Review Paper

Constrains, production systems and roles of phosphorus in rice production in Tanzania.

ABSTRACT

Rice is the second most cultivated food and commercial crop in Tanzania after maize, with a cultivated area of about 365000 ha, which represents 18 percent of the cultivated land. Rice is used almost solely for human consumption, and is second only to maize in terms of calorie supply, it is accounting for around 8 percent of the nation's calorie intake. In 2010, Tanzania became a net exporter of rice, producing over 2.6 million tons and was ranked to the second highest levels in Africa, directly behind Madagascar. Soil fertility is essential for a rice plant to grow and for physiological development. Phosphorus is one of 17 essential nutrients, its functions cannot be performed by any other nutrient, and an adequate supply of P is required for optimum rice growth and reproduction. Phosphorus is frequently deficient for crop production and is required by rice crop in relatively large amounts. Phosphorus deficiency affects the major functions in energy storage and transfer of rice plants which include tillering, root development, early flowering, and ripening. Soluble phosphorus from fertilizer or natural weathering, reacts with clay, iron and aluminum compounds in the soil, and is converted readily to less available forms by the process of phosphorus fixation. This fixed, residual phosphorus remains in the rooting zone and will be slowly available to crops. Adequate supplies of other plant nutrients and plant promoting regulators (hormones) tend to increase the absorption of phosphorus from the soil. However, the number of crop problems can be related to nutrient imbalance in the field such as soil moisture, temperature, pests and diseases. Therefore, this review paper aimed to explore the rice yield levels, production constrains and systems, role of phosphorus and strategies to enhance phosphorus use efficiency in rice farms in Tanzania

Keywords: Constrains, phosphorus, production systems, rice, yield levels,

1. Introduction

Rice (*Oryza sativa L.)* is a cereal grain that belongs to the family *Poaceae* and ranks second highest in production worldwide after maize [1]. Nutritionally, husked rice grain provides 20% and 15% of global human per capita energy and protein, respectively [1]. In other countries such as Japan and Korea rice is used as food as well for making alcoholic products and the rice straw is used as building materials mats and hats [2]. In Africa and Tanzania in particular, rice is a strategic component of food security and crucial element for income generation. The demands for rice are postulated to be rising continuously due to increase in population and consumption rate [2]. A study by Amur [3] indicated that, rice after maize has been an important staple food for the majority of Tanzanians and will continue to be so for the foreseeable future. Rice is grown in many parts of Tanzania covering an area of over 365000 hectares in varied ecosystems ranging from uplands to lowlands [4]. In Tanzania lowland and upland rice is mainly cultivated on large scale farms like the Kapunga Rice Farms which cover approximately 20000 hectares [3]. Small scale farmers' irrigation rice schemes like the Lower Moshi project also contribute substantially to rice production in Tanzania. The most important rice growing regions in Tanzania include Tabora, Morogoro, Mbeya, Shinyanga and Coast [5]. A number of factors such as declining soil fertility, inadequate use of fertilizers, poor crop husbandry and inadequate rainfall have been reported to contribute to the low levels of rice yields in Tanzania [6]. Of these factors, soil fertility and nutrient management have a major influence on both the rice yields and quality [7]. Rice like any other crop requires balanced nutrients for optimum yields and one of the most deficient or limiting nutrients in rice production in Tanzania is phosphorus [8]. Its functions in rice plants include stimulating root development, early flowering, and ripening, enabling the plant to counteract the unfavourable effects of late transplanting hence induces the plant to tiller more adequately [9]. Phosphorus also improves the food value of rice and ensures normal grain development [9]. The plant growth regulators (PGR), also termed as plant exogenous hormones are synthetic substances that are similar to natural plant hormones which have ability to increase and regulate the availability of nutrients concentration in the rhizosphere [9] by fixing nutrients, thus preventing them from leaching out hence increases the availability of phosphorus by the rice plant. An understanding of rice production systems, roles of phosphorus and constrains will provides the great knowledge to farmers on how they can manipulate the resources and boost the rice productivity under varied agro ecosystems.

2. Rice yield levels

In East Africa, Madagascar, the Comoros and Tanzania are among the world's leading rice-consuming nations. However, only Madagascar claims to be self-sufficiency in rice production [10]. In 2006, paddy rice production in Sub-Sahara Africa was estimated at 14.2 million tons [10] and the rice production grew at 3.23% per annum from 1961 to 2005. This growth rate was higher than the yearly population growth rate of 2.90% in some major rice producing countries like the Comoros and Madagascar during the same period hence led to excess rice stocks which were sold hence improved the living standards and tax revenue for the countries [10]. In East Africa, the average annual milled rice production was 2.6 million tons in the period 2001-2005 [10]. In 2006 the milled rice production estimate for East Africa was 3.1 million tons, with Madagascar and Tanzania accounting for 2.3 million tones and 525,300 tones, respectively [10]. This increase in production was mainly due to the use of fertilizers as a soil fertility management strategy, adoption of irrigation practices, growing of improved rice varieties, control of pests and increase in the land areas under rice production.

3. Rice Production Constraints

It has been reported that adequate supply of nutrients in the form of fertilizers and manures are equally important to manage soil moisture for increased rice productivity in any rice production system [11]. The moisture deficit, nutrient and pest management may vary from one rice cultivation area to another due to physico-chemical and biological properties of the soils. Fertilizers use in Tanzania is mostly imported, except for rock phosphate that is mined in the country. Farmers grow mainly local and traditional varieties, many of which have low yield potential. Most of the rice grown depends on rainfall and many irrigation schemes need urgent rehabilitation. Upland systems are prone to drought, weed infestation (including Striga), and attacks by pests and diseases (blast) [10]. Rainfed lowland systems suffer from floods during heavy rains but can also face drought. Weed infestation, pests (African rice gall midge and stem borers), and diseases (rice yellow mottle virus, blast, bacterial leaf blight) cause low yields. Soil fertility is generally low [10]. Rice competes with other crops such as maize, for land and labor. Inadequate postharvest technologies result in low-quality rice and low prices in the market. Farm operations are mostly (95%) done manually [10]. Farmers and processors do not have easy access to credit. The infrastructure for transportation, storage, and processing is often lacking or in need of rehabilitation. Environmental constraints in rice production refer to unpredictable rainfall (heavy rainfall or low rainfall) with poor distribution for the upland rice production systems. This condition has been attributed to global climate change [11]. Also, socio-economic constraints is another factor which lead to low rice production in Tanzania because inputs such as subsidised fertilizers, farm machinery, farmer's loans, pesticides and improved rice seeds are not easily accessible by the majority of the small scale rice farmers. Therefore, yield constraints' analysis should be systematically carried out so as to develop and chart out the appropriate soil and crop management strategies for sustainable rice production [12].

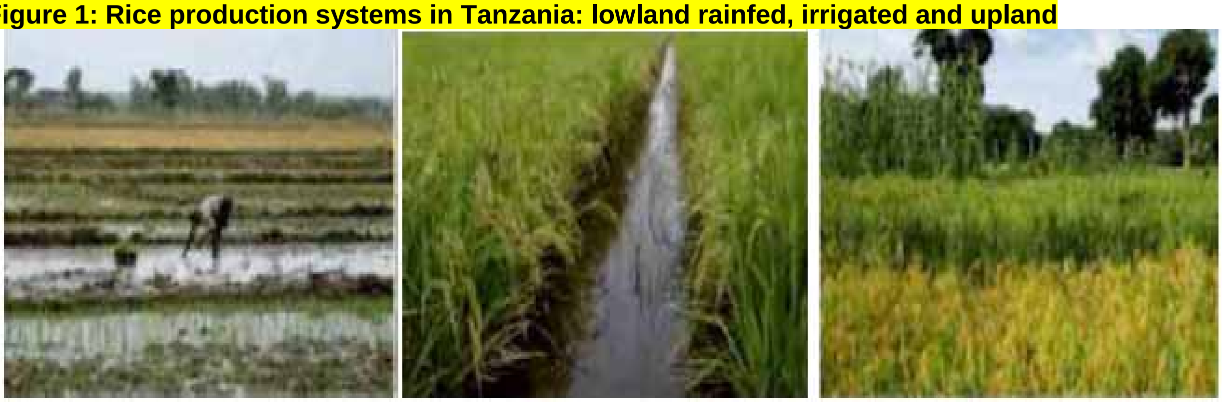
4. Soil moisture-nutrient interaction in rice production

It has been reported that the performance of rainfed lowland rice is variable due to seasonal rainfall variations conditions and spatial heterogeneity over soil types and topographic positions, consequently, agro- hydrology might vary from field to field depending on texture of the soils especially clay soils and vegetation cover [13]. Drought stress is commonly considered the most severe limitation to soil productivity in semi arid areas even if ponding or even complete submergence may occur some days during the cropping season. If water stress occurs at tillering stage, it causes the reduction of number of productive tillers and panicles per hill [14]. However, some experiments have shown that water stress event at flowering and early grain filling period reduced rice panicle and grain fertility [15]. This is due to the fact that soil moisture stress affects nutrient availability by limiting the translocation of nutrients from the soil mass to the root surfaces and the metabolic processes in the plants [15]. Further, it has been shown that the performance of different rice varieties vary in response to water stress [16]. Some rice varieties are susceptible to soil moisture stress at vegetative stage and others at flowering and grain filling stages hence low yields [1]. The fluctuations in soil moisture conditions from anaerobic to aerobic also have profound consequences on nutrient availability because of redox reactions in the soils [17]. Bell and Seng [18] argued that the common effect of soil-moisture stress may be due to limited nutrient availability and uptake than the drought *per se* because the soil solution dissolves nutrients to form ions in the soil for easier plant uptake. Bell *et al.* [19] reported that for very strong to strong acid soils, variation in soil-water saturation interact with nutrient availability as water logging conditions tend to increase the soil pH to about 5.5 to 6.5 where most of the nutrients become available to plants. Therefore, standing water in rice paddies increases the availability of N, P and Si compared to non submerged conditions due to limited translocation of these nutrients from the soil mass to the root surface in soil moisture deficit soils as reported by Regland and Boonpuckdee [20].

5. Rice production systems

De Datta [16] classified rice cultivation in accordance with sources of water supply as either rainfed or irrigated rice. Rice is grown in three major ecosystems, rainfed lowland, upland, and irrigated systems. The area under rice increased from about 0.39 million ha in 1995 to about 0.72 million ha in 2010 [10]. Based on land and water management practices, lands suitable for rice production are classified as lowland (wet land preparation of fields) and upland (dry land preparation of fields) [1]. Further, according to soil water regime, rice production systems have been classified as upland rice with no standing water, lowland rice with 5-50 cm of standing water and deep water rice with greater than 50 cm of standing water during half of the growing season [16]. It is, therefore, of greater importance to explore how the rice production systems associate with the production constrains and final grain yields to assist farmers to opt the best bet technology in their production areas.

Figure 1: Rice production systems in Tanzania: lowland rainfed, irrigated and upland



6. Lowland rice production

In West Africa, the rainfed lowland rice cultivation system occupies about 82% of the area under rice cultivation and accounts for 75% of the rice produced in the region [21, 22]. By origin and preference, rice is primarily a lowland crop and its semiaquatic character was the key to the development of wet land rice in Asia during the early stages of the history of rice culture [23]. In Tanzania, 74% is under rainfed lowland rice and 6% is irrigated rice [24]. Rice grows and thrived in those lowlands without the need for extensive drainage [25]. Based on physiography and hydrology, rice lands were classified by Moormann and VanBreemen [26] into irrigated (where water supply is assured) and rainfed where water supply is uncontrolled. The cultivation of rainfed lowland rice in Cambodia [27], Loas, Nepal, Thailand and Madagascar [28] showed that the main management practices do not differ from those practiced in semi arid areas of Tanzania. These management practices include; land preparation, crop establishment (direct seeding or transplanting), weeding and harvesting. The only exceptions are rice fields in the flood plains near rivers which receive water from floods [29] where the rice fields are not bunded. This type of rice production is called unbunded flooded rainfed lowland rice system due to adequate water availability and widespread in the southern parts of Tanzania [14] where the rainfall is higher than 800 mm per annum and reliable.

7. Upland rice production

The characteristics of soils on which upland rice is grown are non-specific in respect to soil texture, pH, organic matter content, slope and soil fertility variations [30]. In Tanzania, 20% of the rice production is from upland rice [24]. According to Moorman and Dudal [31], sandy clay soil texture affects negatively the moisture status of a soil more than any other property except topography that makes sandy texture soil particularly important in upland rice fields which are bunded to hold water. For upland rice, it is important to consider texture of the subsoils as it serves as a moisture reservoir [16]. Textures of upland rice soils vary greatly like for example in Thailand, most upland rice in the hills is grown on clayey and clay loam soils which are characterized by high soil moisture retention capacities [16]. Therefore it is important to manipulate and establish the management practice in rice production systems to influence the production.

8. Forms of P and P transformation in flooded soils

Most mineral soils contain total phosphorus ranging from 0.09 to 0.18% P [32]. The total phosphorous in mineral soils is present as insoluble and soluble phosphates, both organic and inorganic, and as slightly soluble salts of calcium [33]. The soils may contain iron, aluminium, and calcium phosphate as determined by the pH of the soils [33]. Depending on the relative amounts of the phosphate forms, the mineral P in soils could be roughly classified into four categories namely (i) iron phosphate $Fe(H_2PO_4)_2$ (including occluded phosphate such as in lateritic soils with strong acidity), (ii) calcium phosphate $(Ca(H_2PO_4)_2$ (in soils of medium to slightly acid reaction), (iii) tricalcium phosphate $Ca_3(PO_4)_2$ (soils of neutral to alkaline reactions, such as calcareous soils) and (iv) aluminium phosphate $Al(H_2PO_4)_3$ in soils developed from volcanic tuff [34].The behavior of phosphates in flooded soils is markedly differently from that of phosphate in upland soils and also the availability of P is high under flooding conditions [34]. Under flooding a more soluble ferrous phosphate ($FePO_4.2H_2O$) which is the source of P available to plants is formed from the reduction of ferric phosphate ($Fe(OH)_2H_2PO_4$) [16, 35]. In general, wetland rice is much less responsive to phosphate than are dryland crops grown on the same soils, because flooded soils have more available native and added phosphates than well drained soils [34]. The increased availability of P in submerged and reduced soils is attributed to the redox potential of ferric phosphate to release the occluded phosphate and phosphate sorbed on amorphous iron and manganese oxides [34]. This is due to the reduction of ferric oxides and desorption by clays and aluminium oxides with increasing soil pH [34], according to the reaction;

$$HO—M—OH + H_2PO_4^- \longleftrightarrow HO—M—O—\underset{\displaystyle OH}{\overset{\displaystyle O}{\overset{\|}{\underset{|}{P}}}}—OH + OH^- \quad \text{...........................} \quad (i)$$

where M is Al or Fe

These oxides are the most reactive cationic centres at low soil pH values [35]. Chang [34] claimed that the reduction of iron phosphates was the main source of available P for wetland rice. Besides the transformation of the various P compounds into soluble forms, increased P diffusion due to the increase in the extent and continuity of the soil solution contributes to increased availability of P in flooded soil and subsequently to the increase in its uptake by rice plants. As the rate of plant P uptake increases also the rate of release of P from the various compounds increase into the soil solution so as to maintain the P equilibrium [34]. In this context, the measurement of P availability could provide useful information concerning soil health and also serve as a good index of chemical status in different rice crop management systems.

10. Role of phosphorus in rice production

Phoshorous is taken up by plants as $H_2PO_4^-$ and HPO_4^{2-} [9]. Phosphorus in rice plants as it for other plants is involved in storage and transfer of high energy compounds, the most common compound being adenosine triphosphate (ATP); regulatory role in plant metabolism, influences the activity of enzymes and is a constituent of a number of structural units of plants such as nucleic acids (DNA and RNA) and phosphoproteins [15]. The concentration of P in the rice plant depends on plant age, variety, season and available P level in the soil [9]. Ishizuka [36] reported that the percentage of P is high in seedlings, decreases after transplanting, then gradually increases, peaks at primodial initiation and decreases after the flowering stage until the dough stage. This behavior is attributed to the mobility of phosphate within plants. The variation in P concentrations in rice plants is related to the P absorbing power of the rice roots, which is high during the vegetative and reproductive period [9]. The P absorbed by the rice plants can be translocated from the older to the younger leaves. Because of its mobility in plants, adequate P supplied at early growth stages ensures adequate P for grain development. Tandon [37] pointed out that no soil can sustain high yields if it is deficient in P. It is, therefore, evident that no plant can grow normally or give good yield if it suffers from P deficiency and this conforms to the Liebig's Law of Minimum and Mitscherlich's equation of plant growth with respective to nutrient supply and availability [38].

11. Critical P levels in soils

The critical P concentration in soil is the level above which little or no response to added P is obtained and below which response to added P is expected [39]. Many soil P testing methods have proved inadequate in determining the P supplying capacity of wetland rice soils because of the different P retention mechanisms and transformations in paddy soils as governed by the soil moisture levels in such soils [40]. Acid extractants like NH_4F- HCl that dissolve only calcium and aluminium phosphate provide poor indications of available phosphate in soils containing appreciable amounts of iron phosphate and reductant soluble phosphate that become available to the crop after waterlogging. This is because under flooding a more soluble ferrous phosphate ($Fe_3(PO4)_2.8H_2O$) which is the source of P available to plants is formed from the reduction of insoluble ferric phosphate ($FePO_4.2H_2O$) as reported by Patnaik [35] and De Datta [16]. The hydrolysis of aluminium and iron phosphates at higher soil pH, desorption of phosphorus from clay and oxides of aluminium and iron and dissolution of apatite due to higher CO_2 pressure in the soil solution are the other causes for the higher availability of P in flooded soils. According to Chang [34], when the iron phosphate is dominant (usually at pH above 5.5), most of the methods like Bray1 extractant often give good correlations and when calcium phosphate is dominant (usually with pH above 6.5), the use of alkaline extractant, like the Olsen's extractant (0.5M $NaHCO_3$) is preferable [41]. Also when the various phosphates have mixed distribution patterns, alkaline extractants, such as the 0.5M $NaHCO_3$ and weak acidic extractants containing a complexing radical for trivalent cations (Al, Fe), like the NH_4F- HCl are desirable. Critical P concentrations in the soils for rice which have been reported by various scientists show wide variations depending on the method of extraction, soil types and climatic conditions. The critical P value in the soils of warmer regions for rice has been reported to be 26 mg P kg^{-1} soil as determined by 0.03M NH_4F+0.1NHCl [40]. The Philippine Council for Agriculture Resource Research and Development [42] established the critical Olsen P level for rice at 10 mg P kg^{-1} soil. These variations are attributed to the amounts of phosphate in soil solution that depends on soil pH, buffer capacity of the soil, quantity of labile solid phase P, diffusion rate, levels of Al and Fe and their oxides in the soil, temperature and source of available P [38]. However, currently P availability as extracted from soils by various extractants is expressed in terms of critical ranges, like critical nutrient ranges instead of absolute critical concentration values [38]. Understanding the dynamics and critical P levels in the soils is crucial for predicting their interactions as in turn its activity may regulate P uptake and plant growth in the production systems.

12. Critical levels of P in rice plants

The critical nutrient concentration ranges of elements in rice plants is defined as the level below which deficiency symptoms may develop or above which toxicity symptoms may become visible [16]. The critical levels of P in rice plants vary according to crop age and plant part analyzed because of the mobility character of P in plants. Further, Marschner [43] reported that synergetic and antagonistic interactions between N and P influence the concentrations of either of them in the plant especially when their levels in the soil are near the deficiency range. Increasing the supply of only one of them stimulates growth, which can induce the deficiency of the other through the dilution effect. The concentration of phosphorus (P) in most plants is between 0.1 and 0.4% [38]. Tanaka and Yoshida [44] reported that rice plants whose P concentrations at tillering stage is 0.1% or lower are P deficient while those with P concentration > 1.0% suffer from P toxicity. Similarly, Mikkelsen [45] reported that the critical concentration of P in the rice plant at maximum tillering was 0.1%, the results also indicated that adequate P concentrations in the rice plants were in the range of 0.12 to 0.24%. Studies in Tanzania by Semoka and Shenkalwa [46] showed that a P value of 0.21% at panicle initiation stage in rice shoots was associated with the highest DM yield. When P was applied to soils at the rate of 60 kg/ha, to soils with initial 7.0 mg P kg^{-1} Bray-1-P, suggesting that this level of P was adequate for rice. Deficiency symptoms of phosphorus include reduction in leaf expansion and leaf surface area [47] as cited by Marschner [15] and number of leaves [48] as cited by Marschner [15]. Premature senescence of leaves and delayed flower initiation are also regarded as deficiency symptoms of P [15]. It is, therefore, apparent that P concentration values in rice shoots of around 0.2% at maximum tillering or panicle initiation could be taken to indicate adequate P content in rice plants.

13. Strategies and approaches to enhance P use efficiency by rice plants

The reversion of plant available P to unavailable forms is a process that cannot be avoided, but with proper management can lead to increase in plant use efficiency of fertilizer P [49]. According to Sanchelli [50], practices that directly affect the availability of native or applied P include liming, application of manure and crop residues, fertilizer placement, rate, time and frequency of phosphate application. Management of P intensity influences the contents and forms of P in soils. Richards *et al.* [51] reported that resin and $NaHCO_3$-P were increased by 3% as a result of P fertilizer application. Tunney *et al.* [52] found that labile P fractions were increased to a greater extent by long term application of P than the more stable fractions of P. Further, Jama *et al.* [53] observed that moderate rates of P (10-20 kg P ha^{-1}) could give economic increased in yield and at the same time bring about a gradual build up of the P status of soils under acidic conditions due to the fixation of the P applied by Fe and Al. Adequate availability of P for growing plants has been enhanced by methods of P fertilizer applications and rates of P application [8]. Concentrating the phosphate fertilizer near the seed has been found to reduce phosphate fixation and ensure a high concentration of soluble P for plants because P released from P fertilizers is easily taken by the very young seedlings [54], [52]. Other studies by Olson and Engelstad [55] showed good responses with appreciable residual effects from nominal rates (30 to 60 kg P ha^{-1}), while others emphasized the need to satisfy the P-retention capacities of soils by heavy P dressings before effective crop response occurs. Further, Juo and Fox [56] reported that in order to maintain a given level of solution P in soils with high P retention capacity, it is advisable to add larger quantities of P fertilizers. Higher amounts of P fertilizer application are recommended for soils with low initial P and high P fixing capacities in order to reach the critical concentration range of 15 - 50 mg P kg^{-1} soil for plant uptake [57]. Furthermore, Mozaffari and Sims [58] recommended long-term applications of P so as to reduce P sorption capacity in some soils while Griffin and Hanna [59] suggested the need for heavy and band applications of phosphate fertilizers for substantial plant response to be realized. Izac [60] and Buresh e*t al.* [61] supported both approaches as means of improving P fertility of soils which would result into increased yields and income to farmers. However, Jones *et al.* [40] recommended that to offset the rapid fixation of the applied phosphates, P fertilizers should be applied frequently instead of large infrequent applications aimed at supplying the P needs for plants for three or more years. Also the use of plant growth regulators such as auxins, gibberellins, cytokinins, abscisic acid (ABA) and ethylene are important because some have the ability to solubilize phosphate [62], resulting in an increased availability of phosphate ions in the soil, which can be easily taken up by the rice plants.

14. Conclusion

Because of increasing human population and rice consumption rates, the priority for rice production in Tanzania have to be placed on the irrigated lowland, rainfed lowland, and upland ecosystems. Also for any production system the correctly outlining of other unknown constrains/ factors that affects rice growth is important to enable farmers to suggest strategies which lead to increased production through improved plant nutrition. Future research should focus on role of phosphorus and manipulating the production constrains in the variable rice production systems to enhance rice yields.

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