

## PRODUCTION SYSTEMS: BIOPHYSICAL AND ECONOMIC ENVIRONMENT AND CONSTRAINTS

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Rice production in Nigeria and West Africa<sup>1</sup> dates back 2,000 to 3,000 years ago. Such production was mostly in the flood plains of the Niger River (Figure 1.1 in Chapter 1) and involved one of only two species of cultivated rice in the world, *Oryza glaberrima*, or African rice. The introduction of the second species, *Oryza sativa*, or Asian rice, occurred after the arrival of the Portuguese in the 17th century (Linares 2002). However, it was only during the last few decades that rice production in Nigeria began to emerge as an important food security issue, as demand outstripped supply with ever-increasing gaps.

The growing gap indicates that the expanding market for rice has not been followed by a supply response among domestic producers. In particular, rice yields have grown very little in Nigeria. A crucial question, therefore, is whether Nigeria has a comparative advantage in rice production. In order to address this question, we need to examine whether biophysical and socioeconomic conditions are favorable among Nigeria's most promising rice production systems, and if they are, how the productivity gap can be reduced.

The objective of this chapter is to provide a descriptive overview of the current rice production systems in Nigeria, their underlying biophysical and socioeconomic constraints, and their potential for expanding rice production. The chapter is organized as follows.

First, we describe current production technologies and practices in use in Nigeria, such as the uses of modern inputs (improved varieties and fertilizer) and technologies (irrigation and mechanization). From this information, a typology of rice-producing households in Nigeria is determined according to the type of technologies and production environment and their capacity to expand rice production in the short to medium term.

In the second and third sections, we review some of the key biophysical and socioeconomic constraints, respectively, that affect the potential for

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<sup>1</sup> For the definition of West Africa, see footnote 2 in Chapter 1.

expanding rice production in different parts of the country. We show, for example, that the typical rice-production environments in Nigeria, such as climate, water access, and soils, may not be as favorable as they are in major rice-producing regions of Asia. Nevertheless, compared to other tropical West African countries, the prevalence of a lowland rice ecology in Nigeria offers it the greatest potential in the region for production growth, except for certain socioeconomic constraints that prevent households from adopting modern inputs and improved technologies. Based on this review, we conclude the chapter by summarizing the key characteristics of current rice-production environments in Nigeria.

The information and data used in this chapter are based on an extensive literature survey, international data sources, and data gathered from the most recent Nigeria Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS–ISA) described earlier in Chapter 2. In particular, in Chapters 3 and 4, we use not only the data from the LSMS–ISA’s agricultural modules in 2011 (LSMS–ISA 2011), but the 2013 version (LSMS–ISA 2013), to which we were given advanced access at the time of writing this book.

Data from the agricultural module are based on the same sample as those used in the demand analyses in Chapter 2. They contain detailed information on production practices for various crops and the use, at the plot level, of inputs such as fertilizer, irrigation, and agricultural machinery for approximately 3,000 farm households out of a total of 5,000 households interviewed. These farm households were selected in the same way as the remaining non-farm households, through stratified random sampling. Among the farm households interviewed, approximately 300 were rice-producing households. The module provides the most up-to-date and nationally representative picture of rice-production systems in Nigeria.

## **Production Systems and Farming Practices**

Rice production in Nigeria has traditionally been characterized by low yields and slow growth. Yield reached a peak in the mid-1980s and has since been stagnant or even declining (row 19, Table 3.1). This is in contrast to Asian and Latin American countries, as well as many other West African countries. Though rice production has increased in the last four decades, this has been driven mostly by area expansion.

The current rice area in Nigeria is approximately 2.4 million hectares (ha), the largest within Africa south of the Sahara (SSA) and almost twice as large as that of the second largest producer, Madagascar (Seck et al. 2012). The

**TABLE 3.1** Rice paddy yield trends (five-year average, tons per hectare)

(1) Periods	1961– 1965	1966– 1970	1971– 1975	1976– 1980	1981– 1985	1986– 1990	1991– 1995	1996– 2000	2001– 2005	2006– 2011
(2) Bangladesh	1.7	1.7	1.7	1.9	2.1	2.4	2.7	3.0	3.6	4.1
(3) Brazil	1.6	1.5	1.5	1.4	1.6	1.9	2.3	2.8	3.3	4.2
(4) Cambodia	1.1	1.3	1.3	1.0	1.2	1.4	1.5	1.9	2.1	2.8
(5) China	2.6	3.2	3.4	3.9	5.0	5.5	5.8	6.3	6.2	6.5
(6) Colombia	2.0	2.6	4.0	4.2	4.4	4.5	4.1	4.8	5.8	5.2
(7) India	1.5	1.6	1.7	1.8	2.1	2.4	2.7	2.9	3.0	3.3
(8) Indonesia	1.8	2.1	2.5	2.9	3.8	4.1	4.4	4.3	4.5	4.9
(9) Iran	2.7	2.7	3.1	3.5	3.4	3.5	4.0	4.2	4.4	4.5
(10) Philippines	1.3	1.5	1.5	2.0	2.5	2.7	2.9	2.9	3.4	3.7
(11) Sri Lanka	1.9	2.2	2.0	2.3	2.9	3.1	3.1	3.3	3.5	3.8
(12) Thailand	1.8	1.8	1.9	1.8	2.0	2.1	2.3	2.5	2.9	2.9
(13) Venezuela	1.7	1.9	2.5	3.1	2.7	3.4	4.1	4.7	4.9	5.0
(14) Côte d'Ivoire	0.9	1.1	1.2	1.2	1.2	1.2	1.1	1.6	1.9	1.8
(15) Ghana	1.0	1.2	1.0	0.9	0.9	1.3	1.9	1.9	2.2	2.2
(16) Guinea	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.9
(17) Liberia	0.5	1.1	1.2	1.2	1.3	1.2	1.0	1.3	1.0	1.3
(18) Mali	1.1	0.9	0.9	1.2	1.0	1.4	1.7	2.0	2.0	2.7
(19) Nigeria	1.1	1.4	1.7	1.7	2.1	2.1	1.8	1.6	1.4	1.7
(20) Senegal	1.3	1.2	1.1	1.2	1.9	2.1	2.3	2.4	2.5	3.2

Source: Authors' calculations based on FAO (2014).

dominant rice-production systems in Nigeria can be described as comprising lowland, upland, and irrigated rice. Among these, the rainfed lowland system covers about 64 percent of the area under rice and therefore contributes the most to national production (column 2, Table 3.2). The system is found in river valleys and swampy alluvial lowlands along the Niger River and especially in the *fadama* farming system areas in Niger and Kaduna states (for the location of states, see Figure 1.1 in Chapter 1).<sup>2</sup>

In contrast to the rainfed lowland system, irrigated lowlands account for only 4 percent of the national area and contribute only 7 percent to the total volume of rice produced in the country. The remaining rice production comes mostly from upland systems. Less common are the deepwater, floating rice

2 *Fadama* is a Hausa name in Nigeria for irrigable land in low-lying plains of shallow aquifers found along major river systems.

**TABLE 3.2** Dominant rice-production systems in Nigeria

(1) Production system	(2) Average share of national area (%)	(3) Average share of national production (%)	(4) Average yield range per year (tons/ha)
Irrigated	4	7	> 2.0
Rainfed lowland	64	65	1.0–3.0
Rainfed upland	30	27	1.0–2.0
Mangrove/deepwater	2	1	NA

**Source:** Authors' estimates modified from Table 1 in Ezedinma (2005), Table 1 in Erenstein et al. (2004), and National Bureau of Statistics and World Bank (2011, 2013).

**Notes:** NA = figures not available. We adjusted the irrigated area downward to be consistent with the estimates from National Bureau of Statistics and World Bank (2011, 2013) and included the difference in the rainfed lowland category. We then adjusted the share of national production proportionately.

systems found in the Sokoto-Rima Valley (Drabo 1976) and mangrove rice systems in the Niger Delta's tidal mangrove swamps.

Not surprisingly, yields are highest for the irrigated systems (typically more than 2 tons/ha), followed by rainfed lowland systems (between 1 and 3 tons/ha) and finally upland systems. The North Central zone produces the most rice, accounting for 30 to 50 percent of national production (Table 3.3).<sup>3</sup> The North West and North East zones each produce about 15 to 30 percent, respectively. Production from the South East, South South, and South West zones combined accounts for only 10 to 20 percent of total production in Nigeria. The majority of the rice is produced by small-scale farmers on less than 1 hectare plots of land (Table 3.4). Only about 20 percent and 5 percent of rice producers cultivate plots of more than 1 ha and 3 ha, respectively.

Farming practices, modern input use, and water control practices can vary widely within each production system. In the lowland rice system, for example, land preparation techniques range from traditional practices of cultivation to the use of herbicides and mechanized tillers. Water control practices, such as bunding, are not common. Rice is either directly seeded or transplanted. In almost all cases, one crop per year is harvested, except in irrigated areas. In upland rice systems, intercropping sometimes occurs, especially with maize, cassava, yams, and vegetables (Longtau 2003a). Rice is seeded directly or broadcast on level and sloped hillsides. Much of the upland rice is grown in southern Nigeria, where rainfall is higher, which also explains the use of intercropping common in the humid forest zones.

3 See the footnote in Figure 1.1 for the location of the six geopolitical zones in Nigeria. Ranges of estimates are somewhat large due to the small sample sizes.

**TABLE 3.3** Rice production shares by geopolitical zones (percent)

Geopolitical zones	NBS (average 2007–2010)	NAERLS (average 2008–2009)	LSMS–ISA (average 2010/2012, harvested between September and March) [95% CI]
North West	29	23	22 [16, 28]
North East	21	15	21 [17, 27]
North Central	31	42	41 [32, 51]
South East	8	11	15 [8, 23]
South South	2	2	1 [0, 1]
South West	2	7	0 [0, 0]

**Source:** National Bureau of Statistics (NBS), National Agricultural Extension and Research Liaison Services (NAERLS), and authors' calculations based on Nigeria, NBS and World Bank (2011, 2013).

**Note:** LSMS–ISA = Living Standards Measurement Study–Integrated Surveys on Agriculture. Numbers in brackets are 95% confidence intervals (CI). A list of the states in each geopolitical zone is provided in Figure 1.1 in Chapter 1.

**TABLE 3.4** Percentiles of household-level rice area distributions in Nigeria (average of 2010 and 2012)

Categories	Percentiles						
	1%	5%	25%	50%	75%	95%	99%
Upper bound (ha)	0.02	0.05	0.2	0.4	0.8	3.7	8.3
Adjusted for multiple crops (ha)	0.01	0.03	0.1	0.3	0.7	2.7	7.6

**Source:** Authors' calculations based on Nigeria, NBS and World Bank (2011, 2013).

**Note:** ha = hectare. "Upper bound" assumes rice takes up the entire plot even though multiple crops are reported on the same plot. "Adjusted for multiple crops" assumes rice share is the area of the plot divided by the number of crops reported.

Modern input use generally involves purchased inputs such as improved seeds, fertilizer, and chemicals. In the past, the use of improved modern seed varieties was most common in irrigated lowland areas (80 percent), moderate in upland areas (67 percent), and lowest in rainfed lowland ecologies (37 percent) (Dalton and Guei 2003). The majority of the most popular improved varieties listed in Table 3.5 are not originally from Nigeria (column 5). The popular Nigerian-bred variety, FARO 15, is considered old, indicating the absence of newer superior varieties that can replace it.

Fertilizer use in rice production is also generally higher in lowland and irrigated areas, but application rates vary widely across regions and rice ecologies. Table 3.6 summarizes rice yield, fertilizer use, and nitrogen levels obtained from LSMS–ISA (2011) data in both northern and southern Nigeria. Northern and southern Nigeria are defined as in Takeshima and Edeh (2013), where the northern region consists of pastoral systems, agropastoral/sorghum and millet systems, irrigated systems, and cereal/root crop mixed systems,

**TABLE 3.5** Popular rice varieties grown in Nigeria

(1) Variety	(2) Year released	(3) % share	(4) Pedigrees	(5) Origin
FARO 44	1993	11	SIPI 661044, SIPI 651020	Taiwan
FARO 15	1974	7	FARO 1 (BG 79) × IR-8	Nigeria
FARO 46	1992	6	ITA 150 (63-83/Multiline)	IITA
Ex China	1988	5	Unknown	China
FARO 52	2001	4	WITA 4 (TOX 3100-44-1-2-3-3)	IITA (Benin)

**Source:** Authors' modifications from ASTI (2013) and Takeshima (2014).

**Note:** IITA = International Institute of Tropical Agriculture.

while the southern region consists of root crop systems, tree crop systems, and coastal artisanal systems.

While fertilizer use is still low in Nigeria (Liverpool-Tasie and Takeshima 2013), its use is higher when limited to the rice plots. At the national level, around 75 kilograms per hectare (kg/ha) and 215 kg/ha of inorganic fertilizer are used on rice plots and irrigated rice plots, respectively (columns 4 and 7 in Table 3.6), although these estimates are subject to a large margin of error due to the small sample size. Assuming NPK (nitrogen, phosphate, and potash) and urea contain 15 percent and 46 percent of nitrogen, this is equivalent to approximately 67 kg/ha and 18 kg/ha of nitrogen used on irrigated and rain-fed rice plots, respectively (columns 7 and 10). Average yields of irrigated rice are estimated to be around 3.7 tons/ha in the northern region and 2.8 tons/ha in the southern region, excluding outliers in the data (columns 5 and 6). The average figures for southern Nigeria for yield and nitrogen are in a similar range as authors' field observations in Nasarawa State presented in Table 4.1 of Chapter 4.

Use of irrigation is limited to areas in northern Nigeria. Out of approximately 81,000 ha of irrigated rice area, about 90 percent are in the North West (48,000 ha) and the North Central (26,000 ha) zones (columns 4 and 2 in Table 3.7). Shares of irrigated area to rice area are slightly higher in the North West zone (around 11 percent). This, however, is still well below shares in Asia witnessed during the Green Revolution. In fact, the limited use of irrigation in Nigeria has not changed much since the 1990s (Oramah 1996).

For the few areas under irrigation, the most common water control system is diverted stream or river. Other types of irrigation systems are also observed, however, particularly in the North West zone, where more than half of the rice area irrigated between January and August uses pump-based irrigation (column 4). As is discussed later, while pump-based irrigation is associated

**TABLE 3.6** Average quantity (per hectare) of fertilizer used and yield of rice production in Nigeria (January–August 2010)

(1) Fertilizer use and yield	All types of production			Irrigated production			Rainfed production		
	(2) Northern	(3) Southern	(4) Country	(5) Northern	(6) Southern	(7) Country	(8) Northern	(9) Southern	(10) Country
All inorganic fertilizer (kg/ha)	104 [76, 149]	67 [39, 111]	75 [47, 114]	228 [116, 388]	195 [100, 374]	215 [125, 319]	81 [58, 121]	64 [35, 103]	67 [41, 97]
NPK (kg/ha)	60 [33, 89]	25 [11, 48]	32 [18, 50]	113 [10, 282]	56 [0, 158]	91 [25, 206]	51 [23, 75]	24 [12, 48]	29 [15, 48]
Urea (kg/ha)	44 [23, 82]	32 [14, 63]	35 [18, 65]	106 [53, 250]	138 [54, 263]	115 [62, 161]	31 [15, 62]	29 [10, 60]	29 [13, 52]
Nitrogen (kg/ha) <sup>a</sup>	29 [20, 47]	19 [9, 35]	21 [12, 34]	66 [37, 126]	72 [37, 136]	67 [44, 109]	22 [15, 35]	17 [8, 32]	18 [10, 29]
Yield (ton/ha)	2.2 [1.6, 3.1]	1.7 [1.1, 2.0]	1.7 [1.2, 2.0]	3.7 [1.9, 4.9]	2.8 [1.3, 3.5]	3.4 [2.4, 4.2]	1.4 [1.0, 1.6]	1.6 [1.0, 2.0]	1.6 [1.0, 2.0]

**Source:** Authors' calculations based on Nigeria, NBS and World Bank (2011).

**Note:** Figures are calculated using sample weights. Numbers in brackets are 95% confidence intervals for estimated averages. For rainfed, we dropped observations with more than 1 ton/ha of fertilizer, which are unlikely. NPK and urea are fertilizer products, while nitrogen is one of the chemical components of these fertilizer products. Yield figures exclude outliers, which are above 3 tons/ha in rainfed, 5 tons/ha in the irrigated southern region, and 10 tons/ha in the irrigated northern region. Here we include only plots where rice areas within the plot are reported. Including other plots with unknown rice area, however, does not significantly change the patterns presented. <sup>a</sup>Nitrogen is calculated assuming NPK 15-15-15 (with 15% nitrogen component), and urea 46%. Since manure is minimal, we ignored nitrogen from manure. Use of manure and other inorganic fertilizer is negligible based on the data.

**TABLE 3.7** Rice irrigation area by water regime (average of 2010 and 2012, January–August, 1,000 ha)

(1) Rice areas by water regimes	Geopolitical zones						(8) Total
	(2) NC	(3) NE	(4) NW	(5) SE	(6) SS	(7) SW	
Rainfed rice area	533 [308, 758]	534 [331, 736]	376 [270, 482]	601 [0, 1,744]	147 [0, 414]	2 [0, 5]	2,194 [975, 3,413]
Irrigated rice area total	26 [15, 37]	5 [0, 11]	48 [20, 76]	2 [0, 4]	1 [0, 2]		81 [51, 111]
(a) Irrigated area (planted Jan.–Aug.)	24 [14, 35]	5 [0, 11]	37 [15, 59]	2 [0, 4]	1 [0, 2]		69 [44, 94]
<i>(i) Irrigation system (planted Jan.–Aug.)</i>							
Diverted stream	24 [14, 35]	3 [0, 8]	12 [4, 20]	2 [0, 4]	1 [0, 2]		42 [28, 56]
Bucket			5 [1, 9]				5 [1, 9]
Hand pump		1 [0, 3]	6 [0, 13]				7 [0, 14]
Treadle pump			0 [0, 1]				0 [0, 1]
Motor pump			15 [2, 27]				15 [2, 27]
Gravity		1 [0, 2]					1 [0, 2]
<i>(ii) Water sources</i>							
Well			2 [0, 6]				2 [0, 6]
Borehole		1 [0, 2]	15 [3, 27]				16 [3, 28]
Lake/ natural pond			3 [0, 6]	2 [0, 4]			4 [1, 8]
Created pond	0 [0, 1]	1 [0, 3]					1 [0, 4]
River/stream	24 [14, 35]	2 [0, 6]	7 [2, 13]	0 [0, 0]	1 [0, 2]		35 [22, 47]
Other		1	10		1		11
(b) Irrigated area (planted Sept.–Dec.)	1 [0, 4]		10 [0, 20]				11 [1, 22]

**Source:** Authors' calculations based on Nigeria, NBS and World Bank (2011, 2013).

**Note:** In order to improve estimates, we present averages based on 2010 and 2012 data combined. Figures are based on sample weights. Numbers in brackets are 95% confidence intervals. While some plots had multiple crops reported, we assumed the entire area of such plots was allocated for rice. This calculation method is found to give aggregated rice area estimates closer to figures in FAO (2014). The figures in 2 to 7 may not necessarily add up to the total figure in column 8 due to the rounding.

with higher production costs and yields, river-diversion irrigation is relatively low cost but results in lower yields.

Most rice farmers also grow other crops, either for their own consumption or as cash crops to supplement rice. Table 3.8 summarizes the share of rice growers in each group of geopolitical zones growing other crops. Generally,

**TABLE 3.8** Share of rice growers growing other key crops (percent), by irrigation status

(1) Crops	All zones		North West, North East		North Central, South East, South South, South West	
	(2) All rice growers	(3) Rice irrigators	(4) All rice growers	(5) Rice irrigators	(6) All rice growers	(7) Rice irrigators
Cowpea	26 [22, 30]	38 [23, 52]	36 [30, 41]	59 [38, 80]	9 [5, 13]	10 [0, 21]
Cassava	19 [16, 23]	22 [13, 32]	9 [6, 11]	5 [0, 12]	38 [31, 46]	43 [26, 61]
Sorghum	56 [51, 61]	57 [42, 71]	63 [58, 69]	55 [33, 77]	43 [35, 52]	58 [40, 76]
Maize	48 [43, 52]	34 [21, 47]	64 [58, 69]	36 [16, 56]	20 [14, 25]	31 [14, 47]
Millet	17 [14, 20]	40 [25, 54]	24 [19, 29]	59 [38, 80]	5 [3, 8]	14 [2, 27]
Groundnut	17 [14, 20]	10 [3, 17]	19 [14, 23]	1 [0, 4]	14 [9, 19]	22 [7, 36]
Yam	15 [12, 18]	9 [3, 15]	4 [2, 6]	0	33 [26, 41]	21 [7, 34]
Vegetables	13 [10, 16]	14 [3, 24]	14 [10, 18]	23 [5, 41]	11 [7, 16]	1 [0, 4]

**Source:** Authors' calculations based on National Bureau of Statistics and World Bank (2011, 2013).

**Note:** Figures are based on sample weights. Numbers in brackets are 95% confidence intervals.

sorghum, maize, and cowpea are the crops that are most commonly grown by rice producers at the national level (column 2). Cassava and yam are also grown by a third of rice growers in the North Central and southern zones (column 6). Interestingly, rice irrigators (columns 3, 5, 7) are more likely to grow some of the rainfed subsistence crops (cowpea, millet) than rainfed rice producers. Rice seems to compete with maize or vegetables for irrigation in some zones. Though more rigorous assessments are needed, current cropping patterns indicate that an expansion of rice irrigation would be likely to displace crops like maize or vegetables.

In addition to low levels of irrigation, mechanization in rice production is low. According to the most recent but limited available data, only about 20 percent of the rice area is cultivated by tractors, although this share is higher than that for other crops.<sup>4</sup> As Table 3.9 shows, mechanization patterns also vary across geopolitical zones. This is partly because of local agroecological and topographical conditions for land clearing. In the North Central zone, which is mostly semihumid and savannah vegetation, 50 percent of the rice areas are cultivated by tractors (column 4). Labor-intensive irrigated and lowland rice production systems in this zone may be less viable (i.e., less profitable) without tractor use.

In contrast, the more humid and forested zones in southern Nigeria rarely use tractors for land clearing (column 3). Use of animal traction is

<sup>4</sup> These results should be interpreted with caution, as the sample size used in the calculations was small and thus has a potentially large margin of error.

**TABLE 3.9** Share (percent) of total rice areas cultivated by tractors and animal traction by geopolitical zones

(1) Category	(2) Total	(3) SE, SS, SW	(4) NC	(5) NE	(6) NW
% of rice area cultivated by tractor	20 [6, 33]	1 [0, 2]	50 [37, 63]	42 [29, 55]	2 [0, 3]
% of rice area cultivated by animal traction	20 [7, 33]	0 [0, 0]	0 [0, 0]	19 [12, 26]	80 [70, 89]

**Source:** Authors' calculations based on Nigeria, NBS and World Bank (2011, 2013).

**Note:** SE = South East, SS = South South, SW = South West, NC = North Central, NE = North East, NW = North West. Numbers in brackets are 90% confidence intervals.

also very limited on rice farms in these zones; according to various local experts, this is due to tsetse flies and heavier soils. In the North West, where livestock production is highest, approximately 80 percent of the rice area is cultivated with animal traction and only about 2 percent with tractors (column 6). Here, animal traction seems to provide an intermediate means for mitigating labor constraints on rice production. The North East zone is somewhat between the North Central and the North West zones with regard to tractor use (column 5).

Altogether, the varied use of technologies—particularly irrigation and mechanization, modern inputs such as improved seeds and fertilizer, and other farming practices and socioeconomic characteristics—results in distinctive types of rice producers in Nigeria. To gain an overview, a cluster analysis, as in Takeshima, Nin Pratt, and Diao (2013), reveals four typologies: (1) subsistence producers; (2) small-scale intensive irrigators; (3) wealthier mechanized producers; and (4) other market-oriented producers (Table 3.10).

Among these, 78 percent of rice producers are market-oriented farmers (columns 3 through 5), while 22 percent are subsistence farmers (column 2). The market-oriented producers include those who give out harvests as gifts.<sup>5</sup> Among market-oriented producers, small shares of two types of competitive producers are also identified—small-scale intensive irrigators and wealthier mechanized producers—each accounting for 7 and 5 percent of total rice producers in Nigeria, respectively (columns 3 and 4). The remaining

<sup>5</sup> Gift giving can reflect informal income transfer (for income smoothing) as in Madagascar, where stock and gifts are considered part of marketable surpluses (Barrett and Dorosh 1996). Similar gift exchange is part of informal insurance and credit in northern Thailand (Townsend 1995). Kin landlords and tenants in the Philippines are found to exchange rice grains as gifts in case of emergency (Sadoulet, de Janvry, and Fukui 1997). Similar arrangements are observed in Nigeria, as indicated in the data.

**TABLE 3.10** Characteristics of major rice producers in Nigeria, 2010

(1) Characteristic	Market-oriented producers			
	(2) Subsistence producers	(3) Small-scale intensive irrigators	(4) Wealthier mechanized producers	(5) Other market- oriented producers
Share of all rice producers (%)	22	7	5	66
Real wage (daily wage/rice price ratio)	13	9	20	23
Farm gate rice price (US\$/kg)	45	59	43	51
Fertilizer (US\$/ha)	13	27	67	27
Chemicals (US\$/ha)	11	24	67	11
% using tractor	13	10	100	10
% using irrigation in diverted stream	3	100	42	0
% with nonfarm income source	51	78	80	54
HH non-food expenditure (annual US\$ per capita)	77	75	111	45
HH assets (US\$)	347	247	738	337
Distance to the nearest dam (km)	60	24	140	62
Farm size for all crops (ha)	0.7	0.5	3.0	0.7
% in northern region	70	89	0	73
Rice harvest per farm household (tons)	0.4	1.3	2.1	1.0

**Source:** Authors' calculations based on cluster analysis.

**Note:** HH = household.

market-oriented producers are less input intensive, with smaller rice production per farm households.

Small-scale intensive irrigators are those who typically operate on 0.5 hectare plots and practice labor- and input-intensive rice irrigation. They are often located within canal irrigation systems relatively close to dams in the North West, North East, or North Central zones. These producers enjoy access to irrigation or water, higher farmgate rice price, and cheaper labor, and they sometimes practice mechanized land preparation. There were approximately 68,000 producers of this type in Nigeria, producing 89,000 tons of rice in the 2010 rainy season and selling more than half of their harvest. Wealthier mechanized rice producers typically use tractors on their plots and use modern inputs (fertilizer, chemicals) intensively, together with some irrigation.

## Biophysical Production Constraints

The varied pattern of rice producers in Nigeria is not surprising considering the diverse nature of the underlying biophysical and socioeconomic endowments of the country, as well as biotic and abiotic constraints, which introduce distinctive challenges for improving rice yields and production output in different parts of the country. In this section, we first review the biophysical production constraints such as climate, water access, and soils, as well as other biotic and abiotic factors that affect yields. This is followed in the next section by a review of the most common socioeconomic production constraints facing Nigerian rice farmers.

### Climate

If there is one thing that most influences the growth of plants in rainfed environments like those in Nigeria, it is climate. More specifically, having the right amount of sunlight, rainfall, and favorable temperatures during the main growing period is critical. These affect physiological processes involved in grain production—vegetative growth, development of spikelets, and grain fillings (Yoshida 1978). Rainfed rice production is generally possible in areas with annual rainfall of more than 1,300 millimeters (mm) (Akpokodje, Lançon, and Erenstein 2001), and a substantial area of Nigeria falls under this rainfall regime. Most regions of the country fall within the Guinea savanna ecoregion, with a growing period of 165 days or more (Andriessse and Fresco 1991), where rainfed rice can be grown with some flexibility in planting and harvesting time.

However, dry season in Nigeria is highly arid. Even in the North Central zone of Nigeria (Minna, Makurdi), monthly rainfall is very low during the dry season (Table 3.11). Such aridity seems more pronounced compared to other major rice-growing locations in similar latitudes outside Africa. With the exception of Bangkok (Thailand), at least 40 mm of monthly rainfall are observed even during dry season in the other rice-growing regions listed in column 3 of Table 3.11 (Sri Lanka, the Philippines, and Colombia). Unless yield response to water is high, dry-season rice production may be limited in central Nigeria because irrigation costs can be high. Though little empirical evidence exists, providing 50 mm of water for 1 ha through pump irrigation in Nigeria's North Central zone can cost roughly US\$70 for pumping alone, as expensive as 100 kg of fertilizer (or about 45 kg of nutrients).<sup>6</sup> Aridity during the dry season, coupled with a low-yield response to water, might partly explain the slower expansion of rice irrigation in central Nigeria compared to other regions.

<sup>6</sup> Based on authors' fieldwork in 2013. Related discussions are provided in the next chapter.

**TABLE 3.11** Annual and dry-season rainfalls in selected locations with distinct dry seasons

(1) Locations/regions	(2) Annual rainfall (mm)	(3) Monthly dry-season rainfall (mm)	(4) Dry-season months (5 driest months)
Kano, northern Nigeria	696	0	November–March
Maiduguri, northern Nigeria	552	0	November–March
Minna, North Central zone, Nigeria	1,210	4	November–March
Makurdi, North Central zone, Nigeria	1,237	8	November–March
Enugu, southern Nigeria	1,695	25	November–March
Ilorin, southern Nigeria	1,185	19	November–March
Port Harcourt, southern Nigeria	2,294	65	November–March
Colombo, Sri Lanka	2,404	136	December–April
Trincomalee, Sri Lanka	1,569	50	March–July
Zamboanga, Philippines	1,067	44	December–April
Bangkok, Thailand	1,498	25	November–March
Benito Salas, Colombia	1,343	58	May–September

**Source:** Authors' calculations based on World Meteorological Organization (2013).

Solar radiation also affects rice production and yield (Yoshida 1971, cited in Barker, Herdt, and Rose 1985). In the dry season responses to fertilizer tend to be more consistent due to high levels of solar radiation (Barker, Herdt, and Rose 1985). Where the plant has adequate water, greater solar radiation leads to better nutrient uptake and higher yields. The wet season typically has lower levels of solar radiation, hence lower yields (Barker, Herdt, and Rose 1985). In northern Nigeria, solar radiation is higher than southern Nigeria (Balasubramanian et al. 2007). Suboptimal solar radiation combined with high humidity is associated with a greater incidence of pests and diseases (Windmeijer and Andriese 1993).

Potential rice yield in the tropics is lower than the subtropics and temperate regions. This is because tropical daylight lasts only 12 hours during the summer production season, as opposed to 16 hours in the subtropics and temperate regions, and warm nights affect respiration (Tinsley 2009). In Nigeria, the grain-filling period for dry-season rice production is around April. At this time, solar radiation in the Sahel region (which corresponds roughly to the northern half of the North West and North East zones and includes states such as Sokoto) and the North Central zone (such as the city of Badeggi) can differ by as much as 4 watts per square meter ( $\text{watt}/\text{m}^2$ ) (based on authors assessment from Ogolo 2011), with 21  $\text{watt}/\text{m}^2$  in Sokoto and 17  $\text{watt}/\text{m}^2$  in Badeggi. As is shown

later, irrigated rice yields are higher in northern Nigeria than central Nigeria. Differences in fertilizer use and yield between the North West or North East zone and the North Central zone may be partly explained by the difference in solar radiation levels.

Temperature also affects rice production. Yield will be drastically reduced if the rice flowers during the cold period, as many of the flowers will abort and will not be able to set seed. The dry-season cropping of rice should be planned so that the flowering will not fall within the cold period of January to March. In northern Nigeria, rainfall and seasonally low night temperature can be constraining (Windmeijer and Andriessse 1993).

When these agroclimatic factors are considered, yield potential in Nigeria is comparable to the other regions in the world. Table 3.12 summarizes agroclimatically attainable yields of *indica* and *japonica* rice under irrigated conditions in Nigeria and other regions.<sup>7</sup> Nigeria has similar yield potential to South America, Southeast Asia, and southern Asia for both types of rice at comparable levels of input use, although it has lower potential than North America, northern Africa, or Central Asia (columns 2–5). Realizing such potential yield, however, depends on other constraints like the cost of water, soil characteristics, and incidence of pests and diseases, which are not considered in Table 3.12.

### Water Access

Rainfed rice production not only depends on sufficient rainfall but requires a rice-production landscape that can maximize water access for the plant during the growing period. Based on the water sources, rice landscape can be classified into pluvial, phreatic, and fluxial (Moormann and van Breemen 1978), and rice ecologies develop as upland, rainfed lowland, and irrigated (IRRI 1984). Because of its semiaquatic nature (Kranjac-Berisavljevic, Blench, and Chapman 2003; Windmeijer and Andriessse 1993) and heavy reliance on water, wetland or lowland is the major production environment for rice.

The biophysical potential of rice production varies across production systems. Different production practices are used and different constraints exist (Akpokodje, Lançon, and Erenstein 2001; Kranjac-Berisavljevic, Blench, and Chapman 2003; Windmeijer and Andriessse 1993). In an upland rice production system, the underground water table is below the root depth, so the

<sup>7</sup> *Indica* and *japonica* are geographic races of the Asian rice species *Oryza sativa*. *Indica* rice is long grained, while *japonica* is short grained. For example, the most commonly known types of *indica* rice grown in Asia are the *basmati* and *jasmine* varieties.

**TABLE 3.12** Agroclimatically attainable yield (tons per hectare) of rice under irrigated conditions with varying input intensity

(1) Country/regions	<i>Indica</i> wet rice (120 days)		<i>Japonica</i> wet rice (120 days)	
	(2) High input level	(3) Low input level	(4) High input level	(5) Low input level
Nigeria	7.4	2.1	6.7	1.7
Central Africa	7.2	2.1	6.8	1.7
Central America	7.9	2.3	7.2	1.9
Central Asia	9.4	2.8	8.1	2.1
Eastern Africa	8.0	2.4	7.0	1.8
Eastern Asia	7.9	2.3	7.0	1.8
Northern Africa	9.0	2.7	7.8	2.0
Northern America	9.1	2.7	8.0	2.1
South America	7.0	2.0	7.1	1.8
Brazil	7.0	1.9	6.4	1.6
Colombia	5.7	1.6	5.4	1.3
Southeast Asia	6.7	1.8	6.3	1.6
Indonesia	6.2	1.6	5.3	1.1
Southern Africa	8.5	2.6	7.5	1.9
Southern Asia	7.7	2.3	6.6	1.7
Sri Lanka	7.4	2.1	6.1	1.2
Sudano-Sahelian Africa	7.9	2.3	7.2	1.8

**Source:** Authors' compilation from Global Agro-ecological Zones (GAEZ) software (v3.0) by Fischer et al. (2012), and figures are averages within each region.

**Note:** Differences in maturity length do not seem to affect the relative agro-climatically attainable yield level within regions. Therefore we report figures only for 120-day maturity varieties. The definitions of regions in this table are based on the GAEZ source.

plant relies exclusively on rainfall. This mostly limits the upland rice system in Nigeria to the southern zones and parts of the North Central zone with annual rainfall greater than 1,300 mm (Akpokodje, Lançon, and Erenstein 2001). Only one crop per year is possible because of dependence on rain in the wet season. This type of system exists at higher elevations, and soil erosion can be a serious problem.

Thus, maintaining soil nutrients is challenging, and rice cannot be grown more than two consecutive years without following to replenish the soil, further limiting the production potential. Upland can be further divided into wet upland and dry upland, depending on the depth of the water table. In order to exploit fully the potential in the upland environment, varieties with greater rooting depth are needed to extract water for survival and grain

production. Drought-resistant varieties that are more efficient in extracting water are also needed (Moormann and van Breemen 1978).

The lowland (also called wetland) rice-production system is diverse. Lowland in Africa can be defined as areas subject to periods of complete saturation of soils, with possible flooding during part of the crop-growing period (Balasubramanian et al. 2007). The lowland environment is suited to intensification, possibly growing two or more crops per year, but excess water may limit crops other than rice (Erenstein et al. 2003). Lowland systems can be further divided into four types based on geographical characteristics: inland basins, inland valleys, river floodplains, and coastal lowlands (Table 3.13).

Among these, much lowland in Nigeria belongs to inland valleys (known as *fadama*) (column 3) and coastal lowlands typically found in the Niger Delta (column 5). More broadly, *fadamas* in Nigeria have features of both floodplains and inland valleys. They tend to be wider than 200 meters, the maximum width for a lowland to be considered as an inland valley yet still have more hydrological similarities with an inland valley than a floodplain (Akpokodje, Lançon, and Erenstein 2001). An inland valley bottom is relatively less prone to drought or submergence compared to other lowlands and is considered a next frontier for intensification of rice-based cropping systems (Balasubramanian et al. 2007). Inland valley bottoms (together with foot slopes) cover 11 million ha in total in West Africa, but they have been only marginally used (Windmeijer and Andriessse 1993), although there has been an increasing focus on this environment in many West African countries (Totin, Stroosnijder, and Agbossou 2013).

**TABLE 3.13** Types of lowlands in Africa

(1) Category	Types of lowlands			
	(2) Inland basins	(3) Inland valleys	(4) River floodplains	(5) Coastal lowlands
Key characteristics	Drainage depressions and inland deltas of rivers, with imperfectly to poorly drained and potentially acidic soils (ultisols, oxisols, alfisols, entisols, and vertisols)	Known as <i>fadamas</i> in Nigeria	A wide, flat plain of alluvium bordering streams and rivers that flood it periodically	Lowlands along the coast
Typical locations	Upper Nile, Sokoto, Lake Chad, Congo Basins	Mostly located in intertropical region where rainfall > 700 mm	Along Niger and Benue Rivers	Niger Delta (Nigeria)

**Source:** Authors' compilation based on Balasubramanian et al. (2007).

**Note:** mm = millimeters.

In Asia, inland valleys are upper reaches of major or minor watersheds, where sediments (alluvial, colluvial) are derived from the adjacent uplands. This is typical in Sri Lanka. Physiographic conditions similar to Sri Lanka's dominate in many of the rice-growing areas of West Africa (Moormann and van Breemen 1978). Given the similar latitude that determines rainfall, temperature, and solar radiation, rice production in Sri Lanka provides an important comparison with the North Central and southern zones of Nigeria.

The third production system, irrigated rice, can be generally categorized in the African context into three types depending on the agroecology: (1) arid and semiarid Sahel; (2) humid forest and savannah; and (3) tropical highlands (Balasubramanian et al. 1995, 2007). In Nigeria, both 1 and 2 are found, while 3 is mostly found in East and Central Africa and Madagascar (Balasubramanian et al. 1995). System 1 is characterized by high solar radiation, lower incidence of pests, significant use of direct seeding, and high water consumption due to high evapotranspiration in the dry season. System 2 is characterized by lower yields relative to 1 due to lower solar radiation, higher pest incidence, and iron toxicity (Balasubramanian et al. 2007). In West Africa including Nigeria, system 2 may be found in inland valley bottoms where rice is rotated with maize, soybean, or vegetables (Balasubramanian et al. 2007).

## Soils

Besides climate and access to water, the nature of the soil can also significantly affect the potential for rice production. Here, citing Moormann and van Breemen (1978), we summarize key aspects of soil endowments in Nigeria that can hypothetically affect the biophysical potential for rice. We emphasize "hypothetical," as this has not been investigated thoroughly in the literature, at least to the best knowledge of the authors.

Soil characteristics can affect rice production in several ways. Soils affect water-holding capacity under freely drained conditions. Types of soils can affect the comparative advantage of rice over other crops and the types of rice varieties that need to be developed. Moormann and van Breemen (1978) examine various types of soils classified in the Food and Agriculture Organization of the United Nations (FAO) soil taxonomy, describe their associations with the prevalence of rice production, and categorize soils by importance in rice production.

Using the descriptions in Moormann and van Breemen, soils in Nigeria can be roughly classified based on their suitability for lowland, upland, and transitional types (Table C.1 in Appendix C). Inceptisols (mostly Cambisols) form the most important single soil order among the rice-growing soils. Rice-growing alluvial plains—both river floodplains and deltaic areas—are to a

large extent Inceptisols (66). This is followed by other soils of major importance, minor importance, and little importance.

Using world soil maps from FAO/IIASA/ISRIC/ISSCAS/JRC (2012), we calculate the area of lowland, upland, and transitional types of soils, with additional separation between Cambisols and other lowland-type soils per person in each country, using the population of the countries in 2010 (Table 3.14). In Nigeria, there are 0.0022 ha (or 22 m<sup>2</sup>) of Cambisols per person (column 2). Figure 3.1 maps their geographical distributions. The breakdown for tropical West African countries is shown in Table 3.15.

Although these classifications are subject to more rigorous assessments, important messages emerge. Given its population density, Nigeria is less endowed with suitable soils for rice production per head of population than Asia, Latin America, and some other West African countries (column 4 in Tables 3.14 and 3.15). The need for rice intensification per hectare may be higher in Nigeria than these countries. It is, however, also important to note that the rice yield in Latin America is much higher than that in Nigeria. Africa's Niger River and its tributaries have narrow floodplains, and their accompanying level terraces are less extensive than in the major rice-growing areas in Asia (Moormann and van Breemen 1978). In order to increase rice production, Nigeria will need to increase rice yield from these soils because

**TABLE 3.14** Rice ecology soil endowment per capita (square meters per person)

(1) Country	Lowland type					
	(2) Cambisols	(3) Excluding Cambisols	(4) Total	(5) Transitional	(6) Upland type	(7) Minor type
Nigeria	22	797	819	680	1,840	2,132
Bangladesh	136	657	793	31	0	83
India	421	627	1,048	68	691	623
Indonesia	699	1,266	1,965	919	525	4,332
Japan	471	238	710	0	531	1,710
Sri Lanka	88	272	360	0	1,754	
Thailand	0	2,493	2,493	287	93	4,491
Vietnam	0	869	869	0	71	2,734
Brazil	352	3,431	3,784	163	4,498	34,639
Colombia	1,589	3,815	5,404	1,108	1,439	15,971

**Source:** Authors' calculations based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and FAO (2012).

**Note:** Per capita soil endowment calculated using 2010 population numbers. Figures in columns 2 and 3 may not add up to total figures in 4 due to rounding.

**TABLE 3.15** Rice ecology soil endowment per capita in some West African countries (square meters per person)

(1) Country	Lowland type					
	(2) Cambisols	(3) Excluding Cambisols	(4) Total	(5) Transitional	(6) Upland type	(7) Minor soils
Nigeria	22	797	819	680	1,840	Ac, A, F, L, R (2,132)
Côte d'Ivoire	1,292	2,979	4,271	166	1,438	A, Ac, F (9,599)
Ghana	49	554	603	70	4,650	Ac, F, L (4,055)
Guinea	439	674	1,113	4	177	Ac, F, L (22,134)
Senegal	727	1,909	2,636	878	2,422	A, L, R (8,718)
Sierra Leone	0	701	701	150	0	F (8,197)

**Source:** Authors' calculations based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and FAO (2014).

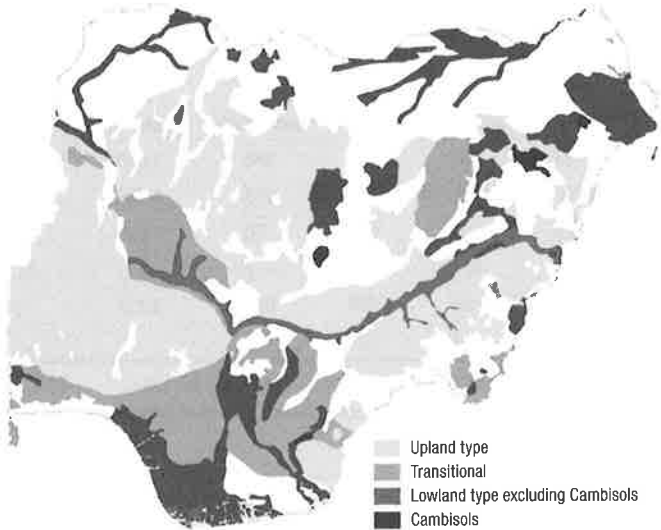
**Note:** A = Arenosols, Ac = Acrisols, F = Ferralsols, L = Lithosols, R = Regosols. Minor soils include types of soils on which rice is rarely grown in Asia.

the expansion potential outside of areas with these soils is limited. One way to improve yield is to increase irrigated areas within these lowland soils.

Comparison within West Africa, however, should be approached with caution. Though the per capita endowment of soils suitable for rice production is generally lower in Nigeria than other coastal West African countries (column 4 in Table 3.15), Nigeria has an advantage over these countries in that relatively more rice is currently produced on the suitable soil area than in the other tropical West African countries. Figure 3.2 indicates that much rice production in Nigeria is found along the Niger and Benue Rivers (see Figure 1.1) and the Sokoto River, which runs across Sokoto State, as well as in the South East zone, including Ebonyi, where lowland-type soils are common (Figure 3.1).

In Côte d'Ivoire, Sierra Leone, and the Republic of Guinea, main rice-production areas are often on minor soils (Figure 3.3). In fact, the dominant rice ecology in these countries is upland, while it is lowland in Nigeria (Dalton and Guei 2003; Seck et al. 2012). Conditions in tropical West Africa are in stark contrast to those in countries such as Thailand, where the rice-production area closely matches major soils (Figure 3.4). As is discussed in the following section, this mismatch may partly explain why substantial domestic breeding efforts in countries such as the Republic of Guinea and Côte d'Ivoire have not led to substantial yield growths. Nigeria seems to be in a better position than these countries to develop new varieties by crossing Asian varieties (which may have high yield response in suitable soils) and local varieties (with suitable genes for the local production environment).

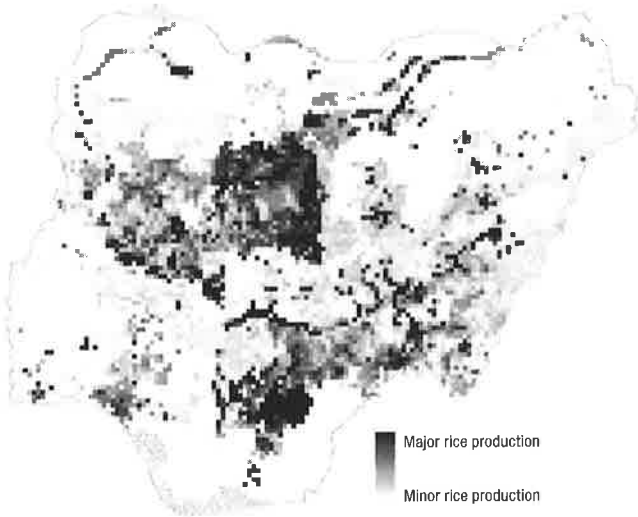
**FIGURE 3.1** Soils in Nigeria suitable for different rice ecologies



**Source:** Authors' analyses based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and Moormann and van Breemen (1978).

**Note:** White space represents the soil less suitable for rice production.

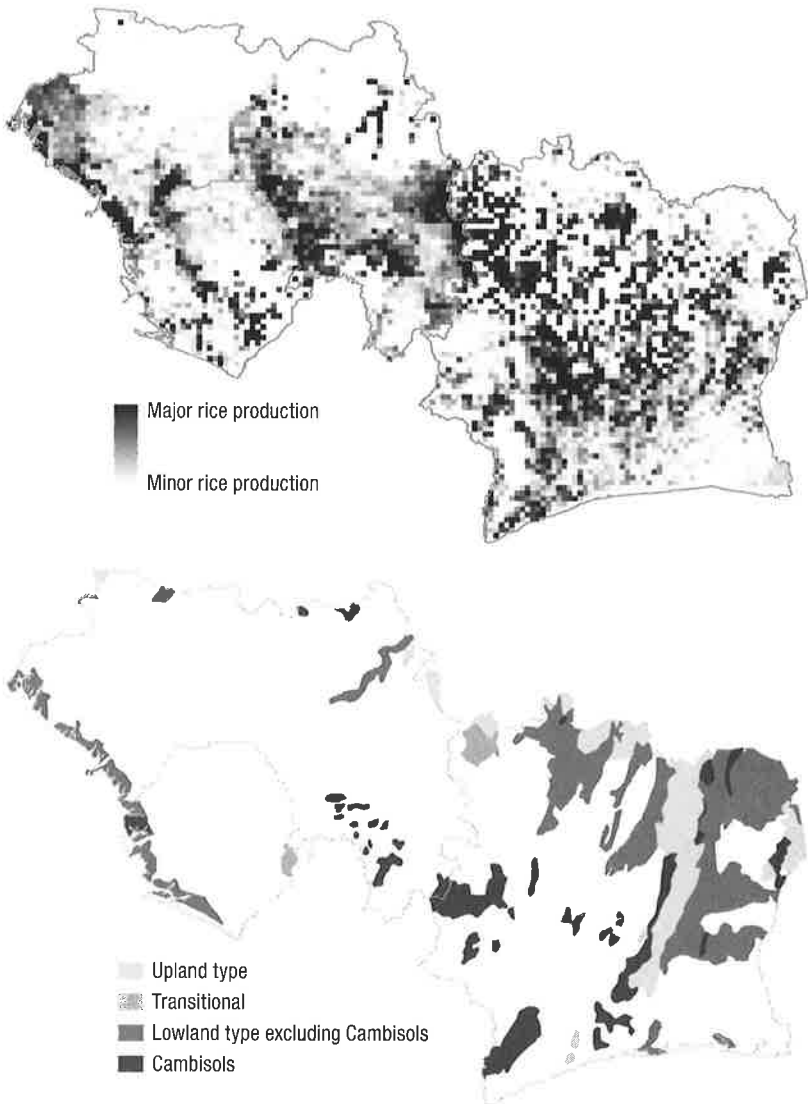
**FIGURE 3.2** Rice-production areas in Nigeria



**Source:** Harvest Choice (2012).

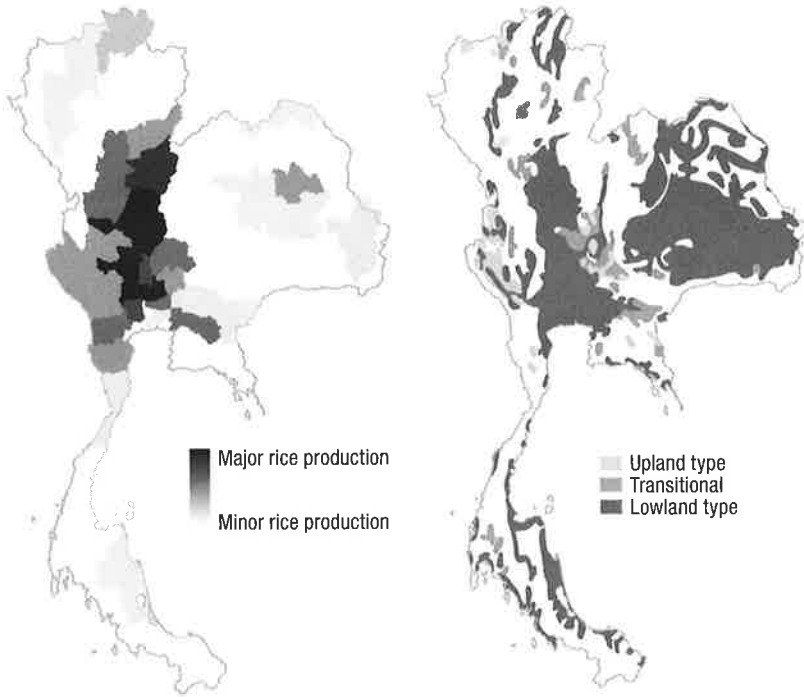
**Note:** The relative darkness of the shading indicates the scale of rice production: very dark gray = major rice production; lighter gray = minor rice production.

**FIGURE 3.3** Soils suitable for rice and actual rice production in the Republic of Guinea, Sierra Leone, and Côte d'Ivoire



**Source:** Top figure is based on Harvest Choice (2012); bottom figure is authors' analyses based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and Moormann and van Breemen (1978).

**Note:** In the top figure, the relative darkness of the shading indicates the scale of rice production: very dark gray = major rice production; lighter gray = minor rice production.

**FIGURE 3.4** Actual rice production and rice-suitable soils in Thailand

**Source:** Left figure is based on USDA, Foreign Agricultural Service (2013). Right figure is authors' analyses based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and Moormann and van Breemen (1978).

### Biotic and Abiotic Constraints

Rice production around the world faces various biological or biotic constraints, including pests and diseases, weeds, flooding and rainfall shortage, and iron toxicity.

#### PESTS AND DISEASES

The major rice pests in Nigeria include African rice gall midges (AfrGM), stem borers, stem/leaf suckers, leaf/stem feeders, vertebrate pests, birds, and nematodes (Table C.2 in Appendix C lists the types of pests, their stages of attack, and control methods). Bacteria and fungus also cause downy mildew, bacterial blight, bacterial leaf streak, and brown rot. In Nigeria, major rice diseases are blast, leaf scald, grain discoloration, sheath blight and false smut, and rice yellow mottle virus (RYMV) (Ahonsi et al. 2000; Akpokodje, Lançon, and Erenstein 2001; Alam et al. 1986) (Table C.3 in Appendix C lists the

types of pathogens, symptoms of attack, and control methods).<sup>8</sup> Varieties resistant to pests and diseases in Asia may lose such resistance in Nigerian conditions because many of the pests and viruses are of different biotypes, given the country's diverse agroecology. Diseases such as blast can also have diverse pathogen types in tropical conditions (Rutger and MacKill 2001).

AfRGM is considered one of the most serious insect pests of lowland and irrigated rice in Africa (Ogah et al. 2012). It is distinct from the Asian rice gall midge, indigenous to Africa (Ukwungwu and Misari 1997), and was first identified by Harris and Gagné (1982). AfRGM attacks rice at the vegetative stage and destroys the growing primordial, forming a tubular gall or onion shoot. Attacked tillers are irreversibly damaged and produce no panicle (Ogah et al. 2012).

Outbreaks of AfRGM on wet-season rice crops have increased in Nigeria since the 1970s (Ukwungwu, Winslow, and John 1989; Ukwungwu and Joshi 1992a) as well as in other West African countries. In Nigeria, AfRGM had damaged over 50,000 ha, causing total yield loss in the fields worst affected (Williams et al. 1999a). Although the area damaged is relatively small compared to the total rice area in Nigeria, which currently stands at around 1.5 to 2 million ha, it has been one of the key factors affecting the performance of externally introduced varieties.

AfRGM and RYMV are not easily controlled by chemicals (Williams et al. 1999b). Screening and breeding of resistant varieties have been ways used to deal with the problems. In Asia, the similar Asian rice gall midge has been successfully treated with resistant varieties. AfRGM was serious in Ebonyi until the introduction of the Indonesian variety, *cisadane*, in the late 1990s (Maji and Fagade 2002). Though many foreign varieties break down in Nigeria due to indigenous pests and diseases, developing resistant varieties still seems the most feasible option.

Various field trials indicate that the incidence of and susceptibility to RYMV and iron toxicity may vary across varieties and locations within Nigeria. Even for the relatively newer major varieties (FARO 44, FARO 51, and FARO 52), the severity of major diseases varies significantly across locations within each of Niger, Kogi, Benue, and Nasarawa States (NCRI 2013). Even in the drier northern region (e.g., Kano), a high incidence of mottle virus has been reported (Abo, Ukwungwu, and Onasanya 2002).

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8 RYMV is specific to Africa, first discovered in Kenya in 1966 (Abo, Sy, and Alegbejo 1997). It appears to have emerged after the introduction of Asian rice (*Oryza sativa*) into Africa, although this virus is absent in Asia. RYMV can also be serious in an irrigated environment, which has induced farmers in Mali to use the resistant *kogoni* variety instead of BG 90-2 (Wopereis et al. 1999).

It is difficult to combine resistance to pests with tolerance for abiotic stress. For example, among two popular lowland varieties in Nigeria, FARO 44 (*sipi*) and FARO 52 (WITA 4), FARO 44 is resistant to AfRGM but susceptible to iron toxicity, while FARO 52 tolerates iron toxicity but is susceptible to AfRGM and RYMV. African varieties (*O. glaberrima*) are generally more resistant to biotic stresses (rice diseases, insect attacks) (Diagne et al. 2011; Evenson and Gollin 1997) but less responsive to fertilizer.

## WEEDS

Weeds are also known to be a key obstacle to crop production (Bakare 2007; Herdt 1991). In Nigeria especially, they are considered one of the greatest inhibitors to higher yield growth and quality improvements in rice (Ukwungwu and Abo 2004). Weeds compete with rice for nutrients, space, and light. They have caused rice yield losses of 28 to 100 percent in Nigeria (Imeokparia 1994; Akobundu 1987; Rodenburg and Johnson 2009). Recently, weeds have accounted for 3 to 75 percent of yield losses in lowland areas, depending on location, and 75 to 100 percent in upland areas (Ismaila et al. 2013). In the tropical environment of Nigeria, weeds can grow very rapidly compared to temperate regions.

Common weeds in the rice ecologies in Nigeria can be perennial, annual, or parasitic (Rodenburg and Johnson 2009). Quite a few of these may be indigenous in Africa. For example, the water lily (*Nymphaea lotus* L.) seems relatively absent outside Africa, and little information is available on its biological characteristics and appropriate controls. Tables C.4 and C.5 in Appendix C list the common weeds found in Nigeria's rice ecologies. If containing these weeds requires different technology packages (varieties, types of chemicals) than those transferrable from outside Nigeria, this may pose challenges in achieving the biophysical potential for rice in the short to medium term.

In Asia, where labor is somewhat cheaper, traditional weed control has been through manual weeding followed by herbicide application. However, rising farm wages may make such methods unprofitable. In addition, impacts of weed control measures depend on varieties grown. For example, herbicides can more effectively control weeds such as *Cyperus difformis* L. for FARO 15 and FARO 29 than FARO 27 (semidwarf variety) (Imeokparia, Lagoke, and Olunuga 1992).

African rice (*Oryza glaberrima*) traditionally has had greater tolerance against weeds. It has higher weed competitiveness through greater tillering ability, vigor, better exploitation of soil nutrients, and early seedling capabilities (Maji and Fagade 2002). It also has a high weed-suppressive ability. It can suppress weed growth and reduce weed seed production, and hence it can

benefit weed management in the subsequent growing season (Saito, Azoma, and Rodenburg 2010). The key challenge is to transfer such genes into higher yielding varieties from Asia. Though development of New Rice for Africa (NERICA) varieties is promising—and some NERICA lines show greater weed competitiveness than popular Asian varieties (Rodenburg and Johnson 2009)—many of the developed lines so far have lower weed-suppressive ability than traditional African varieties (Saito, Azoma, and Rodenburg 2010).

#### FLOODING AND RAINFALL SHORTAGE

Besides biotic constraints, rice production systems around the world also face major abiotic stresses. Among them, flooding can significantly affect rice production, either directly by submerging rice plots or indirectly by submerging paths (roads, etc.) to the plots and rendering them inaccessible. Rice should not be submerged for more than 48 hours (Windmeijer and Andriessie 1993). Flooding also forces farmers to choose suboptimal production timing. In Nigeria, flooding is one of the major disasters that can affect the production of rice-growing households.

Table 3.16 shows the percentage of farmers in each geopolitical zone who were affected by flooding, poor rains, and pests in 2010. Due to the small sample sizes, figures for rice-growing households in southern Nigeria are not included. Flooding might have affected significant amounts of rice production in the North East zone, where about 10 percent of rice-growing households experienced flooding (column 2). Generally, rice-growing households experienced greater incidence of flooding and poor rain compared to pests in 2010.

**TABLE 3.16** Share of farmers and rice farmers in Nigeria affected by flood, poor rain, and pests in 2010 (percent)

(1) Geopolitical zones	Rice-growing households			All farm households		
	(2) Flood	(3) Poor rain	(4) Pest	(5) Flood	(6) Poor rain	(7) Pest
North West	3 [0, 6]	1 [0, 3]	1 [0, 2]	3 [1, 4]	2 [1, 3]	1 [0, 2]
North East	11 [5, 18]	4 [0, 8]	1 [0, 4]	5 [3, 6]	3 [2, 4]	1 [0, 2]
North Central	4 [0, 9]	3 [0, 6]	0 [0, 1]	1 [0, 2]	1 [0, 3]	0 [0, 1]
South East				2 [0, 3]	1 [0, 2]	4 [3, 6]
South South				1 [0, 1]	0 [0, 0]	0 [0, 0]
South West				0 [0, 0]	2 [0, 2]	0 [0, 0]

**Source:** Authors' calculations based on Nigeria, NBS and World Bank (2011).

**Note:** Numbers in brackets are 95% confidence intervals. All figures are calculated using sample weights. The figures do not distinguish whether rice production itself was affected by these events. "Poor rain" is a term used in the LSMS-ISA (2011), which may indicate either drought or overall shortage of rainfall throughout the production season.

Deepwater varieties are found among both local African varieties and modern varieties such as FARO 15 (called “Water Proof” in Nasarawa State), which can tolerate flooding to some degree thanks to their high elongation and early maturing abilities. However, these varieties may not have high yield potential. For example, FARO 15 tends to lodge heavily if too much nitrogen is applied (Maji and Fagade 2002).

Drought and rainfall shortages can also affect rice production or its cost if they lead to additional irrigation. While the incidence of poor rainfall was less widespread than flooding, it still affected up to 4 percent of rice-producing households in the North East in 2010 (Table 3.16).

### IRON TOXICITY

Iron toxicity is also considered a major abiotic stress on lowland rice production in Africa (Singh et al. 2004). Rice suffers from iron toxicity, resulting in discoloration of leaves, if dissolved iron in the rooting medium exceeds 300–500 parts per million (ppm) or even 30 ppm if soil nutrients (potassium and phosphorus) are low (Moormann and van Breemen 1978). The condition is often associated with nutrient deficiencies in the soil. It often emerges on acid saline soil (IRRI 1982), with pH below 5 when aerobic (Moormann and van Breemen 1978). Salinity and acidity are problems of Gleysols and Fluvisols (which are two of the major lowland-type soils listed in Table C.1 in Appendix C) in the coastal fringes, and iron toxicity can also occur on these soils in inland areas. Iron toxicity has been commonly observed in inland valleys in Sri Lanka, Orissa and Kerala States in India, and West Africa (Moormann and van Breemen 1978).

But in West Africa, where bunding and leveling are still less common than in Sri Lanka and India, the severity of iron toxicity can vary greatly across locations (Moormann and van Breemen 1978). Sri Lanka has invested in developing varieties that are resistant to iron toxicity, while Nigeria has mostly relied on importing foreign varieties such as Sri Lankan BW348-1 (Singh et al. 2004), which may not always suit local production environments. Susceptibility to iron toxicity also varies across varieties. In an advance yield trial carried out at NCRI with respect to the response of different rice lines and varieties to iron toxicity and AfrGM, the average grain yield varied between 1,965 kg/ha (*suakoko 8*) to 1,336 kg/ha (*manbefuchi*) across varieties (NCRI 2008). While iron toxicity-tolerant varieties and nutrient management showed promising results on a long-term basis (Sahrawat 2004; Sahrawat et al. 1996), their adaptability as well as the management costs are not yet known in Nigeria.

## **Socioeconomic Production Constraints**

Despite Nigeria's modestly promising biophysical environment for rice production, various socioeconomic factors can prevent the wider adoption and diffusion of modern inputs and technology practices in the dominant rice-production systems. Access to markets, credit, and extension, for example, can affect this. But even more importantly, it is a case of the new technologies' viability in ensuring a positive return to the farmer given input and output prices, resource requirements, and costs (e.g., labor, land, and capital) and the effect on incomes.

In other words, what matters is the marginal productivity and return from the inputs and technologies being adopted, output prices of rice and other competing crops, and the opportunity costs or shadow prices of land, labor, and other household capital. Weak market linkages (or even market failures) for key inputs and technologies, access to capital, and insurance add to information and transaction costs that further affect rice-production decisions of the farmer.

In what follows, we review in more detail many of the socioeconomic constraints affecting the adoption and diffusion of modern rice technologies in Nigeria. The degree to which these are widely prevalent in Nigeria helps explain the low performance in yields relative to other countries in the region and other major developing regions of the world. It also implies a great potential to accelerate yield and output growth by removing many of these constraints through public interventions and institutional strengthening.

## **The Economics of Rice Production**

A farm household mobilizes and allocates its resource endowments with respect to land, labor, capital, and knowledge in order to extract the maximum benefits from these endowments. It does not have to depend on farming activities alone. For example, many Nigerian farm households are engaged in other noncrop (e.g., livestock) and nonfarm income-earning activities (Oseni and Winters 2009) that are just as important in contributing to the overall income of the household. Such activities also serve to guard against risks associated with weather shocks or seasonality in agricultural earnings.

For farmers to engage in crop production, or any other activity for that matter, the production must be economically feasible or profitable. In other words, the farmer will produce up to the point when the marginal cost of an additional input is just equal to the resulting marginal utility derived from it. Under conditions of limited access to inputs such as irrigation and fertilizer in crop production, yields must be sufficiently high to ensure a positive return. Traditional staples or subsistence crops such as cassava, maize, sorghum, and millet typically fit these criteria well, as they are able to grow under harsh

conditions of modest and unstable supplies of water and limited access to fertilizer, hired labor, or up-front cash payments.

For farmers to be induced to grow rice, its price must be high enough relative to other crops. They also need to be able to afford hiring labor for land preparation, weeding, bird scaring, and harvesting. As it is difficult to monitor the efforts of these workers, farmers must bear the risks of poor performance. Additionally, they must also be able to afford inputs such as fertilizer and agrochemicals, as these are needed more in rice production than in the production of other traditional staple crops.

Due to poor rural road infrastructure, modern inputs can be substantially pricier in rural areas than at the source, whether this involves fertilizer, certified seeds, hired labor, agrochemicals, irrigation pumps, tractors, or crop husbandry knowledge from extension agents. Similarly, the farmgate price of paddy rice can be substantially lower than consumer prices. These infrastructure-related transaction costs can be more serious for cash crops like rice than for traditional subsistence crops that do not require many modern inputs and do not need to be transported to the market.

Weak-performing markets (or even market failure) also complicate the economic structure of rice production. Credit market failures arise in rural areas due to the high cost of monitoring payments and long lending cycles inherent in agriculture. Farmers often lack enough cash at the beginning of production seasons to purchase modern inputs and to invest in technologies, even if these can bring higher returns. Although traders or moneylenders sometimes offer credit, yield returns must be substantially high so that taking out loans at high interest rates is justified.

Farmers therefore often continue cultivating traditional staple crops that do not require much up-front cash expense, rather than intensifying rice production. Credit for off-farm income-earning activities can be less constrained because of shorter lending cycles; a longer cycle can make lending for rice production relatively costly. Insurance market failures can also arise due to adverse selection, moral hazard, and the covariate nature of risks. While rice is subject to less price volatility than perishable crops thanks to its storability, poor infrastructure and subsequent lack of market integration can generally lead to high local price variation, and farmers may have more incentives to grow subsistence crops to avoid market risks.

### **Factors Constraining the Intensification of Rice Production**

Once a farmer decides to grow rice, various factors can affect the adoption and use of modern inputs and technologies and therefore the rate at which

production can be intensified and output expanded. Many economic factors, aside from prices alone, can influence such adoption behavior. For example, farm size, access to extension and on-farm trials, access to inputs and credit, productivity potential, and price risks are all relevant. However, other noneconomic factors such as those based on social and cultural considerations may also be important. Finally, because multiple technologies are often involved, interrelatedness or complementarity can affect adoption behavior.<sup>9</sup> Here we focus attention on the key factors affecting rice intensification with regard to adoption of improved rice varieties, irrigation, fertilizer, mechanization, and crop husbandry practices.

### IMPROVED RICE VARIETIES

The adoption of improved rice varieties over traditional varieties depends on the superiority of traits (high-yielding genes, responses to fertilizer and water), resistance to various stresses, price premiums, required quantities and costs of additional inputs, additional crop husbandry knowledge, farmers' wealth, and the degree of risk aversion. Traditional varieties are easily diffused and adopted. Through farmers' natural selections over centuries, the traits of many existing traditional varieties have been adapted to suit the local production environment. In addition, farmers have adapted traditional varieties to match local taste preferences. They are resistant to pests and diseases, tolerate flooding or drought, and grow relatively well without external inputs like fertilizer or irrigation. Yields are modest but certain and preferred by risk-averse farmers. Modest yields can be obtained without elaborate production practices. Varieties are readily available in the informal seed sector and much cheaper than improved varieties.

The Nigerian seed system has been weak and underdeveloped for supplying improved varieties that are substantially superior to traditional varieties. The generally weak capacity of the public seed system further raises the cost of certified seeds for farmers. The pace of varietal release may be slow (Takeshima et al. 2010). Weak infrastructure also raises the costs of disseminating information on varieties. The existence of an informal seed sector partly fills these gaps, but seed qualities (variety identities and purities) are only imperfectly controlled by sellers concerned about reputations. Certified seeds are typically distributed through the Agricultural Development Project (ADP), which is a state-level agricultural extension agency to which many farmers do not have easy access. In addition, demand for rice seeds in Nigeria

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<sup>9</sup> For interested readers, a survey of the literature on the determinants of technology adoption in developing countries can be found in Feder, Just, and Zilberman (1985).

can be seasonal (Takeshima and Nagarajan 2015), but the formal seed sector may not be flexible in adjusting the timing of seed supply.

Improved varietal development, on the other hand, has typically relied either on the international agricultural research centers—such as the International Institute of Tropical Agriculture and the Africa Rice Center—or on foreign varieties. Local national agricultural research institutes (NARIs) have mostly focused on field trials and evaluations. The NCRI has the mandate for rice research in Nigeria, with seven research stations located throughout the country.<sup>10</sup> Although some varieties are evaluated and released by other institutions, including universities, this has been rare (Takeshima 2014). The weak capacity of NARIs has constrained the development of locally adoptable varieties. Yet Nigeria was still one of only two countries conducting varietal development in West Africa at the turn of the century, along with the Republic of Guinea (Dalton and Guei 2003).

The weak NARIs and seed systems have not prevented sufficiently good varieties from finding their way to farmers. For example, the RYMV-resistant *cisadane* variety from Indonesia had been adopted by farmers in Ebonyi State even before its official release as FARO 51 (Maji and Fagade 2002). Traits of improved varieties must be substantially superior to traditional varieties to be adopted because of various market failures and weak seed systems. In the case of maize, farmers often do not buy new varieties unless they receive a marginal return of at least 100–300 percent (US\$1 in additional seed cost must return US\$2–\$4 in increased profits) (Pray 1997; Lopez-Pereira and Filippello 1994). Similar patterns may apply to rice seeds.

#### USE OF IRRIGATION, FERTILIZER, AND MECHANIZATION

Traditional varieties have often evolved resistance to water stress, and they benefit only marginally from irrigation. Improved varieties exhibit higher responses to irrigation, but this can be costly if land-leveling is insufficient. Pump-based irrigation requires substantial fuel cost for frequent water lifting compared to gravity irrigation. Affordable irrigation pumps with sufficient suction and delivery capacity are needed, unless there is access to gravity systems. Significant capital is needed to buy fuels to operate the pump frequently, as well as to buy fertilizer and herbicide. In Nigeria, substantial labor is used to smooth plot surfaces to aid water flow, in addition to labor requirements for other farm practices. Credit constraints can affect the purchase of these inputs and investments in irrigation pumps and water channel construction for river diversion.

10 Based on personal communications with NCRI staff.

Even if irrigation is feasible, rice may not be as profitable as other crops such as vegetables or sugarcane that also attract high prices in Nigeria or vegetables and maize that grow well with less irrigation water (Adeniran et al. 2010; Bello 1987). For farmers to irrigate rice, they often need to have access to highly water responsive varieties and much less costly access to water. This “tragedy of commons” is often unavoidable. If returns from irrigation are only modest, farmers may have less incentive to coordinate the water allocation or mobilize collective action for canal maintenance, further reducing irrigation returns and leading to rejection of irrigation. Low government funding for irrigation further aggravates this problem. These factors can constrain rice irrigation.

Traditional rice varieties often do not respond well to inorganic fertilizer. Historically, rice farmers in southern Nigeria maintained soil fertility through crop rotation (Welsch 1965). Improved varieties, on the other hand, respond better to fertilizer. However, fertilizer responses of existing varieties in Nigeria may be lower than newer varieties currently grown in Asia, perhaps due to the antiquity of many improved varieties. A weak extension system may also be limiting the transfer of knowledge regarding optimal fertilizer use. Fertilizer response can be optimal if the applications (dosages) are appropriate to local conditions with regard to the amount, timing, and nutrient combinations and are strictly adhered to.

Aside from fertilizer application practices, fertilizer use can be constrained by farmers’ risk aversion, liquidity constraints, and a weakly functioning fertilizer market. Fertilizer is often a risk-increasing factor; even at high fertilizer use, yield can be low in some years due to both biotic and abiotic stresses. Farmers are often averse to such risks, and unless the response is exceedingly high they may not spend much on fertilizer. Because of cash constraints, fertilizer use is often suboptimal. It is generally more expensive in Nigeria—partly due to poor road infrastructure that raises domestic transportation costs—than in developed countries (Liverpool-Tasie and Takeshima 2013).

Fertilizer markets are still relatively thin in Nigeria compared to countries such as India, especially in terms of a strong retail network. While India has about 280,000 fertilizer sales points (one in every 12 km<sup>2</sup> of land and 6 km<sup>2</sup> of arable land) (Ramani 2007), Nigeria has only about 4,000 to 10,000 (one in every 90–250 km<sup>2</sup> of land or 36–90 km<sup>2</sup> of arable land) (Liverpool-Tasie and Takeshima 2013). The market is thus imperfect and inefficient in meeting demand in a timely manner. Imperfect competition and a weak regulatory enforcement capacity induce suppliers to extract rents by selling adulterated fertilizer (Liverpool-Tasie et al. 2010). These factors raise the de facto price of fertilizer for farmers and inflate the risks for its use, further discouraging the adoption

and use of fertilizer for rice. However, this may be changing given recent reforms to deregulate the market and permit the formation of stronger retail networks.<sup>11</sup>

Finally, because rice production can be far more labor intensive than other crops, especially during land preparation and weeding, it can benefit from greater mechanization. During land preparation, the harrowing or plowing of a rice paddy field is typically done to help improve the nutrient structure of the soil and to reduce competition with weeds. If done well and combined with the use of improved varieties that are less weed competing and can take better advantage of the improved soil nutrients than traditional varieties, yield increases can be substantial.

A farmer typically will decide to mechanize these activities when yield improves from such operations, manual labor is costly, and mechanization services are available at a reasonable cost. Additionally, mechanization may also be limited if there are serious credit constraints due either to missing credit markets or high costs of credit. Availability and costs of insurance, maintenance costs, and other transaction costs may also be just as important. For example, tractors are often purchased by a few wealthy farmers with better access to low-cost credit. However, because of the difficulties in accessing credit with favorable terms in rural areas, this has often resulted in less capital investment in tractors. The exception is credit for cheaper, smaller tractors or power tillers. Using smaller tractors, however, may be less profitable if yield advantage is small, and speedy operation on larger farm plots is more practical and results in greater benefits.

Because the majority of rice plots are limited to small geographical areas that rely heavily on access to water (e.g., in the *fadama* areas), they tend to be dispersed and fragmented and to have poor road access. Providing insurance for tractors is costly in rural areas due to high monitoring cost, adverse selection, and moral hazard, further discouraging investments. All this raises the cost of supplying tractor services to farmers without some sort of government intervention to subsidize this activity, which the government is beginning to pursue. Most Nigerian farmers, therefore, do not adopt mechanization unless the yield enhancement of intensive land preparation is sufficiently high and the cost difference between manual labor and tractor services is sufficiently large.

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11 A good example is the government's new Growth Enhancement Support program, which is intended to encourage the participation of private-sector dealers in distributing subsidized fertilizer to farmers. The program utilizes electronic vouchers received by farmers through mobile phones, as an "e-waller" system. Registered farmers receive text messages alerting them that they can pick up their input package at a local redemption center operated by a private-sector agricultural input dealer.

### CROP HUSBANDRY PRACTICES

Traditional rice varieties generally grow well without sophisticated production practices. For improved varieties, optimal sequencing and timing of numerous input applications and farm activities are critical for achieving a maximum yield potential on farmers' plots. Practicing such ideal crop husbandry is challenging due to its high labor requirements. For farmers to adopt improved production practices, therefore, the returns must be substantial. The cost of diffusing such technical knowledge, through extension services, for example, can also be high due to weak communication infrastructure and geographical dispersion of farmers. As a result of these constraints, farmers' access to such knowledge is very limited.

Access to extension agents is still low in Nigeria (Omotayo, Chikwendu, and Adebayo 2001). In addition, rice varieties tend to be more susceptible to local environmental conditions compared to crops like wheat (Byerlee and Traxler 2001). Extension systems must be able to inform on the right varieties and husbandry practices that are most suitable to each location—but farmers can also learn from practice. For example, rice producers in Asia have been shown to derive some of their best practices through self-learning (Munshi 2004).

Owing to such inherent challenges for raising yields in Nigeria, as discussed earlier, yields for many improved varieties are often below their full potential. Narrowing the yield gap will take time. Until new varieties can do fairly well under suboptimal input use and production practices, farmers will continue growing those rice varieties, or even other crops, with which they are more familiar and on which they have come to rely. Extension units are also often separated from research units in Nigeria, as most extension service is provided by the ADPs that are not involved in crop research. It may be difficult to incorporate farmers' feedback into varietal development research. The participatory varietal selection method implemented alongside recent variety development (such as NERICA) is promising in that regard, but its application is limited to small geographical areas (Maji and Fagade 2002).

### Conclusion

Nigeria has the largest rice cultivation area in Africa south of the Sahara. Because of its size, rice production systems are highly diverse. Not only encompassing all three major ecologies, including upland, rainfed lowland, and irrigated land, they are also distributed across a range of latitudes. Each of these systems has distinctive characteristics, leading to different biophysical and socioeconomic potentials and constraints for yield increases.

Nigeria's overall biophysical potential for rice may not be as good as the potential in most of Asia. It is limited by the following factors: (1) Nigeria's tropical environment (low latitude) is not suitable for temperate varieties, although northern Nigeria has a relatively favorable environment where Asian varieties can be adopted; (2) the area with suitable soils for rice production is relatively small compared to Asia; (3) aridity in dry seasons is very high in most of Nigeria, possibly raising irrigation costs; and (4) some pests, diseases, and weeds are relatively unique to Nigeria, and transferring Asian rice varieties may often be difficult.

The biophysical potential for rice is better than in some tropical West African countries, given the dominance of lowland production, and is comparable to some tropical Asian countries such as Sri Lanka. However, Nigeria has yet to fully realize its biophysical potential for rice production, especially if improvements are made through greater investment in the sector. Among possible options for the public sector, the most essential will be investments to expand the irrigated rice area and development of superior-quality and high-yield varieties.

As in agriculture in general, rice production in Nigeria is largely represented by low-income, asset-poor, resource-constrained smallholder farmers. Larger and more commercialized rice farms are rare. At the same time, rural Nigeria remains underdeveloped with respect to markets, institutions, and physical infrastructure. Consequently, the adoption of modern technologies has been limited due to problems of underdeveloped input markets, competition with other crops and nonfarm income-earning activities, weak extension systems, poor access to credit and insurance provisions, high market transaction costs, and insufficient rural infrastructure more generally, all of which can affect the profitability of technology adoption (Feder, Just, and Zilberman 1985).

The next chapter provides a more in-depth empirical investigation into these socioeconomic constraints in order to explain current levels of profitability and, ultimately, the type of government interventions needed to promote paddy production and induce a supply response drawing on lessons and experiences from other major rice-producing regions in the developing world.