Indian Journal of Agronomy **59** (3): 350–358 (September 2014)

Review/Overview Article

Rice (*Oryza sativa*) cultivation in Brazil

N.K. FAGERIA[1], A.E. WANDER[2] AND S.C. SILVA[3]

National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Santo Antônio de Goiás,
Goías, Brazil, CEP 75375 000

Received : June 2014; Revised accepted : July 2014

ABSTRACT

Rice (*Oryza sativa* L.) is staple food for the population of South America, including Brazil. In Brazil, it is produced under 2 ecosystems known as upland and lowland. Furthermore, based on farm size, rice is cultivated on small, medium and large farms in Brazil. Small-and medium-farm holdings contribute 26% rice production, while large-scale farms contribute 74% of total rice production in the country. Major part of rice production is totally mechanized in Brazil. During 2012–2013 cropping season, Brazil produced about 12 million tonnes of paddy rice. Area planted under both systems is about 2.62 million ha. Average yield of upland rice is about 1.8 Mg/ha and lowland rice is about 7.0 Mg/ha. Low yield of upland rice compared to lowland rice is due to many biotic and abiotic stresses. These stresses are drought, low soil fertility, diseases, insects and weeds. Lowland rice is mainly grown in 2 southern states known as Santa Catarina and Rio Grande do Sul. Upland rice is mainly grown in the central part of Brazil, locally known as Cerrado region. Upland as well as lowland rice is planted during the rainy season which occurs from October to March. Average rainfall in the Cerrado region is about 1,500 mm and in the southern region where lowland rice is mainly planted is 1,400 mm. Average minimum and maximum air temperature in the Cerrado region during rice-growing season is about 19 and 28°C respectively. Overall, minimum and maximum air temperature during lowland rice growing season in the 2 southern states is 16 and 27°C. Brazil is the fourth largest grain producing country in the world after China, USA and India. However, it is projected that Brazil will be super-grain producing country in the world in the coming decades owing to large land area, water availability, favourable climatic conditions and availability of technology.

Key words : Cerrado region, Lowland rice, Upland rice, Climatic conditions

Rice is an important food crop for a large proportion of the world's population. It is staple food in the diet of the population of Asia, Latin America and Africa (Fageria *et al.,* 2011). Rice is cultivated on all the continents except Antarctica, over an area of more than 161 million ha (production of about 680 million metric tonnes), but most rice production takes place in Asia (Fageria, 2014). It occupies about 23% of the total area under cereal production in the world (Jagadish *et al.,* 2010). The historical importance of rice in Asia is so significant that it supported many civilizations in the river deltas of India, China, and Southeast Asia and has become deeply intertwined with the cultures in these regions (Krishan *et al.* 2011). More than 90% of rice is produced and consumed in Asia (Grewal *et al.,* 2011). During the thousands of years since its domestication, Asia rice has been cultivated under significantly diverse agro-ecosystems to meet different human demands (Xiong *et al.,* 2011). This has resulted in tremendous genetic diversity in rice around the world, as shown by different molecular tools such as the analysis of restriction fragment length polymorphism and simple sequence repeats (Zhang *et al.,* 1992). As a consequence, many rice varieties with different characteristics have arisen under natural and human selection (Vaughan *et al.,* 2007). Yan *et al.* (2010) studied genetic diversity in the USDA rice world collection and concluded that germplasm accessions obtained from the southern Asia, Southeast Asia, and Africa were highly diversified, while those from North America and western and eastern Europe had the lowest diversity.

In Latin America, including Brazil, rice is mainly eaten with common bean (*Phaseolus vulgaris* L.) everyday with all sections of society. Brazil is large country in land area and its size is about 8.5 million km^{-2}, which is about 2.6 times greater than India. Brazilian population is about 200 million people compared to 1.25 billion in India. Brazil has about 14% freshwater of the world, an important natu-

---

[2,3] **Corresponding author Email:** alcido.wander@embrapa.br, silvando.silva@embrapa.br

[1-3] National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Santo Antônio de Goiás, Goías, CEP 75375-000, Brazil

ral resource for agricultural production. Water availability and population distribution is given in Fig. 1. Looking at the land availability and favourable climatic conditions, Brazil has the largest potential of food production in the world. In the future, Brazil is projected to one of most important countris in food and fibre production worldwide. The objective of this article is to review rice production scenario and management practices adopted for rice cultivation in Brazil.

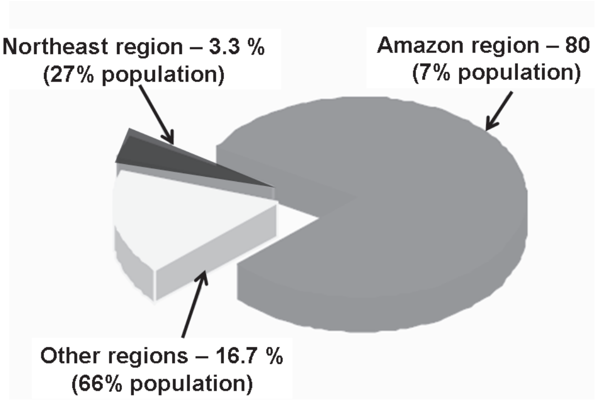

Fig. 1. Water availability in the Brazil. (*Source:* Adapted from Paz *et al.,* 2000).

Rice ecosystem in Brazil

Ecosystem is defined as crop-growing environment. Description of a crop ecosystem is important for adopting or improving production practices for higher yields. There is no true consensus on the terminology used to describe the different rice-growing systems and environments. There are 2 main ecosystems of rice cultivation in Brazil. These are known as upland rice and irrigated lowland rice. However, a small area is also under rainfed lowland rice (Table 1). Rice grown in rainfed, naturally well-drained soils, without surface water accumulation, normally without phreatic water supply, and normally not bunded is called upland or aerobic rice (Fageria, 2001). Globally, upland rice is planted on about 20 million ha about 60% in Asia, 30% in Latin America and 10% in Africa (Gupta and O´Toole, 1986). Brazil is the largest upland rice-producing country in the world. Brazilian upland rice area is about 1.18 million ha. Upland rice is distinct from lowland or irrigated rice, which is usually grown in saturated or submerged soil for a part or all of the growing season. Upland rice yield is quite low in all rice-growing regions. For example, average yield of upland rice in Brazil is quite low (»1,800 kg/ha) compared with lowland or irrigated (»7000 kg/ha) (Table 1). In Asia, upland rice yields average only about 1,000 kg/ha vs about 4,900 kg/ha for irrigated lowland rice (George *et al.,* 2002). The low yield of upland rice is associated with many biotic and abiotic stresses. Although upland rice has low yield, it will continue to be an important components of cropping systems in South America, Africa and Asia, because of its low cost of production and lack of irrigation facilities. In Brazil, when land is cleared first time for crop production, upland rice is generally planted in the first year. This is mainly due to acidity tolerance of rice and in the second year the area is used for pasture establishment.

Additionally, upland rice has high degree of drought tolerance to cope with periods of water stress that occurs in rainfed production. Breeders in Brazil and China developed locally adapted upland rice cultivars, yielding 5 to 6 Mg/ha (Wang *et al.,* 2002; Fageria, 2014) with limited water supply (600 mm of rainfall and irrigation water in northern China), resulting in almost double water-use efficiency and 50% water savings relative to conventional lowland rice (Zhao *et al.,* 2010). A study at Laos showed that under rainfed conditions, upland or aerobic rice cultivars were more responsive to N and 86% higher yielding than traditional upland rice varieties across 6 sites and three N levels (Saito *et al.,* 2007; Zhao *et al.,* 2010). Atlin *et al.*, (2006) reported that in Asia upland rice cultivars give yield of about 5 Mg/ha when environmental conditions are favourable.

Irrigated or flooded rice is defined as rice cultivated on relatively flat lands with water control, so that rice is flooded for all or part of the growing season (Fageria *et al.,* 2003). Irrigated lowland rice system accounts for about 57% of the worlds harvested rice area and contributes about 76% of global rice production (Fageria, 2003; Fageria *et al.,* 2003; Zhao *et al.,* 2010; Mohapatra *et al.,* 2011). In Brazil, irrigated rice is planted on area of about 1.42 million ha and average yield is about 7 Mg/ha.

The presence of floodwater for part or all of the grow-

Table 1. Rice production (paddy), area, and yield in Brazil under different ecosystems. (Averages of 3 years data 2010–12).

Variable	Irrigated (lowland)	Rainfed (lowland)	Upland (rainfed)	Total
Production (million metric tonnes)	9.90	0.05	2.14	12.09
Area planted (million ha)	1.42	0.02	1.18	2.62
Yield (Mg/ha)	7.00	3.43	1.80	4.63

Source: Brazilian Institute of Geography and Statistics (IBGE). 2014.

ing season requires that the rice root-system is adapted to largely anaerobic soil conditions. The rice plant has adapted to this environment by transporting oxygen from the aerial portions of the plant to the root-system via aerenchyma tissues (Yoshida, 1981; Fageria *et al.*, 2006; Fageria and Moreira, 2011; Fageria, 2013). A secondary adaptive mechanism is the development of an extensive lateral, fibrous root-system located in the surface 1 to 2 mm of oxidized soil at the soil-water interface. Oxygen diffusing through the water layer allows this zone of soil to remain oxidized. For these reasons, flooded rice normally has a shallow, fibrous root-system (Wells *et al.,* 1993). The aquatic environment not only influences the development of the root-system, but also alters the availability of several essential nutrients, affects nutrient uptake and use efficiency, fertilization practices, and makes rice especially unique among crop-production systems. Rice is probably the world's most diverse crop and also is probably the world's most versatile crop. Rice undoubtedly evolved very high levels of adaptability to various ecological habitats, most of which are characterized by their unique hydrological states (Nguyen *et al.,* 1997). It is cultivated at more than 3,000 m elevation in the Himalayas and at sea level in the deltas of the great rivers of Asia (Santos *et al.,* 2003). Floating cultivars grow in water as deep as 5 m in Thailand, in Brazil rice is grown as dryland crop much like wheat [*Triiticum aestivum* (L.) emend. Fiori & Paol.] or corn (*Zea mays* L.). In West Africa, rice is grown in mangrove swamps (Santos *et al.,* 2003). Rice is grown in both dryland and wetland conditions and over a wide range of latitudes (Fageria, 2001). For example, rice is grown in north-eastern China at 53° North latitude, in central Sumatra on the Equator, and in New South Wales, Australia, at 35° South latitude (Mae, 1997). Bouman *et al.* (2007) reported that the irrigated and the rainfed rice ecosystem, which forms the major mainstay of food security in Asia, has been highly sustainable with the environment having few adverse impacts.

Lowland or flooded rice production is being threatened by growing water shortage worldwide (Tuong and Bouman, 2003). By 2025, physical water scarcity is projected for more than 2 million ha of dry season lowland rice and 13 million ha of wet season lowland rice in Asia and an economic water scarcity is expected to hamper most of Asia's 22 million ha of dry season lowland rice (Tuong and Bouman, 2003; Zhao *et al.,* 2010). Under these situations, cultivation of upland or aerobic rice is a promising strategy to have water resources and maintain rice production (Zhao *et al.,* 2010; Fageria, 2014).

Climatic conditions in the rice-growing regions of Brazil

Climatic is an important factor in crop production and important components of climate which determines crop productivity are temperature, precipitation and solar radiation. Data of air temperature and precipitation in the upland rice-growing central part or Cerrado region of Brazil are presented in the Table 2 and Table 3. Similarly, temperature and precipitation data of 3 years in the lowland rice-producing 2 states, viz. Rio Grande do Sul and Santa Catarina, are presented in Tables 4–7. Overall, average temperature is slightly lower in the lowland rice-growing southern states compared to central part where upland rice is mainly grown. Precipitation in lowland rice-growing 2 states is also lower compared to upland rice-growing region.

Soil types of rice-growing regions of Brazil

In the central part of Brazil locally known as Cerrado region (Fig. 2), major part of the soils are classified as Oxisols and Ultisols. Oxisols are intensely weathered soils

Table 2. Minimum and maximum temperatures (°C) in the Cerrado region central part of Brazil. (Data were taken from the record of Meteorological Station of National Rice and Bean Research Centre, Santo Antônio de Goiás, state of Goias, Brazil)

Month	2011		2012		2013		Average	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
January	19.4	27.5	18.7	26.4	19.6	27.7	19.2	27.2
February	19.2	28.5	18.3	28.2	18.9	29.4	18.8	28.7
March	19.5	27.3	18.7	29.4	19.9	28.8	19.4	28.5
April	18.4	29.2	18.9	29.6	18.3	28.0	18.5	28.9
May	16.0	28.0	16.4	27.2	16.7	28.4	16.4	27.9
June	14.9	27.4	16.7	28.1	16.9	27.6	16.1	27.7
July	15.1	28.6	15.0	28.3	14.6	27.9	14.9	28.3
August	17.2	31.4	16.2	28.4	14.5	28.6	16.0	29.5
September	18.8	32.2	18.9	32.0	18.1	29.8	18.6	31.3
October	18.9	28.5	19.9	32.5	19.4	29.0	19.4	30.0
November	18.7	27.5	20.2	28.3	19.0	28.5	19.3	28.1
December	19.3	27.0	19.7	29.6	18.9	26.9	19.3	27.8

Table 3. Precipitation (mm) in the Cerrado region central part of Brazil. (Data were taken from the record of Meteorological Station of National Rice and Bean Research Centre, Santo Antônio de Goias, state of Goias, Brazil)

Month	2011	2012	2013	Average
January	208.4	338.2	380.0	308.9
February	260.0	310.8	229.6	266.8
March	339.2	163.0	257.0	253.1
April	49.0	54.0	112.2	71.7
May	0.8	15.6	74.0	30.1
June	17.8	13.2	20.4	17.1
July	0.4	5.2	0.0	1.9
August	0.0	0.0	3.2	1.1
September	0.4	109.6	2.4	37.5
October	290.6	51.6	92.0	144.7
November	195.2	183.4	218.6	199.1
December	200.4	212.6	354.4	255.8
Total	1562.2	1457.2	1743.8	1587.7

Fig. 2. Geographical map of Brazil showing Cerrado region with yellow boundary where upland rice is mainly planted and 2 states Santa Catarina and Rio Grande do Sul where major part of lowland rice is produced

of tropical and subtropical environments. They are dominated by low-activity minerals such as quartz, kaolinite and iron oxides. They tend to have indistinct horizons. Oxisols, characteristically occur on land surfaces that have been stable for a long time. They have low natural fertility as well as a low capacity to retain additions of lime and fertilizer (Fageria, 2014). Similarly, Ultisols are strongly leached soils with a subsurface zone of clay accumulation and <35% base saturation. These soils are found in humid areas. They formed from fairly intense weathering and leaching processes that result in a clay-enriched subsoil dominated by minerals, such as quartz, kaolinite, and iron oxides (Fageria, 2014).

In Brazil, there are about 35 million ha of poorly-drained soils, known locally as ‘Varzea’, distributed throughout the country. At present about less than 3 million ha of these soils are cultivated, primarily to lowland rice, during the rainy season. Generally, Varzea soils have good initial soil fertility, but after 2 to 3 years of cultivation, the fertility level is known to decline. Farming systems need to be developed with improved soil-management technology to bring these areas under successful crop production. A sufficient supply of nutrients is one of the key factors required to improve crop yields and maintain sustainable agricultural production on these soils. Flood-irrigated rice is an important crop that needs to be included in the cropping system of these poorly-drained areas during the rainy seasons. During dry periods, other crops can be planted in rotation, provided there is a proper drainage. These soils generally have an adequate natural water supply throughout year, but are acidic and require routine applications of lime if legumes are grown in rotation with rice. In the future, these soils may be largest land area for lowland rice production in the world. Chemical properties of upland and lowland rice grown soils are presented in Table 8.

Rice crop-management practices

Crop-management practices adopted in rice cultivation in Brazil are related to improvement in soil quality and crop growth with the objective to maximizing crop yield. These practices are liming, use of adequate plant density and spacing, fertilization, control of weeds, insects and diseases, water management, crop rotation and harvesting at appropriate moisture content in the grains.

Liming

Modern agriculture production requires the implementation of efficient, sustainable, and environmentally-sound management practices. Rice is mostly grown on acid soils in Brazil. In addition, rice is an important component of crop rotation with soybean, dry bean and corn. These crops require higher pH and Ca and Mg for maximizing yields in acid soils (Fageria, 2009). In this context, liming is an important practice to achieve optimum yields of all crops grown on Brazilian acid soils. Liming is the most widely used long-term method of soil-acidity amelioration, and its success is well documented (Fageria and Baligar, 2008). Application of lime at an appropriate rate brings several chemical and biological changes in the soil, which is beneficial or helpful in improving crop yields on acid

Table 4. Minimum and maximum temperatures (ºC) in the state of Rio Grande do Sul of Brazil where maximum lowland rice is produced. (Data were taken from the record of Meteorological Station of Temperate Climate Research Centre, Pelotas, state of Rio Grande do Sul, Brazil)

Month	2011		2012		2013		Average	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
January	21.0	30.0	17.9	284	17.5	27.5	18.8	28.6
February	19.9	28.7	20.2	29.8	19.1	28.0	19.7	28.8
March	17.2	26.8	16.6	28.1	15.2	27.3	16.3	27.4
April	14.1	24.7	12.8	23.7	13.8	24.5	13.6	24.3
May	11.1	21.0	12.2	23.9	10.5	20.6	11.3	21.8
June	8.7	17.7	7.3	19.5	8.0	18.4	8.0	18.5
July	7.6	16.2	5.6	16.8	7.2	17.8	6.8	16.9
August	9.2	17.0	12.6	22.9	6.9	16.7	9.6	18.9
September	10.1	20.0	12.3	21.3	6.9	17.0	9.8	19.4
October	13.5	22.1	15.9	23.7	13.5	22.1	14.3	22.6
November	15.1	25.3	16.6	27.0	16.9	24.9	16.2	25.7
December	16.2	26.0	18.7	29.3	18.9	29.2	17.9	28.2

Table 5. Precipitation (mm) in the state of Rio Grande do Sul, Brazil where maximum lowland rice is produced. (Data were taken from the record of Meteorological Station of Temperate Climate Research Centre, Pelotas, state of Rio Grande do Sul, Brazil)

Month	2011	2012	2013	Average
January	71.2	73.6	69.2	71.3
February	90.9	171.9	177.3	146.7
March	144.4	49.0	27.6	73.7
April	111.5	52.4	147.4	103.8
May	118.3	5.1	84.1	69.2
June	116.2	78.0	75.8	90.0
July	70.8	137.9	56.6	88.4
August	114.2	103.1	95.3	104.2
September	75.1	115.3	95.3	95.2
October	75.9	106.5	214.0	132.1
November	60.3	52.1	136.3	82.9
December	53.7	175.1	78.4	102.4
Total	1102.5	1.120.0	1257.3	1159.9

soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn and H, improves soil structure (aeration), availabilities of Ca, P, Mo, Mg, pH, and N_2 fixation.

Use of adequate lime rate to correct soil acidity and production of maximum yield of a crop species is an important consideration for economic and ecological reasons. Quantity of liming material required is determined on the basis of soil pH, base saturation and aluminum saturation adjustment at appropriate levels. Appropriate levels of these acidity indices vary with soil type, soil fertility, plant species and crop genotypes within species (Fageria and Baligar, 2008). In addition, crop-response curves related to lime rate and yield is another criterion, that can be used to define lime requirement for any given crop species. Crop-response curves to lime levels should be determined for each crop species under different agroecological regions to make liming recommendations effective and economical.

Table 6. Minimum and maximum temperatures (ºC) in the state of Santa Catarina of Brazil where maximum lowland rice is produced. (Data were taken from the record of Meteorological Station of National Institute of Meteorology, Itajaí, state of Santa Catarina, Brazil)

Month	2011		2012		2013		Average	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
January	22.6	29.6	20.3	28.2	20.0	28.0	21.0	28.6
February	21.9	28.4	22.0	30.7	21.4	29.4	21.8	29.5
March	20.0	26.3	19.3	29.2	20.1	27.1	19.8	27.5
April	17.8	27.1	18.0	25.8	16.8	26.2	17.5	26.4
May	15.2	23.7	15.2	24.2	14.7	23.2	15.0	23.7
June	12.0	20.3	13.9	21.0	14.9	21.3	13.6	20.9
July	12.4	19.8	12.1	20.4	11.3	19.7	11.9	20.0
August	13.7	20.2	16.0	22.5	12.1	20.6	13.9	21.1
September	12.9	21.7	15.7	24.0	15.0	23.4	14.5	23.0
October	17.4	24.1	18.4	25.3	16.9	24.2	17.6	24.5
November	17.6	25.4	19.0	26.7	18.8	26.4	18.5	26.2
December	19.0	27.7	22.0	29.2	21.0	29.2	20.7	28.7

Table 7. Precipitation (mm) in the state of Santa Catarina, Brazil where maximum lowland rice is produced. (Data were taken from the record of Meteorological Station of National Institute of Meteorology, Itajaí, Brazil)

Month	2011	2012	2013	Average
January	341.0	154.2	54.4	183.2
February	281.5	60.6	119.4	153.8
March	183.4	38.2	289.6	170.4
April	99.0	161.8	232.6	164.5
May	57.4	50.2	82.0	63.2
June	97.3	151.2	139.8	129.4
July	167.4	128.6	150.2	148.7
August	300.4	34.0	109.4	147.9
September	187.0	29.0	142.2	119.4
October	99.8	89.8	117.2	102.3
November	81.2	31.6	47.2	53.3
December	106.2	64.4	97.8	89.5
Total	2.001.6	993.6	1.581.8	1.525.7

Table 8. Selected chemical properties of Cerrado (upland rice) and Varzea (lowland rice) soils of Brazil (0–20 cm depth).

Soil property	Cerrado[1]	Varzea[2]
pH in H_2O	5.2	5.3
Ca (cmol$_c$/kg)	0.64	4.9
Mg (cmol$_c$/kg)	0.58	3.1
Al (cmol$_c$/kg)	0.64	1.3
P (mg /kg)	1.2	16
K (mg/kg)	47.2	92.0
Cu (mg /kg)	1.3	2.2
Zn (mg/kg)	1.0	2.4
Fe (mg /kg)	116	303
Mn (mg/kg)	14	59
OM (g/kg)	15	31
Base saturation (%)	17	50

[1] The data are average values of 200 soil samples collected from 6 states covering the Cerrado region; and [2] the data are average values of 55 soil samples collected from 8 states covering the Varzea soils. *Source*: Fageria and Stone (1999)

In Brazil, lime rate is determined on the basis of Ca, Mg and Al contents and base saturation and following equations are used (Fageria and Baligar, 2008);

$$\text{Lime rate (Mg/ha)} = (2 \times \text{Al}) + [2\text{-}(\text{Ca} + \text{Mg})$$

where Ca, Mg, and Al are in cmol$_c$/kg soil.

Base saturation is another important chemical property of soils used as a criterion for liming recommendations. Base saturation is defined as the proportion of the cation-exchange capacity (CEC) occupied by exchangeable bases. It is calculated as follows (Fageria, 2008):

$$\text{Base saturation (\%)} = \text{“(Ca, Mg, K, Na)/CEC X 100}$$

where, CEC is sum of Ca, Mg, K, Na, H, and Al expressed in cmol$_c$/kg

In Brazil, Na^+ is generally not determined because of a very low level of this element in Brazilian Oxisols. Hence, Na is not considered in calculation CEC or base saturation. For crop production, base saturation levels in soil may be grouped into very low (lower than 25%), low (25 to 50%), medium (50 to 75%), and high (> 75%) (Fageria and Baligar, 2008). Very low and low base saturation means a predominance of adsorbed hydrogen and aluminum on the exchange complex. Deficiencies of calcium, magnesium, and potassium are likely to occur in soils with low CEC and very low to low per cent base saturation. Quantity of lime required by base saturation method is calculated by using the following formula (Fageria *et al.,* 1990):

$$\text{Lime rate (Mg/ha)} = [\text{CEC } (B_2 - B_1)/\text{TRNP}] \times \text{df}$$

where CEC = cation-exchange capacity or total exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, $H^+ + Al^{3+}$) in cmol$_c$/kg, B_2 = desired optimum base saturation, B_1 = existing base saturation, TRNP = total relative neutralizing power of liming material, and df = depth factor, 1 for 20 cm depth and 1.5 for 30 cm depth. For Brazilian Oxisols, the desired optimum base saturation for most of cereals is in the range of 50–60%, and for legumes it is in the range of 60–70% (Fageria *et al.,* 1990).

Use of adequate plant spacing and plant density

Use of adequate plant spacing and plant density is an important cultural practice in crop production, because it does not cost extra to the farmers. Plant spacing used for planting upland rice is 30 cm between rows and 17 cm for lowland irrigated rice in Brazil. The seed rate for upland rice is about 60–70 kg/ha and lowland rice 110–120 kg/ha to produce adequate plant number per unit area. Sowing depth lower than 3 cm and seed treatment with fungicides are important practices for the establishment of an adequate plant density, especially in irrigated rice.

Fertilization

Fertilizer recommendations for mobile nutrient like N are based on results of field trial and immobile nutrients such as P and K are based on soil-test analysis. Nitrogen recommendations for upland rice are about 100 kg N/ha to obtain a grain yield of about 5,000 kg/ha (Fig. 3). Similarly, for lowland rice, N recommendations are about 140 kg N/ha to obtain a grain yield of more than 7,000 kg/ha (Fig. 4). Half of the N is applied at sowing and remaining half is top-dressed at active tillering growth stage in both upland and lowland rice. In some cases, N is also applied at 3 times during the crop growth, i.e. one-third at sowing, one-third at active tillering growth stage and one-third at

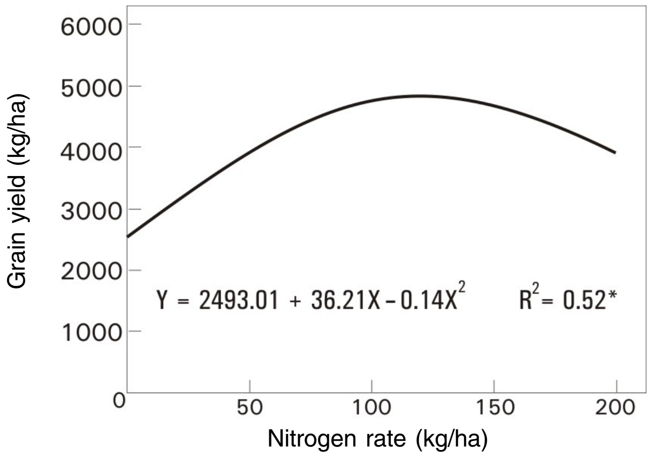

Fig. 3. Relationship between nitrogen rate and grain yield of upland rice. (Values are averages of 2 years field experiments and 12 genotypes).

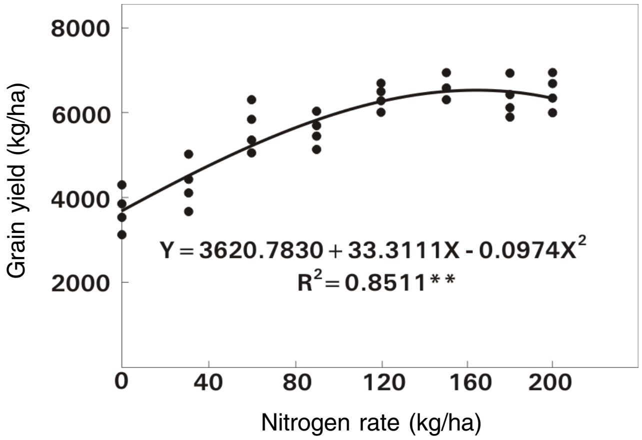

Fig. 4. Relationship between nitrogen rate and grain yield of lowland rice. (Values are averages of 2 years field experiments and 12 genotypes)

Table 10. Potassium fertilization recommendations for upland and lowland rice production in Brazil.

Soil K test (mg/kg)[1]	Interpretation	Upland rice (K_2O/ha)	Lowland rice (K_2O/ha)
0–25	Very low	100	120
25–50	Low	80	100
50–100	Medium	60	80
>100	High	40	60

[1] Upland and lowland rice. Potassium was extracted by Mehlich 1 extraction solution (0.05 M HCl + 0.0125 M H_2SO_4)

maximum tillering growth stage (Fageria and Baligra, 2005). These N recommendations are more common when organic matter content of the soil is < 3%. Phosphorus and potassium recommendations are based on soil-test results, especially by medium-and large-farm holders (Tables 9, 10). In upland rice zinc deficiency is frequently observed and a rate of 5 kg Zn/ha is recommended to overcome Zn deficiency at sowing (Fageria *et al.,* 2003; Fageria, 2014).

Water management in irrigated or lowland rice

Water management is key issue in irrigated rice to obtain the maximum economic yield. Crop should be flooded when rice plants had 3 to 4 fully developed leaves. At this stage, rice plants have sufficient height to stand a water depth of about 5 to 10 cm. This water depth should be maintained throughout the crop-growth cycle and drained about 1 week before harvesting. The irrigation applied at this stage may also help in controlling weeds which are not controlled by herbicides and also control diseases and insects. Results obtained in the state of Rio Grande do Sul showed that for every 10 days of irrigation delay, the growth of plants is adversely affected and there is a loss of about 1.0 metric tonnes/ha in grain yield ((Menezes *et al.,* 2013).

Crop rotation

Crop rotation is an important management practice in crop production because it reduces biotic and abiotic stresses and improve soil quality. In Brazil, rice is mainly rotated with soybean, dry bean and corn. Upland rice cultivation in monoculture significantly reduced upland rice in the Cerrado region of Brazil due to allelopathic effects (Fageria *et al.,* 2008). Allelopathic effects is significantly reduced when rice is planted in rotation with soybean, dry bean and corn (Fageria and Baligar, 2003).

Table 9. Phosphorus fertilizer recommendations for upland and lowland rice production in Brazil.

Soil P test[1] (mg/kg)	Interpretation	P_2O_5/ha	Soil P test[2] (mg/kg)	Interpretation	P_2O_5/ha
0–3.0	Very low	100	0–3.0	0–3.0	120
3.1–6.0	Low	80	3.1–6.4	3.1–6.0	100
6.1–9 0	Medium	60	6.4–12.0	6.1–9 0	80
>9.0	High	40	> 12.0	> 9.0	60

[1] Upland rice and [2] lowland rice. Phosphorus was extracted by Mehlich 1 extraction solution (0.05 **M** HCl + 0.0125 **M** H_2SO_4).

Table 11. Classification of rice farms on land area basis in Brazil.

Farm type	Number of farms	% of total	Share in production (%)
Small-scale farms (<50ha)	354,677	89.5	6
Medium-scale farms (50-200ha)	33,024	8.3	20
Large-scale farms (>200 ha)	8,688	2.2	74
Total	396,389	100	100

Source: Brazilian Institute of Geography and Statistics (IBGE). 2006

Table 12. Rice harvesting methods in Brazil.

Farm type	Number of farms	% of total	Share in production (%)
Totally mechanized (combines)	25,427	6	76
Partially mechanized (harvesting by hand and threshing with stationary threshers)	7,327	2	2
Harvesting by hand and threshing by hand	363,874	92	22
Total	396,628	100	100

Source: Source: Brazilian Institute of Geography and Statistics (IBGE). 2006

Control of weeds, diseases and insects

Control of weeds, diseases and insects are fundamental to obtain higher grain yield of both upland and lowland rice. Weeds are controlled by use of herbicides, especially on medium and large farms. Similarly, diseases and insects are also controlled by use of fungicides and insecticides on these farm holdings. Weeds on small holdings are manually controlled and these farmers do not use fungicides and insecticides to control diseases and insects. Diseases and insects pressure in the irrigated rice of the state of Rio Grande do Sul and Santa Catarina is much lower than tropical rice of central part of Brazil owing to sub-tropical climate of these 2 states.

Harvesting

Upland as well as lowland rice are harvested when moisture content of the grains are about 22%. Harvesting is totally mechanized on large-scale farms (>200 ha) and partially mechanized on medium farms (50–200 ha) and on small-scale farms harvesting as well as threshing is done manually (Tables 11, 12).

CONCLUSION

Brazil has the largest potential of increasing grain production, including rice, in the world owing to land, water, favourable climatic conditions and availability of technology. It has about 35 million ha of lowland which is located near lakes, rivers and water streams. At present, less than 3 million ha of this land is under cultivation, mainly as lowland rice. During the rainy season, rice is potential crop to be planted in this area but during dry period other crops like soybean, corn, dry bean, wheat, barley, vegetables and forages can be grown successfully. At present, Brazil is producing about 200 million metric tonnes of foodgrain, including about 90 million metric tonnes soybean, largest soybean-producing country in the world. Brazil produced about 12 million metric tonnes of rice, which is sufficient to feed its population. It is assumed that in coming 10 years, Brazil will be one third largest grain-producing country in the world after China and USA. Genetic improvement of modern cultivars and development of related cultivation practices will be the driving forces behind the impressive growth in grain production including rice.

REFERENCES

Atlin, G.N., Lafitte, H.R., Tao, D., Laza, M., Amante, M. and Courtois, B. 2006. Developing rice cultivars for high-fertility upland rice systems in the Asian tropics. *Field Crops Research* **97**: 43–52.

Bouman, B.A.M., Humphreys, E., Tuong, T.P. and Barker, R. 2007. Rice and water. *Advances in Agronomy* **92**: 187–37.

Brazilian Institute of Geography and Statistics (IBGE). 2006. Agricultural Census 2006. Available at: <*http://www.sidra.ibge.gov.br*>. Access on: 17 March, 2014.

Brazilian Institute of Geography and Statistics (IBGE). 2014. Municipality Agricultural Research Available at: <*http://www.sidra.ibge.gov.br*>. Access on: 17 March, 2014.

Fageria, N.K. 2001. Nutrient management for improving upland rice productivity and sustainability. *Communications in Soil Science and Plant Analysis* **32**: 2603–29.

Fageria, N.K. 2003. Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. *Communications in Soil Science and Plant Analysis* **34**: 259–70.

Fageria, N.K. 2008. Optimum soil acidity indices for dry bean production on an Oxisols in no-tillage system. *Communications in Soil Science and Plant Analysis* **39**: 845–57.

Fageria, N.K. 2009. *The Use of Nutrients in Crop Plants*. CRC

Press, Boca Raton, Florida.

Fageria, N.K. 2013. *The Role of Plant Roots in Crop Production*. CRC Press, Boca Raton, Florida.

Fageria, N.K. 2014. *Mineral Nutrition of Rice*. CRC Press, Boca Raton, Florida.

Fageria, N.K. and Baligar, V.C. 2003. Upland rice and allelopathy. *Communications in Soil Science and Plant Analysis* **34**: 1311–29.

Fageria, N.K. and Baligar, V.C. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy* **88**: 97–185.

Fageria, N.K. and Baligar, V.C. 2008. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy* **99**: 345–99.

Fageria, N.K., Baligar, V.C. and Clark, R.B. 2006. *Physiology of Crop Production*. The Haworth Press, New York.

Fageria, N.K., Baligar, V.C. and Edwards, D.G.1990. Soil-plant nutrient relationships at low pH stress. (In:) *Crops as Enhancers of Nutrient Use*, pp. 475–07. Academic Press, New York.

Fageria, N.K., Baligar, V.C. and Jones, C.A. 2011. *Growth and Mineral Nutrition of Field Crops*, 3rd edn 3, CRC Press, Boca Raton, Florida.

Fageria, N.K. Barbosa Filho, M.P. and Guimares, C.M. 2008. Allelopathy in upland rice in Brazil. *Allelopathy Journal* **22**: 289–98.

Fageria, N.K. and Moreira, A. 2011. The role of mineral nutrition on root growth of crop plants. *Advances in Agronomy* **110**: 251–31.

Fageria, N.K., Slaton, N.A. and Baligar, V.C. 2003. Nutrient management for improving lowland rice productivity and sustainability. *Advances in Agronomy* **80**: 63–152.

Fageria, N.K. and Stone, L.F. 1999. Acidity management of Cerrado and Varzea soils of Brazil. EMBRAPA Rice & Bean Research Centre, Document No. 92, Santo Antônio de Goias, Brazil.

George, T., Dennis, R.M., Garrity, P., Tubana, B.S. and Quiton, J. 2002. Rapid yield loss of rice cropped successively in aerobic soil. *Agronomy Journal* **94**: 981–89.

Grewal, D., Manito, C. and Bartolome, V. 2011. Doubled haploids generated through another culture from crosses of elite indica and japonica cultivars and/or lines of rice: Large-scale production, agronomic performance, and molecular characterization. *Crop Science* **51**: 2544–53.

Gupta, P.C. and O‘ Toole, J.C. 1986. *Upland Rice: A Global Perspective*. International Rice Research Institute, Los Baños, Philippines.

Jagadish, S.V.K., Cairns, J., Lafitte, R., Wheeler, T.R., Price, A.H. and Craufurd, P.Q. 2010. Genetic analysis of heat tolerance at anthesis in rice. *Crop Science* **50**: 1633–41.

Krishnan, P., Ramakrishnan, B., Reddy, K.R. and Reddy, V.R. 2011. High-temperature effects on rice growth, yield, and grain quality. *Advances in Agronomy* **111**: 87–206.

Mae, T. 1997. Physiological nitrogen efficiency in rice: Nitrogen utilization, photosynthesis, and yield potential. *Plant Soil* **196**: 201–10.

Menezes, V.G., Anghinoni, I., Silva, P.R.F., Petry, V.R.M.C.C., Grohs, D.S., Freitas, T.F.S. and Valente, L.A.L. 2013. Project 10-Management strategies to increase productivity and sustainability of irrigated rice fields growth in the state of Rio Grande do Sul, Brazil: A developments and new challenges. Porto Alegre, Brazil: IRGA/Estação Experimental do Arroz.

Mohapatra, P., Panigrahi, R. and Turner, N.C. 2011. Physiology of spikelet development on the rice panicles: Is manipulation of apical dominance crucial for grain yield important? *Advances in Agronomy* **110:** 333–59.

Nguyen, H.T., Babu, R.C. and Blum, A. 1997. Breeding for drought resistance in rice: Physiology and molecular genetics considerations. *Crop Science* **37**: 1426–34.

Paz, V.P.S., Teodoro, R.E.F. and Mendoça, F.C. 2000. Water resources, irrigated agriculture and the environment. *Rev. Bras. Eng. Agric. Ambien*. **4**: 465–73.

Saito, K., Atlin, G.N., Linquist, B., Phanthaboon, K., Shiraiwa, T. and Horie, T. 2007. Performance of traditional and improved upland rice cultivars under nonfertilized and fertilized conditions in northern Laos. *Crop Science* **47**: 2473–81.

Santos, A.B., Fageria, N.K. and Prabhu, A.S. 2003. Rice ratooning management practices for higher yields. *Communications in Soil Science and Plant Analysis* **34**: 881–18.

Tuong, T.P. and Bouman, B.A.M. 2003. Rice production in water-scarce environments. (In:) *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, pp. 53–67, Kijne, J.W., Barker, R. and Molden, D. (Eds). CABI Publishing, Wallingford, UK.

Vaughan, D.A., Balazs, E. and Heslop-Harrison, J.S. 2007. From crop domestication to super-domestication. *Annals of Botany* **100**: 893–01.

Wang, H.Q., Bouman, B.A.M., Zhao, D.L., Wang, C. and Moya, P.F. 2002. Aerobic rice in northern China: Opportunities and challenges. (In:) *Proceedings of the International Workshop on Water-Wise Rice Production*, pp. 143–54. Bouman, B.A.M., Hengsdijk, H., Hardy, B., Binraban, P.S., Tuong, T.P. and Ladha, J.K. (Eds.) IRRI, Los Baños, Philippines.

Wells, B.R., Huey, B.A., Norman, R.J. and Helms, R.S. 1993. Rice. (In:) *Nutrient Deficiencies and Toxicities in Crop Plants*, pp. 15–19. Bennett, W.F. The American Phytopathological Society, St. Paul, Mennesota.

Xiong, Z.Y., Zhang, S.J., Ford-Lloyd, B.V., Jin, X., Wu, Y., Yan, H.X., Liu, P., Yang, X. and Lu, B.R. 2011. Latitudinal distribution and differentiation of rice germplasm: Its implication in breeding. *Crop Science* **51**: 1050–58.

Yan, W.G., Agrama, H., Jia, M., Fjellstrom, R. and McClung, A. 2010. Geographic description of genetic diversity and relationships in the USDA rice world collection. *Crop Science* **50**: 2406–17.

Yoshida, S. 1981. *Fundamentals of Rice Crop Science*. International Rice Research Institute, Los Bãnos, Philippines.

Zhang, Q.F., Saghai-Maroof, M.A., Lu, T.Y. and Shen, B.Z. 1992. Genetic diversity and differentiation of *indica*and *japonica* rice detected by RFLP analysis. *Theoretical Applied Genetics* **83**: 495–99.

Zhao, D.L., Atlin, G.N., Amante, M., Cruz, T.S., and Kumar, A. 2010. Developing aerobic rice cultivars for water-short irrigated and drought-prone rainfed areas in the tropics. *Crop Science* **50**: 2268–76.