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REVIEW

Developing fertilizer recommendations for rice in Sub-Saharan Africa, achievements and opportunities

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Abstract
Improving agricultural productivity to keep pace with the fast-growing food demand is a huge challenge for sub-Saharan Africa (SSA). Fertilizer is a powerful productivity-enhancing input; nevertheless, farmers of SSA use only 5–9 kg ha^{-1} of fertilizer, which is ten times lesser than Latin America and Asia (50 and 80 kg ha^{-1}, respectively). Rice (*Oryza sativa*) is one of the most important food crops of SSA, and its consumption is growing faster than any other commodity in Africa. Rice-based systems have high potential for improving food production through an efficient management of fertilizers. The biophysical environment, cropping systems and socio-economic status of farmers including market opportunities are the main factors for developing appropriate fertilizer recommendations. Many research efforts have been invested in different countries to develop fertilizer recommendation for rice. However, the diversity of rice ecologies, the type and the cost of fertilizers available on local market are the main constraints for development of blanket recommendations of fertilizer usually applied in many countries. Here, we make a reviews of the progress made on the development of fertilizer recommendations for rice-based systems in SSA. The utilization of the new concepts and decisions support tools for development of fertilizer recommendation and the main achievements and weakness are discussed. The opportunities offered by the new concepts, modeling and decision support tools are discussed in a regional strategic approach for better management of fertilizers in the diversified ecologies of rice-based systems.

Keywords Nutrient · Fertilizer · Soil · Rice ecologies · Modeling · Decision support tools

Introduction

To keep pace with the fast-growing food demand, countries of sub-Saharan Africa (SSA) must improve their agricultural productivity. Fertilizer is a powerful productivity-enhancing input, yet SSA uses very less quantity of fertilizers compared to the rest of the world. From 1970 to 2000, SSA applied 5–9 kg ha^{-1} of fertilizer, while Latin America and Asia applied 50 and 80 kg ha^{-1} of fertilizer, respectively (Yanggen et al. 1998).

Rice (*Oryza sativa*) is one of the most important food crops of the developing world and the staple food of more than half of the world's population. Rice consumption is growing faster than the consumption of any other commodity in Africa. From 1961 to 2006, rice production grew at 3.23%, while the consumption increased by 4.52% (Diagne et al. 2012; Seck et al. 2012), indicating the widening gap between supply and demand. Rice is the leading source of nutrition and all member countries of the Economic Community of West African States (ECOWAS) are net rice importers (Seck et al. 2010; Fiamohe et al. 2012). Regarding the importance and opportunities of rice production in Africa, many initiatives have been developed involving multiple stakeholders. Coalition for Africa Rice Development (CARD) is an initiative with an overall strategy and framework to respond to the increasing demand for rice. This initiative is jointly proposed by the Alliance for a Green Revolution in Africa (AGRA) and the Japan International Cooperation Agency (JICA).

Sub-regional institutions and international frameworks of stakeholders are implemented to assist efforts by African countries to increase the local rice production while building on existing structures, policies and programs, such as the

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Africa Rice Center (AfricaRice), the Comprehensive Africa Agriculture Development Program (CAADP) and the Africa Rice Initiative (ARI). Many countries are investing significant efforts and resources in the rice sector, particularly after the rice food crisis of 2008. However, the low productivity due to the high cost of inputs such as fertilizer remains a limiting factor to increase the global rice production in Africa. For example, while the simulated potential yield of irrigated rice with new improved varieties is 8–12 tons ha^{-1} in West Africa Sahel (WAS) (Dingkuhn and Sow 1997), the average yields in farmers' fields vary from 4 to 6 tons ha^{-1} (Haefele et al. 2002; Kebbeh and Miezan 2003). Yanggen et al. (1998) calculated the ratio of kilograms of output per kilogram of input for rice in SSA to be ranging from 7 to 20 with an average of 12. This is higher than the rule-of-thumb threshold of 10 and close to the average of 11.4 for Asia and Latin America. The yield for unfertilized rice in SSA was roughly the same as Asia and Latin America, indicating that rice has more favorable ratio than maize in Africa. This better land productivity with rice is probably explained by the fact that most of the rice is irrigated or cultivated in lowland environment with reduced water stress. Working on economic analysis of factors of productivity in Senegal, Diagne et al. (2012) pointed out that fertilizers are robustly found to be the single most important source of productivity and technical efficiency levels of rice.

Rice is grown in West Africa in a wide range of agro-ecological zones ranging from the humid forest to desert areas. Within these regional agro-ecological zones, five main systems of rice cultivation exist with respect to water supply, soil hydrology and topography (Windmeijer et al. 1994). Irrigated rice systems are primarily cultivated in deltas and floodplains with good water control. The lowland rainfed rice systems are mostly cultivated in valley bottoms and floodplains with varying degrees of water control. The rainfed upland rice systems are cultivated on upland and slopes on aerobic soils. The deepwater and mangrove systems present along riverbeds and in tidal areas (lagoons, deltas and coastal) rarely have water control on anaerobic soils for most of the season.

Compared to traditional cereals (millet, sorghum, maize), rice has the highest yield potential. Improving the availability, fertilizer recommendations could highly contribute to food security while reducing rice import in Africa. There is scope for sustainable intensification of the existing cropping rice-based systems through an efficient management of nutrients both from soil and fertilizers. In line with the efforts by African governments, under the Abuja Convention to increase mineral fertilizer use to 50 kg of nutrients per hectare by 2015 and based on its potential productivity as well as its regional and international market opportunities, ECOWAS has identified rice as one of its priority crops. While rice has tremendous potential to be a cash crop, it is also a cereal crop, which is widely cultivated in diversified environments and ecologies.

For example, lowland rice is cultivated in heavy soils under periodical submersion that affect the dynamic of soil organic carbon, soil nutrients and fertilizer use efficiency. In contrast, upland rice is cultivated on upland soils, which are generally of poor quality compared to lowland soils. The main constraints of upland soils are the low contents of clay, organic carbon, exchange capacity (EC) and nutrients availability. Between the lowland and upland ecologies and depending on water management and cropping systems, rice is cultivated in a diversity of biophysical environments that affect the nutrient use efficiency and productivity of rice-based systems. While nitrogen (N) deficiency is the main limiting factor of yield for lowland irrigated rice (Wopereis et al. 1999; Haefele et al. 2002; Bado et al. 2008), phosphorus deficiency particularly in the low acidic soils is the main limiting factor for upland rice. Any fertilizer recommendation should take into account the biophysical environment, the cropping system and also the socio-economic environment of farmers including market opportunities. This paper reviews rice-based systems and the main achievements on fertilizer recommendation to improve fertilizer use and rice productivity. Rice ecologies are used as the basis for strategic management of fertilizers for rice-based systems. Based on the main achievements and weakness, this paper discusses the challenges and opportunities to improve fertilizer use efficiency in rice-based systems. The goal is to suggest alternatives for better management of fertilizers to improve nutrient use efficiency and productivity of rice-based systems in diverse ecologies.

Soil constraints in rice ecologies

Rice is both a staple and cash crop but also a strategic commodity in the international and regional markets. Due to the fast-growing demand for rice, many efforts and initiatives have been invested to increase rice production, particularly after the food crisis of 2008 (Diagne et al. 2012; Seck et al. 2012). As for many crops, mineral fertilizer is one of the main factors of productivity and profitability. However, the use of fertilizer is limited by several factors. Most important factors limiting the use of fertilizers are cost, affordability and profitability. The development of fertilizer recommendation is generally based on the use of response curves to different nutrients (N, P, K) and calculation of the dose of fertilizer nutrients to apply for a target yield. Then, fertilizer recommendations are based on the optimum yields calculated from different nutrient requirements. However, in most countries in Africa, fertilizer recommendations are out of date and too general ('blanket recommendations') for different ecologies of rice. The rice-based systems have three main ecologies Africa: irrigated lowlands, rainfed lowlands, and rainfed upland. The characterization of rice-growing environments is based on two concepts: toposequence and rice cropping system (Andriesse and Fresco 1991). Rainfed upland rice depends exclusively on rainwater. Rain is the main source of water on the crests and the upper and middle slopes of the toposequence. Excess water is stored in the soil is discharged by run-off or by percolation. Rainfed lowland rice also depends exclusively on rainwater as main source of water. But lowland rice is cultivated in the inland valleys and floodplains in the lowest toposequence. Because of the higher clay content and lower position in the toposequence, excess water is periodically stored in the soil. Irrigated rice is cultivated in inland valleys and flood plains with full control of water through irrigation. With the availability of water, irrigated rice is sometimes cultivated on upland soils. Each cropping system has specific biophysical, agronomic and socio-economic constraints that limit crop productivities. Moreover, the demand for fertilizer and the application of fertilizer recommendations by farmers vary with the rice ecologies (rainfed or irrigated). Water availability, capacity of farmers to purchase fertilizers, manage water and weeds determine their decision and quantity of fertilizer they might apply. For example, irrigated rice systems are the most intensive systems. While mineral fertilizers are systematically used in the intensive irrigated lowland rice-based systems, the use of mineral fertilizers in the rainfed lowland or upland systems is limited.

Soil constraints

As a consequence of biophysical factors and water regimes, rice is cultivated on a diversity of soils. The dynamic of nutrients from soil and fertilizer is differently affected by the management practices of water during the cropping seasons. The main constraints and distribution of fertility groups of soils within the different rice ecosystems and total rice area per system are summarized in Table 1. Using the fertility capability soil classification (FCC) system (Sanchez and Buol 1985; Sanchez et al. 2003), Haefele et al. (2014a, b) identified four groups of soils. The first two groups ('good' and 'poor' soils) do not have major soil chemical constraints, but differ in their degree of weathering and, therefore, their indigenous soil fertility. The third group ('very poor' soils) represents highly weathered soils with very low nutrient availability and a high probability of soil chemical constraints to crop growth (acid, low nutrient reserves, low CEC, Al toxicity, high P-fixation). The last group combines the most frequently cited 'problem soils', i.e., acid-sulfate soils, peat soils, saline and alkaline soils, which are characterized by specific and severe soil chemical constraints. In general, soil pH, available P, exchangeable bases (Ca, Mg, K, and Na), and ECEC decrease while total C, total N and exchange acidity (Al and H) increase with increasing rainfall. This tendency is mostly explained by the enhanced biomass production and soil weathering sequence governed by the climate (Abe et al. 2010). The majority of rice soils are very poor (37%), followed by equal fractions of poor (28%) and good soils (27%). Overall, problem soils are not common and make up 'only' 8% of all rice soils in Africa.

Table 1 Distribution of the different soil characteristics, constraints and fertility groups (%) within the different rice ecosystems (%) and total rice area per system in Africa. *Source* Adapted from Haefele et al. (2014a, b)

Fertility groups and soil constraints	Cropping systems/ecologies of rice (%)				
	Irrigated summary	Rainfed summary	Other, deepwater/ mangroves	Rainfed, lowlands	Rainfed uplands
Good soils: Calcareous (basic reaction) common Fe and Zn deficiencies cracking clays, vertic properties, very sticky plastic clay, amorphous volcanic, high P-fixation by allophane waterlogging, gleyic conditions	19.7	17.8	11.8	22.8	11.4
Poor soils: Limited aluminum toxicity, intermediate, Weathering, low organic C, shallow/obstacles to roots, gravel slight alkalinity	25.7	16.0	25.2	16.7	12.8
Very poor soils: Low nutrient capital reserves, Al toxicity for most common crops or very low pH, Very shallow soil moisture stress (three month dry season); High leaching potential, low buffering capacity, low ECEC, very low organic C, high P-fixation by Fe and Al oxides	47.8	63.9	60.8	57.6	74.4
Problem soils: Saline, sulfidic, presence of cat clays, organic alkaline or sodic	6.3	2.3	2.1	2.9	1.3
Total rice area per system (000 ha)	2215	8251	678	4611	2963

Rainfed upland rice

Rice upland soils cover the upper and middle slopes of the catena are generally well drained, deep to very deep, and coarse- to medium-textured or gravelly in the humid forest and Guinea savanna zones. Soils in the upper parts of the toposequence are moderately to well drained, shallow to medium in depth, and coarse- to medium-textured or gravelly in the Sudan savanna transition zones (Andriesse and Fresco 1991). The red clayey or clay-loam soils dominant in the humid forest and Guinea savanna zones are classified as Ultisols and Oxisols, and some as Alfisols; the brown sandy or sandy loam soils of the Sudan savanna transition zones belong to Alfisols, Inceptisols, or Entisols; and the organic matter (OM)-rich, relatively fertile soils of the highlands of East and Central Africa and Madagascar are mostly Inceptisols. The inherent fertility of most upland soils is low pH, cation exchange capacity, and base saturation in warm and humid zones due to intense weathering of parent materials, and medium to high in semiarid zones due to less intense weathering and, deposition of Ca, Mg, and K from dust deposits from the Sahara Desert that occur in the dry season (DS) (Andriesse and Fresco 1991). Subsoil acidity and Al and Mn toxicity are common problems in some soils. Due to high P-fixation, P fertilization is an important requisite to get a crop response to other nutrients such as N (Sahrawat et al. 2003).

Upland rice production is mostly by subsistence-oriented farm households with limited use of external inputs. Upland rice is grown as a sole crop or mixed with maize and beans both in slash-and-burn systems and in intensified systems, where upland rice is rotated with other crops on permanently cultivated lands. Under this rice-growing system, the land is tilled before the rainy season arrives, and the rice seed is normally broadcasted. While the upland rice area is relatively small (9.2%) in Asia, it covers 44% of the total rice cultivated in Western and Central Africa, mainly in coastal areas in the humid and sub-humid agro-ecological zone (Defoer et al. 2002; Seck et al. 2010). Due to erratic rainfall patterns, poor weed control, low fertilizer use, and high disease incidence, yields remain low, averaging about 1 ton ha^{-1}. Weed competition is the most important yield-reducing factor (Johnson 1997) followed by drought, blast, soil acidity and general soil infertility. Farmers traditionally manage these stresses through long periods of bush fallow. However, population growth has forced farmers to reduce the fallow periods and concentrate their farming activities toward the fragile upper parts of the upland slopes. The slash-and-burn method of land clearing can reduce weed pressure but also led to a decline in soil fertility. Farmers also face high risk of crop failure and generally lower productivity levels. The main factors that limit rice yields under rainfed conditions are frequent drought, lack of water management and poor soils.

The upland rice production systems account for almost one-half of the rice area and contribute to 29% of the total rice production in West Africa. Upland rice is cultivated on poor soils, which are generally acidic, fragile and prone to degradation and nutrient depletion. The low productivity of the upland rice-based system is partly due to the limited use of nutrient inputs by resource poor smallholder farmers and limited investment in fertilizers (Buresh et al. 1997; Becker and Johnson 1999; Oikeh et al. 2010). Even though these production systems have the potential for 2–4 tons ha^{-1}, rice yields are seldom above 1-ton ha^{-1} in most smallholder farmers' fields due to constraints such as soil acidification, inherently low soil fertility, and limited use of fertilizers (Oikeh et al. 2010). Most upland rice-based systems under shortened fallow management are characterized by inherently acidic, P-deficient and low organic matter contents. An Appropriate management option is to develop low external input systems that sustainably increases soil fertility to match appropriate varieties (acid-tolerant, P-efficient), enhances soil organic matter N-balance through integration of N-fixing legume, crop residue management and use of phosphate rock alone or in combination with organic amendments.

Lowland rice

Rainfed lowland rice and irrigated lowland rice are cultivated on wetlands or lowlands in different ecologies. Lowlands are found not only in low-lying areas (river and coastal flood-plains, deltas, and depressions) but also on upper river terraces, foot slopes, and hilltops. For example, in West and Central Africa, lowlands are a part of the inland valley system, which is a continuum of drylands on upper and mid-slopes and lowlands in valley bottoms. On lower slopes, the boundary between wetland and dryland is often gradual. About 40% of lowlands are found in the equatorial region and the rest in the Guinea savannas. About 36 million ha of lowlands are located in the tropical highlands of East and Central Africa and Madagascar (Balasubramanian et al. 2007). Inland basins are the largest area suitable for rice with 45% of the total lowlands in Sub-Saharan Africa (SSA). They comprise drainage depressions and inland deltas of rivers, with imperfectly to poorly drained and potentially acidic soils (Ultisols, Oxisols, Alfisols, Entisols, and Vertisols). Inland valley lowlands occupy 36% of the total wetland area in SSA (Balasubramanian et al. 2007). Most inland valley lowlands are concentrated in the intertropical zone where rainfall is superior to 700 mm. The soils (Entisols) in the valley bottoms are flooded during the rainy season, whereas the soils (Ultisols, Oxisols, Alfisols, and Inceptisols) on adjacent drylands are aerobic and prone to erosion.

Floodplains (12% of lowlands) are wide, flat plains of alluvium bordering streams and rivers that periodically flood them. Well-developed flood plains extend from either side of large rivers such as the Gambia, Niger, Benue, Zaire, Zambezi, Limpopo, Tana, White and Blue Nile, and Chari. Soils of the floodplains (Entisols, Inceptisols) are moderately well to poorly drained and medium to fine textured with moderate to high fertility. Soils can be saline and/or alkaline in drier regions (Balasubramanian et al. 2007). Coastal lowlands (7%) of lowlands) comprise Deltas of Niger in Nigeria, Rufiji in Tanzania, and Zambezi in Mozambique; Estuaries at the mouths of the Zaire, Cross, Gambia, and Corubal rivers; Intertidal flats or lagoons along the West and East African coasts. Soils (Entisols, Inceptisols, Histosols) are poorly drained and nonsaline in freshwater swamps, acid sulfate (Entisols, Inceptisols) in mangrove swamps, poorly drained and saline (Inceptisols) in lagoons, coarse-textured (Entisols, Inceptisols) in sand bars and dunes, and organic (Histosols) in permanently flooded areas. In general, soils of lowlands are fairly rich in exchangeable bases (Ca, Mg, and K), slightly acidic to neutral (pH 6–7), low in P-fixation capacity, and not Al toxic (Balasubramanian et al. 2007).

Rainfed lowland rice

About 40–45 million ha of rainfed lowlands supply around 20% of the world's rice production (IRRI, AfricaRice, CIAT 2010). The rainfed lowlands constitute 26% of the total rice area in Asia (Swain et al. 2005). In West and Central Africa, the rainfed lowland systems (floodplains and valley bottoms) constitute 31% of the total rice area (Defoer et al. 2002). Inland valleys constitute over 38% of the total wetlands in sub-Saharan Africa and are cropped extensively with rainfed lowland rice in the wet season (Africa Rice Center—WARDA 2008). In West Africa, this ecosystem forms significant rice-growing areas in Senegal (47%), Burkina Faso (65%) and Gambia (64%) (Seck et al. 2010). On-farm yield level is generally low due to various biophysical constraints and poor crop management practices (Becker and Johnson 2001b; Touré et al. 2009). Furthermore, in inland valleys, natural resources (particularly water and soil resources) are strongly correlated with their position in the toposequence (Homma et al. 2003; Haefele et al. 2006; Tsubo et al. 2006). Most lowland fields have no water control such as bunds or drainage system, despite the fact that bunds could improve productivity by 30–100% (Raes et al. 2007; Worou 2012). For example, in Cote d'Ivoire, applied nitrogen efficiency of rainfed lowland rice is improved by bunds increasing gain by 10–12 kg grain (Becker and Johnson 2001a; Asubonteng 2001; Touré et al. 2009). In a combined analysis over four seasons in Benin, Worou (2012) demonstrated that bounding increased rice yield by 29% and fertilizer application increased rice yield by 28% without interaction between the two factors. Rainfed lowlands in inland valleys present a high potential for rice production in Africa. However, rice yield in the lowlands is in general low due to various constraints such as, poor soil fertility, drought, iron (Fe) toxicity, and poor crop management practices (Worou 2012). Many studies indicate that the application of P, K and Zn in conjunction with N in lowlands is an effective way of reducing iron toxicity in rice (Yamauchi 1989; Yoshida 1981; Worou 2012). Furthermore, iron (Fe) toxicity is considered as one of the major constraints to rice production in rainfed lowlands in West Africa (Becker and Asch 2005). The reductive conditions found in lowland soils are a prerequisite for the development of iron toxicity through the solubilization of virtually all iron compounds in the soil into its ferrous form ($Fe2+$). Two levels of toxicity can be observed in the wetland system: the primary iron toxicity explained by an apparent sensitivity of rice seedlings to high amounts of $Fe2+$ accumulated just after flooding, and the secondary iron toxicity described by the excessive $Fe2+$ uptake caused by an increased root permeability and enhanced microbial iron reduction in the rhizosphere (intensive exudation) during the physiologically active phase of rice plant between heading and flowering (Prade et al. 1986). Iron toxicity can be also linked to nutritional imbalances due to low availability of P, K, Zn, Ca or Mg rather than to a high content of soluble iron in the soil solution. Therefore, iron concentration in the leaf tissue is a much better indicator of the occurrence of iron toxicity than extractable iron in collected soil samples. High iron concentrations in soil can reduce the uptake of other minerals such as nitrogen (N) and phosphorus (P) by rice plants (Yoshida 1981; Diatta and Sahrawat 2005) and consequently reduce rice yield (Chérif et al. 2009). Increased pond water level due to development of bunds to avoid water stress may increase risk for Fe toxicity, resulting in reduced rice yield or fertilizer use efficiency. However, little is known about the effects of bounding and fertilizer application on rice yield in areas where Fe toxicity is a major constraint.

Irrigated lowland rice

The availability of water in irrigated lowland rice system induces some agronomic problems such as weed pressure and nitrogen losses (denitrification, volatilization) more than in the rainfed lowlands system. Irrigation systems include dams, water diversion from rivers and pump irrigation from surface water or tube-wells (Defoer et al. 2002). High-yielding varieties are cultivated with appropriate doses of fertilizers coupled with improved management techniques. During rainy season, farmers do not always have full control over water. Hence, the boundaries between lowland and irrigated systems are not rigid. Water control may change over time and space. The level of water control dictates, in broad terms, the production potential of a system, and knowledge about the dynamics of water control is therefore extremely important. Nutrient recoveries (in particular N use efficiency) are affected by water management. In West and Central Africa, only 12–14% (0.5 million ha) of the total rice area is irrigated (Somado et al. 2008). This includes 80% of the rice area in Cameroon (14,700 ha), 55% in Niger (14,000 ha), 30% in Mali (52,920 ha) and 20% in Burkina Faso (6750 ha). Irrigated rice in these countries (except Cameroon) is mainly in the Sudan Savanna and Sahel, which account for nearly 60% of the irrigated rice area in West and Central Africa. On average, yields from farmers' irrigated rice fields in the Sahel are around 5–6 tons ha^{-1} per season, with potential yields varying from 8 to 11 tons ha^{-1} per season (Haefele et al. 2000). The very high yield potential in the Sahel is due to high solar radiation levels and relatively favorable temperatures. African rice gall midge, rice yellow mottle virus and blast are the major pests found in the irrigated rice ecosystems in Africa (Nwilene et al. 2007). Despite its high yield potential, 'blanket recommendations' of mineral fertilizers are widely used without taking account the new improved varieties, soil type, cropping system, growing season and water management. These lead to poor inputs use returns, increasing production cost and decreasing competitiveness of irrigated rice.

The productivity and profitability of irrigated rice-based systems can be improved by an integrated development and management of technologies adapted to the production environment of small-scale farmers (Kebbeh and Miezan 2003). This objective could be achieved by a systems approach helping decision makers and farmers to adopt dynamic choices according to environment opportunities rather than traditional research (Jones et al. 1998). In addition to these three main ecosystems, mangrove rice-growing systems also form an important part of the rice production systems in some countries.

Fertilizer recommendation for rice

The fertilizer dose, type and nutrients applied by various African countries are summarized in Table 2. The main observation is the high variability of recommendations even for the same ecology. For example, N fertilizer recommendations vary from 90 to 130 kg ha^{-1} in Burkina for the same ecology of irrigated rice cultivated under full water control conditions. As showed by Bado et al. (2011), some explanations of this variability in fertilizer recommendations may result from multiple interactions within soil type, yield potential of varieties, the cropping season, farmer's practices (such as weed control) and the type of fertilizer available to be used for calculating fertilizer recommendations (Fig. 1).

Rainfed upland

In contrast with lowlands, phosphorous deficiency and high P-fixing capacity associated with low organic carbon and low availability of nitrogen are the main limiting factors in upland soils (Becker and Johnson 2001b; Sahrawat et al. 2003). Due to water constraints and frequent droughts, fertilizer application is more effective during high rainfall. In general, the recommended N rates for upland rice usually range from 50 to 80 kg ha^{-1}, applied in 2–3 splits at planting, early tillering and panicle initiation. The critical limit of soil extractable P for upland rice ranges from 14 to 16 mg ha^{-1} (Sahrawat et al. 1997, 2001; Bado et al. 2010), and P fertilizer applications vary from 13 to 25 kg ha^{-1}. Potassium is less limiting, and around 10–20 kg K ha^{-1} are usually applied. Due to poor quality of upland soil (low OC, clay content, acidity and high P-fixing) and limited resources of smallholder farmers to afford mineral fertilizer, organic inputs are an important productivity factor. Promising alternative cropping systems include the use of weed suppressing and multipurpose legumes as short-term fallow crops (Becker and Johnson 1998, 1999; Akanvou et al. 2000; Saito et al. 2010). Intercropping upland rice with grain legumes like cowpea or soybean, rice–grain legume rotations or integrating early maturing legumes as pre- or post-rice crops improve the productivity of upland rice systems (Oikeh et al. 2008).

Fertilizer recommendations (Table 2) present the difficulty of calculating accurate doses of nutrients. Fertilizers communally available in the local market are not always adapted to rice. For example, many formulations of the complex NPK fertilizer available in many countries are formulated for the most important industrial crops such as cocoa (Côte d'Ivoire) or cotton (Burkina Faso). Fertilizer recommendations for rice are generally adjusted using urea and the available NPK fertilizers. For example, excessive doses of P are recommended on lowland rice in Burkina Faso because of the difficulty in balancing N, P and K nutrients with urea (46% N) and NPK fertilizer (14-23-14).

Irrigated and rainfed lowlands

In general, the recommended N rates for lowland rice usually range from 60 to 120 kg ha^{-1}, applied in 2–3 splits at planting, early tillering and panicle initiation. An additional split at booting can be beneficial in very high-yielding systems (Wopereis-Pura et al. 2002), depending of yield potential of varieties and weed control. Good control of weeds is an important factor of fertilizer N use efficiency in irrigated and lowland systems. Good response to fertilizer applications is obtained through adequate weed control, while poor control of weeds leads to poor response to N applications (Bado et al. 2008) (Fig. 1).

Table 2 Fertilizer recommendations for rice in some countries in Africa

Country	Rice ecology	Doses of nutrient applied (kg ha^{-1})	References
Nigeria	Lowland	60N–13P–25K	Ekeleme et al. (2008)
	Rainfed Upland	50N–30P–30K	Oikeh et al. (2017)
Benin	Rainfed Lowland	55N–18P–33K	Worou (2012)
	Rainfed Upland	78N–15P–27K	Oikeh et al. (2017)
Togo	Lowland	122N–13P–25K	Meertens 2001
	Rainfed Upland	45N–10P–19K	Aboa et al. 2008
Senegal	Irrigated Lowland	120N–26P–50K	Haefele et al. 2013
	Rainfed (upland/Lowland)	100N–13P–25K	Lô 2010
Mali	Irrigated Lowland	133N–20P–40K	Nwilene et al. (2007)
	Rainfed (upland/Lowland)	60N–10P–10K	Haefele et al. (2001)
Côte d'Ivoire	Irrigated Lowland	71N–20P–38K	CNRA (2005)
	Rainfed upland	70N–21P–30K	Gala-Bi et al. (2011)
Burkina Faso	Lowland	82N–31P–30K	Segda et al. (2005)
	Rainfed upland	67N–16P–18K	Karboré (2011)
Ghana	Lowland	90N–26P–50K	Buri et al. (2012)
	Rainfed Upland	90N–20P–30K	Nyalemegbe et al. (2012)
Tanzania	Lowland	40N–10P–0K	Mowo et al. (1993)
	Rainfed Upland	–	
Sierra Leone	Lowland	60N–18P–34K	Nyalemegbe et al. (2012)
	Upland	60N–18P–34K	Oikeh et al. (2017)
Egypt	Lowland	143N–16P–47K	Abd El-Hadi et al. (2013)
Malawi	Lowland	83N–11P–0K	Mutegi et al. (2015)
	Upland	83N–11P–0K	
Gambia	Lowland	70N–30P–30K	Ceesay (2011)
	Upland	70N–30P–30K	
Ethiopia	Lowland	69N–10P–0K	Tilahun et al. (2007)
	Upland	–	
Mauritania	Lowland	156N–20P–0K	Haefele et al. (2001)

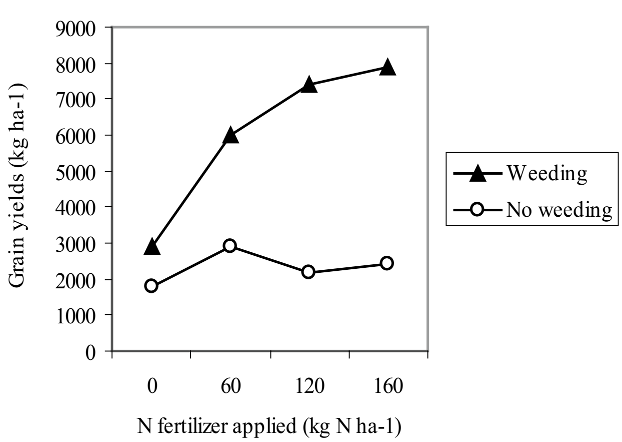

Fig. 1 Effects of weeds control (weeding and no weeding) on irrigated rice responses to N fertilizer applications in the Senegal River Valley (Reproduced with permission from Bado et al. 2011)

Many studies indicate that N fertilizer recommendations depend on the cropping. The optimum rate of N fertilizer varies from 90 to 120 kg N ha^{-1} during the wet season (Haefele et al. 2002; Bado et al. 2010). Very high N rates up to 150 kg ha^{-1} can be recommended in irrigated rice system during the dry season, if high solar radiation enables potential grain yields of up to 12 ton ha^{-1} (Haefele and Wopereis 2004). The critical limits of soil extractable P vary from 7 to 9 mg P ha^{-1} and from 15 to 17 P ha^{-1} with the P-Bray1 and Olsen method, respectively (Haefele et al. 2004; Bado et al. 2008) (Fig. 2). Below these critical limits, the application of 20–25 kg P fertilizer can maintain good level of P to ensure good yields. Potassium fertilizers are to be applied along with N and P on poor soils, if higher yields are desired, and especially if two (high-yielding) crops are grown per year on a regular basis. The amount of K that needs to be applied also depends on K inputs from the irrigation water and from dust depositions. In West Africa, the dust deposition (dry deposition) is high at the northern fringes of the Sahel (e.g., in the

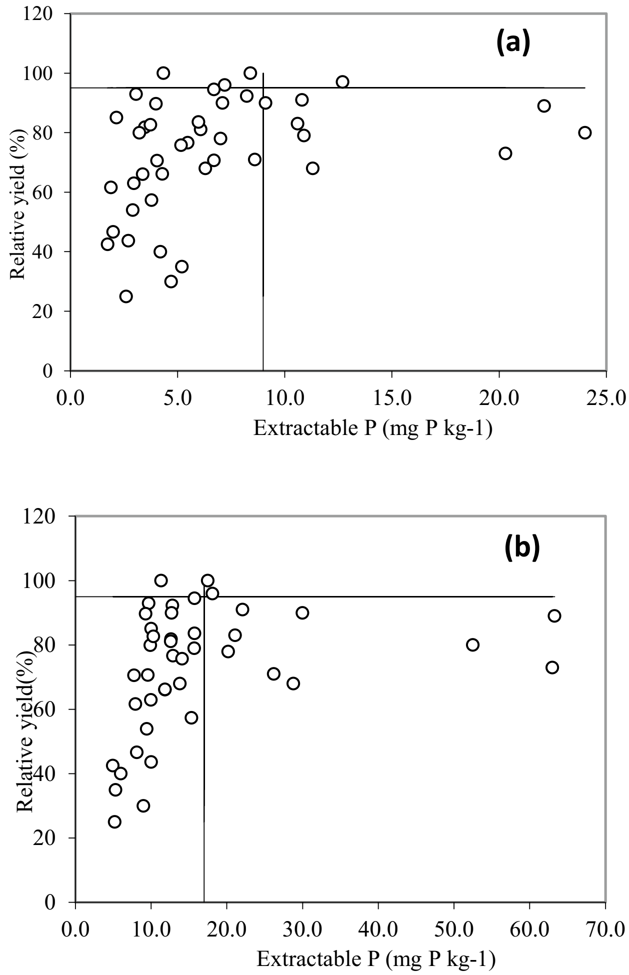

Fig. 2 Relationships between soil extractable P and yields and critical limit of soil P of a Gleysol under irrigated rice in the Senegal River Valley, as determined by the Cate and Nelson graphical method with **a** the Bray1 extractant (9 mg P kg^{-1} of soil) and **b** the Olsen extractant (17 mg P kg^{-1} of soil). *Source*: Bado et al. (2008)

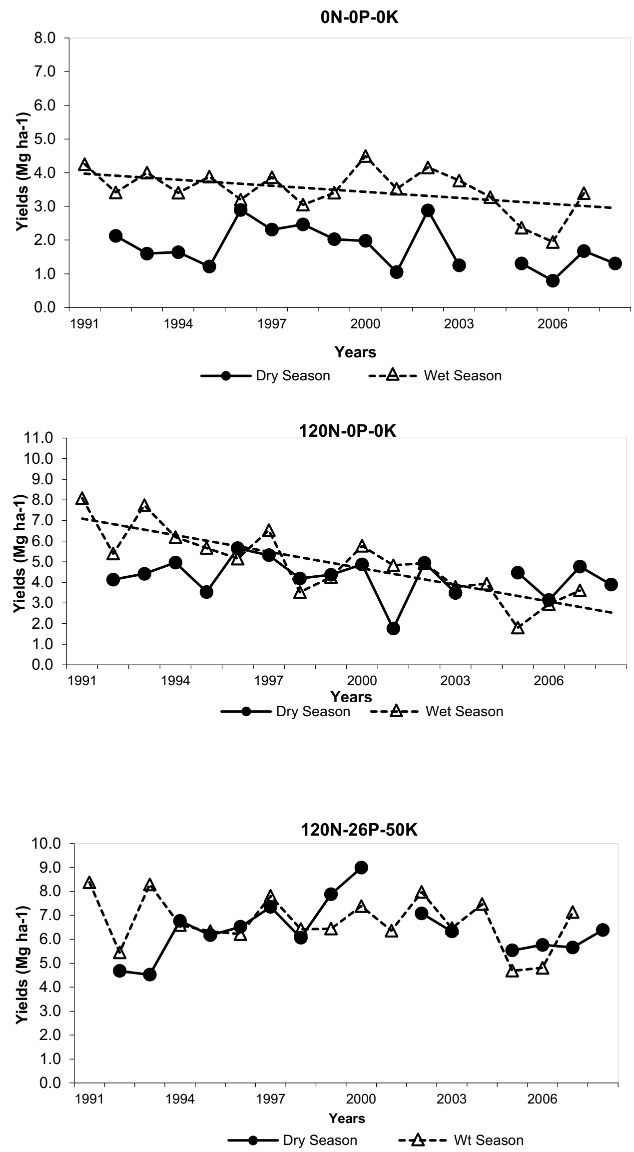

Fig. 3 Influence of fertilizer applications on rice grain yields at Fanaye in the Senegal River Valley during 18 years (1991–2008) during the two cropping seasons per year: Hot Dry Season (HDS) (February to May) and the Wet Season (WS) (June to September). The lines of yield trends indicated that the significant linear relationship ($p < 0.05$) existed between yields and year. *Source*: adapted from Bado et al. 2010)

Senegal River valley and in the Office du Niger, Mali) and decreases toward the south (Haefele et al. 2004, 2013).

On two long-term fertility experiments implemented by AfricaRice in the Senegal river valley, Bado et al. (2010) showed that soil organic carbon remained steady or increased irrespective of fertilizer application and rice yields declined only when rice was cultivated without NPK fertilizer or when only N fertilizer was used (Fig. 3). They suggested seeking alternatives for better management of fertilizers in order to improve irrigated rice productivity and profitability. While N should be applied each season, it is probably not necessary to apply P and K each season. For example, seasonal applications of N (each cropping season) and annual applications (one season per year) of P and K can be an option to improve fertilizer management, rice production and profitability.

New concepts and tools for fertilizer recommendations

The strategic objective of self-sufficiency in rice has become the political slogan of most of the countries in Economic Community of West African States (ECOWAS). Improving fertilizer use efficiency through appropriate fertilizer recommendations would contribute to increasing the productivity, profitability and competitiveness of local rice production, a huge option to reach rice self-sufficiency. Specific approaches and decisions supports tools have been developed for better management of fertilizers in rice systems. The new approaches of fertilizer recommendations aim to achieve more efficiency in the use of fertilizer, increase productivity with more profit to farmers, result in higher yields per unit of applied fertilizer, and protect the environment by preventing excessive use of fertilizer.

The challenges

The technical and environmental challenges to be considered are related to the high diversity of rice ecologies and rice-based cropping systems. The diversity of soils, water regimes, frequent droughts (Balasubramanian et al. 2007), cropping systems and management practices are to be considered in the development of fertilizer recommendations for rice. On the uplands, weak buffering capacity of soils due to low soil organic carbon (SOC) and clay content, low cation exchange capacity (CEC) and P deficiency are the main limiting factors to agricultural productivity of any crop including upland rice. Data from many long-term experiments in upland soils usually show yield declines over time as a consequence of a decrease in SOC, soil acidification and a decrease of nutrient use efficiency (Bationo and Mokwunye 1991; Bado et al. 1997; Bationo et al. 2008). It is necessary to consider the socio-economic realities of smallholder and poor farmers who possess limited resources to buy fertilizers.

In contrast to the poor upland soils, lowland soils of the inland valleys have generally higher organic carbon and clay contents, a better CEC and water retention capacity, offering better conditions for crop production (Bado et al. 2010). The wetlands of sub-Saharan Africa are affected by Fe, Al and Mn toxicity in the wet forest zones and in waterlogged soils (Buddenhagen 1986; Sahrawat 2004). Moreover, permanent water logging and rice monoculture have caused microelement deficiencies, especially zinc and sulfur. Zinc deficiency is normally observed in soils with one or more of the following characteristics: high pH, high organic matter, high availability of P or Si, high Mg/Ca ratio and low availability of Zn (Ponnamperuma and Deturck 1993). The traditional rainfed lowlands are also complex. Soils have better properties, and water is more available compared to the upland environment. However, one of the main constraints comes from the non-control or poor control of irrigation systems, leading to other problems such as nutrient loss (particularly N), pest, weed pressure, and sometimes Fe^{2+} toxicity. Due to these problems, rainfed lowlands are under-utilized. Farmers use many cropping systems in the upland rice-based system. Crop diversification can help better exploit the high production potential of lowlands. Water regime and inputs (fertilizer, herbicides) could help to identify appropriate management options.

Fertilizer requirements of irrigated rice are higher in the more intensive production systems. However, the long-term and intensive cultivation of irrigated rice with periodical flooding affect the dynamics of SOC, soil pH, cation exchange capacity and nutrient use efficiency (Cassmann et al. 1997). Results from long-term experiments in Asia show yield declines of 70 to more than 200 kg ha^{-1} with best management practices over a period of 10–24 years (Flinn and De Datta 1984; Cassman et al. 1995; Cassmann et al. 1997). In West Africa, data of a long-term fertility experiment conducted by AfricaRice showed that soil organic carbon was maintained or even increased with monocropping of irrigated rice over 18 years or 36 cropping seasons (Haefele et al. 2004; Bado et al. 2010). The recycling of crop residues and roots in the flooded conditions of irrigated rice systems explained the status of SOC (Bado et al. 2010). The decomposition of plant residues is typically slower in submerged soil than in aerated soil (Powlson and Olk 2000; Regmi et al. 2002; Sahrawat 2004; Zhang and He 2004; Mirasol et al. 2008). Crop residues are continuously recycled in the soil twice a year as a source of carbon, which are incorporated into young soil organic matter fraction (Cassman et al. 1995; Olk et al. 1996; Witt et al. 2000). In general, most of the irrigated lowland valleys in the Sahel and Sudan savannah have considerable soil K reserves (Buri et al. 1999; Wopereis et al. 1999; Haefele et al. 2004). Probably because of the relatively high soil K status, the exchangeable K did not show any significant depletion with the recommended doses of NPK fertilizer as already noted by Haefele et al. (2004). However, the highest doses of N fertilizers (180 kg N ha^{-1} or more) can probably induce K depletion with long-term cropping. While the quick decline of SOC necessitates the need for organic fertilizers in upland aereted soils, the maintenance or buildup of SOC is consistent or even increases in flooded conditions of irrigated rice (Bado et al. 2010), coupled with the improvement of soil chemical properties (Sahrawat 2004) and better use of nutrients both from soil and fertilizers. Bado et al. (2010) observed that rice yields could be maintained for 18 years with the seasonal application of only chemical NPK fertilizers, probably because of the improvement of soil chemical fertility with flooding (Sahrawat 1998) and the maintenance of SOC and NPK nutrient. Thus, the standard or traditional approach for developing fertilizer recommendations based on the selection of a soil test, calibration of the test levels with crop response to added nutrients, and identification of response categories cannot give accurate recommendations in wetland ecologies of rice. Many studies validate the argument that traditional approach to fertilizer recommendation is unsuitable in lowland soils due to dynamic nutrients in the periodical waterlogging wetlands environment (Haefele et al. 2004). In the traditional approach, fertilizer recommendations are formulated for specific crops regardless of the cropping system or the management of other nutrient sources such as crop residues. Experiments are usually conducted at a particular experimental site in time and space with one or a limited number of plant genotypes. This traditional agricultural research is time consuming, and many experiments on diverse sites over several seasons sometimes provide little information (Jones et al. 1998). The new challenge is to develop new fertilizer management strategies that could integrate the complex interactions within ecological, biophysical and socio-economic factors of rice-based systems.

New concepts and tools

National and international research institutions have invested several efforts to develop decision support tools that aim at improving fertilizer recommendations for rice systems (Table 3). In particular, the International Rice Research Institute (IRRI) and AfricaRice (formerly WARDA) have developed various concepts and methods for better management of fertilizer in rice systems. Moving beyond blanket recommendation, the main objective of the institutions was to propose appropriate methods and tools to develop specific doses of fertilizer for diverse ecologies of rice (uplands, lowlands), time of application, cropping season and system. These recommendations facilitate better productivity and profitability. This approach gave rise to the development of the new concept of site-specific nutrients management for rice.

Site-specific nutrient management (SSNM)

The International Rice Research Institute has developed the concept of site-specific nutrient management (SSNM) for rice (Dobermann and White 1999; Witt et al. 1999; Dobermann et al. 2002; Saito et al. 2015). This approach relies on the scientific principles determined during 15 years of site-specific nutrient management research in Asia (Saito et al. 2015). The concept of SSNM is the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil–plant systems (Dobermann and White 1999; Wang et al. 2001). Balanced fertilization increases nutrient use efficiency, results in higher yields per unit of applied fertilizer and protects the environment by preventing excessive fertilizer use.

A cloud-based decision support tool named Nutrient Manager for Rice (NMR) was developed to deal with such specificity and provide farmers with field-specific nutrient management recommendations before the cropping season. The version currently in the public domain is called Crop Manager; http://cropmanager.irri.org/) (Saito et al. 2015). The NMR provides advice on when, how much, and what sort of fertilizer to apply. Agricultural extension officers or lead farmers can access NMR through a personal computer, smartphone, or tablet. The recommendations are calculated from farmers' replies to questions about the agro-ecological or administrative zone of their field, variety of rice, availability of irrigation water, previous crop and crop residue management, previous rice yield levels, and fertilizer use (Saito et al. 2015). Fertilizer recommendations are developed in five steps: (1) selecting a desired economic yield based on the average yield of the past 3–5 crops (same season) attained by farmers' good crop management practices when nutrient-related constraints are overcome; (2) estimating soil nutrient supplies by using grain yield in nutrient omission plots (under favorable weather conditions and good growing conditions) as an indicator of the potential soil supply of N, P, and K in a cropping season; (3) calculating fertilizer N rates and use of plant need-based N management; (4) calculating fertilizer P_2O_5 rates; and (5) calculating fertilizer K_2O rates. More details are published in a practical guide by Fairhurst et al. (2007). SSNM technologies have been successfully evaluated in a wide range of farmers' fields in

Table 3 Concept, tools and methods utilized by different institutions to develop fertilizer recommendation in rice-based systems

Rice system	Concept	Tools	Institution
Lowland irrigated rice	Site-Specific Nutrient Management (SSNM)	Nutrient manager or Rice Advice	AfricaRice
	Integrated Crop Management (ICM)	RIDEV	AfricaRice
	Site-Specific Mutrient Management	Nutrient Expert	IPNI[a]
Rainfed Lowland	Site-Specific Nutrient Management (SSNM)	Nutrient manager or Rice Advice	AfricaRice[c]
	Site-Specific Nutrient Management	Nutrient Expert	IPNI[a]
	Integrated Soil Fertility Management (ISFM)	DSSAT QUEFTS	IFDC[b]
Rainfed Upland	Site-Specific Nutrient Management (SSNM)	Nutrient manager	AfricaRice
	Integrated Soil Fertility Management (ISFM)	DSSAT QUEFTS	IFDC

[a] *IPNI* International Plant Nutrition Institute

[b] *IFDC* International Center for Research on Soil Fertility and Agricultural Development

[c] AfricaRice (Africa Rice Center, former WARDA)

Asia and are now positioned for wider-scale validation and adaptation by farmers in Asia (Fairhurst et al. 2007).

Other decision supports tools are also used to develop SSMN recommendations. The most popular is the QUEFTS model (Quantitative Evaluation of Fertility of Tropical Soils). The QUEFTS model was initially developed to simulate interactions between N, P and K for tropical soils under maize crop (Janssen et al. 1990; Smaling and Janssen 1993; Janssen 1998; Witt et al. 1999). Information required to estimate the total amount of N, P, and K to be applied included: climatic yield potential; yield goal; definition of the relationship between grain yield and nutrient uptake; recovery efficiencies of N, P, and K fertilizers; field-specific estimates of the indigenous N, P, and K supply; and potential constraints to fertilizer use. Some modified versions of QUEFTS have been performed later for different crops including rice (Haefele et al. 2004; Sattaria et al. 2014).

Haefele et al. (2003) developed a framework for improving fertilizer recommendations by combining the rice yield model ORYZA_S (Dingkuhn and Sow 1997) with a simplified version of QUEFTS, called FERRIZ. The dynamic eco-physiological model, ORYZA_S provided potential rice yields under irrigation, based on weather condition, cultivar choice and sowing date. This yield potential was then used in the static FERRIZ model, together with on-farm data on recovery efficiency of applied N, P and K, indigenous soil N, P and K supply. AfricaRice (former WARDA) has developed a decision support tool called RIDEV, a dynamic model that simulates the optimal timing of the dates of sowing or transplanting, fertilizer application, weeding and harvesting (Dingkuhn et al. 1995; Dingkuhn and Sow 1997; Haefele et al. 2003). This approach revealed that (1) current uniform recommendations for the wet season performed well except on low K soils where the application of K was profitable and (2) adjusting fertilizer doses to the lower yield potential in the dry season reduced costs and risks without reducing profit. Based on the analysis, the existing recommendation could be adjusted for the wet and dry seasons, keeping fertilizer costs and risks low, and having close to optimal net benefits (Haefele et al. 2001).

Segda et al. (2005) used a combination of two simulation models and selected field data to develop alternative fertilizer recommendations for irrigated rice in the irrigation scheme of Bagré (Burkina Faso). RIDEV was used to improve the timing of sowing and application of N fertilizer. The FERRIZ framework was used to determine fertilizer recommendations based on estimations of indigenous nutrient supply for N, P and K, yield potential, internal N, P and K efficiency of rice, fertilizer N, P and K recovery fractions, and fertilizer and rice prices. Simulations suggested decreasing P and K doses while increasing the N dose, leading to an increase in gross returns (Segda et al. 2010).

Nutrient expert (NE)

The International Plant Nutrition Institute (IPNI) has developed a tool, called Nutrient Expert (NE) for fertilizer recommendation. The algorithm for calculating fertilizer requirements in NE is determined from a set of on-farm trial data using SSNM guidelines. The N, P and K requirements are based on the relationship between balanced uptake of nutrients at harvest and grain yield using the quantitative evaluation of the fertility of tropical soils (QUEFTS) model (Mirasol 2016). The fertilizer requirement for a field or location is estimated from the expected yield response to each fertilizer nutrient, which is the difference between the attainable yield and the nutrient-limited yield. These parameters are determined from nutrient omission trials in farmers' fields, while attainable yield is the yield for a typical year at a location using best management practices without nutrient limitation. Nutrient-limited yield is obtained when only the nutrient of interest is omitted. In the absence of trial data for a specific location, NE estimates the attainable yield and yield response to fertilizer from site information using decision rules developed from on-farm trial data. The NE decision support tool allows farmers to set their own yield goal, which might be less than the location attainable yield. The NE is applicable to any cereal crop and geographic location (Mirasol 2016). Versions of the NE software are available for free download to personal computers, tablets and smart phones. However, field validation is needed for a specific crop in specific zones. Field-validated version for rice (NE Rice) is available for China and India.

Rice advice (RA)

Based on the experience in Asia, IRRI and AfricaRice have developed Nutrient Manager for Rice (NMR) and later the Rice Advice (RA) starting with the Senegal River Valley (SRV). It uses data on yields from previous fertilizer trials in irrigated lowland rice for estimating indigenous N supply (e.g., Wopereis et al. 1999; Haefele and Wopereis 2004), potential yield and optimum sowing windows (Dingkuhn and Sow 1997), and expert knowledge on crop duration of popular varieties and crop management (Saito et al. 2015). A NMR for SRV has been developed with IRRI as an HTML5 application, which means it can be accessed through a web browser using any of the major operating systems with equal effectiveness, from a smartphone or a personal computer (http://webapps.irri.org/nm/wa/).

Saito et al. (2015) presented a pre-release version 1 of this tool called, Rice Advice. Evaluating the fertilizer recommendations provided by Nutrient Advice in terms of yield of irrigated lowland rice and profitability in comparison with farmers' fertilizer management practices (FFP) in the

Senegal River valley, Saito et al. (2015) concluded that this new tool increases the yields and profitability in farmers' fields.

Integrated crop management (ICM)

More than availability of inputs (water, seeds or fertilizers), appropriate management of inputs and crop calendars is one of the most important factors for efficient use of resources and rice production and productivity. This is clearly observed for irrigated rice in the Sahel. Despite good climatic conditions and water availability on irrigated schemes, good management of inputs remains essential to increase irrigated rice production and profitability. Based on this experience, AfricaRice has developed the concept of Integrated Crop Management (ICM) for rice. The concept of ICM recognizes that rice cultivation is a production system involving a wide range of components from land preparation to harvest and post-harvest management. These factors interact in an array of complex relationships and interdependencies that together determine crop growth, yield and profitability. Thus, rice productivity and profitability can be boosted through integrated technologies adapted to the production environment of small-scale farmers, combined with optimum management of fertilizers, weeds, varieties, seeds and cultural calendar (Wopereis et al. 1999; Haefele et al. 2000, 2002; Kebbeh and Miezan 2003). A change in the management of one factor can affect the performance of other factors and/or crop growth, yield and profitability. The gains obtained through improved rice cultivars can be further enhanced through application of good agricultural practices, improving nutrient, water and weed management technologies. Adapting technologies to local conditions and using rice production decision support tools based on good agricultural practices could improve resource-use efficiencies and crop productivity (Nhamo et al. 2014). The concept of ICM incorporates a participative approach, focused on integrated management of resources and inputs of farmers for increasing efficiency and productivity of rice. It seeks to develop farm level integrated technologies (with the farmer as the ultimate integrator of management factors) to manage the cultivation of the crop as a total production system, taking into account all factors that impact crop growth, yield, quality and profitability. AfricaRice has particularly used the ICM concept to develop different management options of fertilizer (dose and time of application) for cropping calendar of irrigated rice.

Integrated soil fertility management (ISFM)

Organic inputs are one of the main resources of nutrient inputs for small farmers, particularly on the upland soils. Yet large amounts of organic fertilizer (often not available) are required to maintain adequate levels of soil fertility. Organic input alone cannot ensure optimum productivity and sustainable maintenance of soil fertility. In contrast, the application of inorganic fertilizers alone leads to yield gains in the short term but may lead to soil acidification and declining yields in the long term (Bado et al. 2010). The use of both inorganic and organic fertilizers, associated with high-yielding germplasm, improves nutrient and water use efficiency leading to optimum productivity.

The concept of Integrated Soil Fertility Management (ISFM) is defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al. 2010). All inputs need to be managed as per sound agronomic principles. The goal is to optimize crop productivity through maximizing interactions that occur when farmers integrate fertilizers, organic inputs and improved germplasm, along with the required knowledge. The ISFM approach is more appropriate for rice in the rainfed (lowland and upland) system. Good productivity is obtained by the upland rice-based system with the combined applications of mineral and organic fertilizer and crop rotation with nitrogen fixing legume crops.

Selecting a decision support tool

Despite the availability of tools and methods, many factors should be considered for adoption of specific decision support tool for development of fertilizer recommendations. Depending of the rice ecologies, suitable tools could be adopted as indicated in Table 2. But the first factor for adoption of specific tool is the technical capacities of the research teams and end-users for implementation. This should be accompanied by training support. The Nutrient Manager (or the new version called Rice Advice) is particularly one of the most appropriate tools for rice; which is making successful experience in West Africa. The position of AfricaRice as an association of twenty-four member countries is a comparative advantage that could help for wide dissemination of the Rice Advice in Africa. With more efforts on capacity building of the traditional partners of AfricaRice, mainly scientists of the nation agricultural research systems of member countries, the Rice Advice could be widely disseminated in the twenty-four member countries of AfricaRice as a first step. At the same time, the process could be extended from member countries to many other countries in Africa. But in more complexes situation (balancing of nutrient, sowing date, weed control ect), different tools need to be combined for better management of fertilizers on cropping systems. A good example was given by Haefele et al. (2003) who developed a framework of different tools for optimum management of fertilizers, weeds, varieties and cropping calendar in irrigated cropping system. Similarly in the more complex systems of rainfed lowlands, the concept of ISFM could be used with modeling tools such as DSSAT, APSIM or IAT for better management of fertilizers.

Conclusion

Mineral fertilizers will continue to play a key role in boosting rice productivity given the current very low level of fertilizer use in Africa. In light of the increasing demand, rice is one the best opportunity to enhance the use of fertilizer in Africa. The most pressing challenge for rice-based systems is to promote the use of new decision support tools to improve fertilizer use efficiency on an integrated nutrient management system for rice, rather than blanket fertilizer recommendations. Appropriate management of fertilizers in the complex ecologies of rice systems cannot be achieved with blanket recommendations without considering the specific and diversified ecologies of rice. The development of integrated technologies to increase synergies, using decision support tools would enable rice farmers to improve resource-use efficiencies and rice productivity and profitability. System approaches with decision support tools are providing more flexibility for better management of fertilizers in rice ecologies.

The challenges for popular use of the new tools are the availability of qualified human resources and the limited access to these tools. There is a need to train a new generation of hands-on rice experts, including the management of fertilizers in rice-based systems. To this end, AfricaRice has recently developed a regional training facility in Senegal (West Africa) for this purpose. The two regional institutions, AfricaRice and IFDC have the technical expertise to coordinate and promote the wide diffusion of new decisions support tools in West Africa. There is a need to make these new tools available for use by scientists of National Agricultural Research Institutions, extension agents and farmers. This could be achieved through voluntary training efforts of the stakeholders in partnerships with regional institutions. For example, the West and Central Africa Center for Research and Development (CORAF/WECARD), the Association for Sthrengphening Agricultural Research in East and Central Africa (ASARECA), the Forum for Agricultural Research in Africa (FARA) could contribute to mobilize financial and human resources with international research institutions (AfricaRice, IFDC) to develop and implement a strategy to facilitate the use of decision support tools for fertilizer recommendations in agriculture, including the rice-based systems.

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