize, and upland rice are some of the other major food crops grown in the humid tropics. The Onne station has offered IITA scientists an excellent opportunity to screen improved genotypes of these crops for their performance under humid, tropical conditions.

High-yielding and stable cassava clones that are resistant to African cassava mosaic virus and cassava bacterial blight have been produced by IITA scientists and provided to many NARS, who have released them as cultivars or used them in their own breeding programs (Hahn et al., 1989). Onne Station has been the site for evaluation and selection of cassava genotypes (including polyploids) adapted to acid soil conditions.

The production of upland rice, a major crop in humid forest areas of Liberia, Sierra Leone, Côte d'Ivoire, and Guinea has been limited by insect pests, fungal diseases, and nutritional imbalances common in the highly leached, acid soils of the humid tropics. Through breeding, IITA scientists at Ibadan developed improved rice germplasm that was screened at Onne for various traits, including yield potential and tolerance to acid soils, diseases, and pests (Alluri, 1986). Investigations on rice at Onne suggested that grain-filling was a serious problem because of high sterility and low 1000-grain mass associated with soil acidity and Al toxicity. Genotypes were selected based on clean grains, good milling quality, blast resistance, moderate to high yield potential in limed control plots, and their ability to retain yield in acid, nontreated plots. Though its adoption is not well docu-

mented, rice germplasm developed at Onne Station has had a considerable impact on upland rice production in West Africa. Upland rice developed at Onne has been released as new cultivars by national programs in Congo, Nigeria, and Sierra Leone (IITA, 1992). Also, rice germplasm screened at Onne for blast resistance, management practices, and yield potential was released by national programs in Benin, Cameroon, and Ghana for cultivation in irrigated paddies. The use of these improved cultivars along with appropriate soil and crop management practices has enabled rice farmers in the humid tropics to obtain high yield and sustained production of this important crop. Research at Onne showed that, as with blast, grain discoloration was associated with silicon deficiency (Winslow, 1992). Furthermore, other investigations revealed that silica and magnesium applications reduced grain discoloration and improved yield in upland rice (Yamauchi and Winslow, 1989).

Similarly, enhanced open-pollinated maize germplasm was evaluated at Onne for yield, tolerance to acid soils, and resistance to pests, particularly stemborers. Sweetpotato and cowpea cultivars were also tested at this station, which was selected as a testing site for the forest zone with high rainfall (IITA, 1992). Indeed, germplasm tested satisfactorily at Onne is generally adapted to the West African humid forest.

OUTLOOK

Onne station has proved to be valuable for studying management of acid soils, crop production techniques, and screening for resistance to insect pests and fungal, bacterial, and viral diseases in most crops. More recently, there has been much success in cross-pollination of plantain and banana, thus producing unusually many viable seeds (Ortiz and Vuylsteke, 1995). This result enabled IITA to establish its internationally renowned *Musa* breeding program (Vuylsteke et al., 1997).

In 1995, the External Program and Management Review of IITA reported that "the

Table 2. Monthly and annual summary of weather data at Onne, 1995.

Month	Total rainfall (mm)	Total pan evaporation (mm)	Mean wind speed ^a	Solar radiation ^b	Temperature (°C)			Relative humidity (%)			Rainy days ^c (no.)
					Min.	Max.	Mean	Min.	Max.	Mean	
January	1	137	3.0	13.2	20.8	33.2	27.0	25	81	55	2
February	79	124	3.5	14.1	22.9	33.6	28.3	39	92	63	5
March	196	141	3.7	17.2	23.0	32.4	27.7	53	94	82	10
April	73	125	3.2	14.0	23.5	32.6	28.0	54	93	78	10
May	301	116	3.1	13.4	22.6	31.0	26.8	60	93	78	17
June	319	97	3.4	15.2	22.6	29.9	26.3	62	96	78	21
July	312	74	3.5	11.5	22.4	28.4	25.4	74	97	84	26
August	434	59	3.8	9.7	22.5	28.3	25.4	73	96	83	26
September	375	83	3.7	13.2	22.4	29.4	25.9	67	96	84	24
October	422	94	3.3	12.5	21.8	29.8	25.8	65	95	94	22
November	77	111	2.3	14.7	22.3	31.8	27.1	60	95	78	8
December	4	88	2.4	11.4	21.8	31.8	26.8	53	94	74	6
Annual											
Total	2593	1251									177
Mean			3.2	13.3	22.4	31.0	26.7	57	94	78	

^akm·h⁻¹·d⁻¹

^bMJ·m⁻²·d⁻¹

^cRainy day = when rainfall ≥ 0.2 mm.

Plantain and Banana Improvement Program at Onne is being vigorously pursued at a well-run station." The Director General of IITA, Lukas Brader, has also emphasized that "the High Rainfall Station at Onne should be regarded as the most cost-effective operation of IITA."

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RODOMIRO ORTIZ¹, PIERS D. AUSTIN², AND
DIRK VUYLSTEKE³
International Institute of Tropical
Agriculture⁴, Onne High Rainfall Station,
PMB 008, Nchia-Elleme, Rivers State,
Nigeria

¹Former Officer-in-Charge of the High Rainfall Station. Current address: Dept. of Agricultural Sciences, Royal Veterinary and Agricultural Univ., 40 Thorvaldsensvej, DK 1871 Frederiksberg C, Copenhagen, Denmark.

²Station Manager of the High Rainfall Station and Head of the Research Farms Unit.

³Former Officer-in-Charge of the High Rainfall Station. Current address: IITA, East and Southern Africa Regional Center, P.O. Box 7878, Kampala, Uganda. International mailing address: IITA, c/o L.W. Lambourn & Co., 26 Dingwall Road, Croydon CR9 3EE, England.

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