Basal fertiliser effects on the development of the rhizosphere of rainfed rice in relation with vegetative growth and yield in mid-season drought-prone environment

K.R. N’ganzoua1*, B. Koné1, S. Fatogoma2, E. Jean Baptiste1, A. Yao-Kouamé1, K. Daouda2, C. Mameri3

Felix Houphouet Boigny University, Cocody, Soil Science Department
22 BP 582 Abidjan 22, Abidjan, Côte d’Ivoire
Felix Houphouet Boigny University, Cocody, Plant Physiology Department
Agronomic Research Center-CNRA, Gagnoa, BP 602 Gagnoa, Gagnoa, Côte d’Ivoire

Abstract

Annual rain-fall reduction and variability are associated with increasing duration of mid-season drought period under bimodal rainfall pattern in West Africa. This situation limits the success of basic drought management strategies in rainfed rice production that account for about 80% of cultivated rice surface in sub-region. To enhance adaptation of rice to the actual climate, an agronomic trial was conducted in order to improve rice rhizosphere (root depth, root length density, soil exploration rate by root), its vegetative growth (height, tillers, leaf) and the 1000-grain weight and yield. Seven additive fertiliser treatments (K [T1], KP [T2], KN [T3], NPK [T4], NPKCa [T5], NPKCaMg [T6] and NPKCaMgZn [T7]) were laid out in a complete block design on Arenosols of foot slope, in a guinea savanna ecology of Côte d’Ivoire. No fertiliser treatment was the control and the roots were studied by profile method. Data was transformed by RACINE©. No significant difference was observed for leaf number and plant height by treatment at successive development stages. However, treatments K, KP and KN induced faster growth rate of root and deeper root development enhancing the improving effects of P and N on root elongation and ramification, respectively. Meanwhile, decreasing effect of Ca++ was observed for these parameters even if combined with Mg and Zn which are also potential root improvers. Applying KN was recommended for highest root length density; soil exploration rate, grain filling and yield in the studied ecology. Supplying soil deficient nutrients was further advised as basic concept for mitigating mid-season drought adverse effect in a given environment.

Key words: rainfed rice, root, drought, soil, guinea savanna, West Africa, Côte d’Ivoire

Introduction

Rice (Oryza sativa L.) currently sustains the livelihoods of about 100 million people in sub-Saharan Africa (SSA). It is an important crop in attaining food security and poverty reduction in many low-income, food-deficit African countries. However, the demand for rice far outstrips its production in Africa, which in the last 30 years has increased mainly due to land expansion, with only 30% being attributed to an increase in productivity (Fagade, 2000). To meet the shortfall in production, West Africa region imports more than 6 million tonnes per annum into the sub-region, costing about USD 1 billion in scarce foreign exchange annually (Oikeh et al., 2008). Therefore, it is important to improve rice production in sub-Saharan Africa. However, 80% of cultivated rice surface in West Africa depends on rainfall only (Audebert et al., 1999) whereas the climate change effect is important in this area (CNRS, 2000). The variability and reduction of rainfall in West Africa is associated with prolonged mid-season drought of bimodal raining area (Koné et al., 2008). These characteristics of the actual climate are limit the success of traditional mechanisms of drought management including drought escape, drought avoidance, drought tolerance and drought recovery (Fukai and Cooper, 1995; Price et al., 2002). This situation affects rice
production even on the foot slope soil which includes a seasonal water Table. Therefore, rice cultivation needs adaptation to the actual climatic event for sustainable production in West Africa.

The development of rice rhizosphere can improve both water and nutrient absorptions, thereby reinforcing rice tolerance to drought. Indeed, there is positive interactions between fertilisers and soil moisture content (Koné et al., 1998). Fertiliser can improve crop rhizosphere and yield (Jeon, 2006). In this context, potassium (K) is known to have an increasing effect on root development (Jia et al., 2008). It was assumed that the effect of K can increase by the interaction with the other essential nutrients (N, P, Ca, Mg and Zn) of rice nutrition.

On this basis, an agronomic trial was initiated to explore the possibility to improve upland NERICA 5 rhizosphere (root deep, root length density, root distribution and exploration rate of soil) as well as vegetative growth and yield by applying different combinations of K to N, P, Ca, Mg and Zn fertilisers in a foot slope soil. The aim was to identify the basal fertiliser that can improve rice rhizosphere characteristics and yield in a mid-season drought-prone area.

Materials and methods

Site description

The study was carried out in guinea savanna zone of Côte d’Ivoire at M’be (8°06 N, 6°00 W, 180 m) preceding by one year bush fallow essentially composed of Imperata cylindrica on a foot slope topographic position. Rainy season started from June followed by drought of 21-45 days from August before a new rainfall season of 2 months. The soil was Arenosols characterised by a pH of 6.7, 3.8 g C kg⁻¹, 0.5 g N kg⁻¹, 10 mg P kg⁻¹, 0.01 cmol K kg⁻¹, 2.5 cmol Ca kg⁻¹, 0.3 cmol Mg kg⁻¹ and 2.3 mg Zn kg⁻¹. Seasonal water Table was also observed at the end of rainy season.

Experiment layout and data collection

Seven treatments (K [T1], KP [T2], KN [T3], NPK [T4], NPKCa [T5], NPKCaMg [T6] and NPKCaMgZn [T7]) were applied as basal fertilisers during land preparation. No fertiliser treatment (T0) was the control. NERICA 5 was sown per hill of two grains spaced at 20 cm in a micro-plot of 15 m². Nitrogen was applied at 35 kg ha⁻¹ at rice tillering and topdressing stages, respectively after manual weeding. At tillering, topdressing and maturity stages, core samples of root were taken using PVC of 10 cm in diameter dimension for determining root depth and growing rate. At maturity, data were taken on plant height, numbers of leaves, tillers and panicles before the harvest in 8 m². The grains were sieved and weighed for each treatment in order to calculate the yield. One thousand grains were randomly taken before weighing for estimation of relative grain filling. A profile of 70 × 70 cm was opened at 5 cm from plot border to count root impact in soil using a grille of 30 × 60 cm.

Data management and statistical analysis

The root impact number counted in grille (Ni) was transformed by software named RACINE (Chopart and Christophe, 2004) that can generate root maximum depth, root length density and soil exploration rate. These transformed root data, plant height, numbers of leaves, tillers and panicles. The 1000-grain weight and yield were used for Pearson correlation and ANOVA analysis performed with SAS 10. 

Results

Root and above ground development as affected by treatment

Figure 1 shows the development of rice root at different physiological stages and plant weight according to the studied treatments. No significant difference was observed between mean values of height at topdressing and maturity stage in all the treatment whereas significant lower value was observed at tillering. The plant height was two times higher than the root growth regardless to treatments and rice physiological stages.
There was an increase of root depth from tillering to rice maturity. However, only T2 has induced significant difference between the values observed at topdressing and maturity stages. Treatments 1, 2 and 3 have induced deepest root early at tillering.

Table 1 shows significant overall Pearson correlation between root depth and plant vegetative growth with a variance of this relationship: No significant correlation was observed between the root depths and leaves number per square meter in T2 and T3 whereas, they have highest positive significant correlations value with plant height and tiller number, respectively. The highest value of soil exploration rate was observed in T3 among the studied treatments far away from T2 (Figure 2).

**Figure 1:** Development of plant height (A) and root depth (B) and tillering, topdressing and maturity stages according to the treatments (T0, T1-T7)

**Figure 2:** Soil exploration rate (EXR) by root according to treatment
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Table 1: Pearson correlation values calculated between root depth and plant height, numbers of tillers and leaves by square meter

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.469</td>
<td>0.145</td>
<td>0.684</td>
<td>0.014</td>
<td>0.713</td>
<td>0.009</td>
<td>0.885</td>
<td>0.0001</td>
<td>0.646</td>
</tr>
<tr>
<td>Tillers</td>
<td>0.749</td>
<td>0.008</td>
<td>0.740</td>
<td>0.006</td>
<td>0.771</td>
<td>0.003</td>
<td>0.836</td>
<td>0.0007</td>
<td>0.609</td>
</tr>
<tr>
<td>Leaves</td>
<td>0.111</td>
<td>0.794</td>
<td>0.699</td>
<td>0.054</td>
<td>0.483</td>
<td>0.225</td>
<td>0.580</td>
<td>0.132</td>
<td>0.819</td>
</tr>
</tbody>
</table>

Figure 2: Soil exploration rate (EXR) by root according to treatment

Rice root development and grain production
The grain filling as illustrated by the 1000-grain weight was significantly and positively correlated to the root impact number (Ni), root length density (RLD) and soil exploration rate by root (EXR) (Table 2).

Table 2: Correlation coefficient values between 1000-grain weight and rhizosphere characteristics (Ni, RLD, RD, EXR and MD)

<table>
<thead>
<tr>
<th>Root parameters</th>
<th>Ni</th>
<th>R²</th>
<th>Prob.</th>
<th>RLD</th>
<th>R²</th>
<th>Prob.</th>
<th>RD</th>
<th>R²</th>
<th>Prob.</th>
<th>EXR</th>
<th>R²</th>
<th>Prob.</th>
<th>MD</th>
<th>R²</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight for 1000 grains</td>
<td></td>
<td>0.338</td>
<td>0.058</td>
<td>0.354</td>
<td>0.257</td>
<td>0.206</td>
<td>0.257</td>
<td>0.358</td>
<td>0.044</td>
<td>0.079</td>
<td>0.664</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3: Weighed mean value for 1000-grains per treatment

Although not significantly different, the highest 1000-grain weight was recorded for T3 and the lowest for T2. However, both treatments have induced higher grain yield than the overall mean value obtained during the experiment (Figure 4).

Figure 4: Mean value of grain yield by treatment (horizontal line is grand mean level)

Discussion
Soil and physiological aspects of root development

The Arenosols studied was free of morphological constraint that could have limited rooting depth (Jeon, 2006). However, on foot slope topographic position, the occurrence of seasonal water Table could have restricted root depth especially, in the later development stages, reducing it growth rate between the topdressing and maturity stages. At the end of the rains, there was accumulation of grown water inducing flowing of water Table. This saturation of soil will limit the root depth asphyxiating the meristem (Moormann et al., 1977). However, this constraint could have been mitigated in T2 (PK) that has induced significant root depth between later developments stages underlining positive interaction of P and K on rice rhizosphere. This treatment did not, however, induce high exploration rate of soil by root architecture: Fewer ramifications in rhizosphere can account for this contrasting with the result observed in T3 (KN). Therefore, it is asserted that P can improve rooting depth while N is related to root ramification when they are combined to K, respectively. These characteristics of root are particularly altered by T5 (NPKCa) and T7 (NPKCaMgZn). The effect of T5 can be attributed to the physiological function of Ca++ as signal transducer inducing responses to biotic and abiotic stress (Cvetkovska et al., 2005). Therefore, rice in T5 could be more sensitive to mid-season drought, adversely affecting the activity of biosynthesis hormone (Hong-Bo et al., 2008) hence, limiting rooting depth. This result confirms the findings by Koné et al. (2008) concerning the tolerance of rice to water stress on Acrisols when Calcium was excluded from basal fertiliser.

In T7, minimising effect of Ca++ occurred in spite isomorphic competition with Mg++ as in T6 (KNPCaMg). This competition can mitigate Ca++ effect on root growth. Furthermore, Zn++ in T7 can increase auxin levels in plant, which can enhance root growth (Bennett and Skoog, 2002; Waraich et al., 2011). However, the effect of Zn++ was limited because of the excess induced by 10 kg Zn ha⁻¹ whereas not deficiency (> 1 mg kg⁻¹) in the studied soil. Thus, a reducing uptake and utilisation of manganese by plant for root development can occur (Ranade-Malvi, 2011; Waraich et al., 2011).

We learn from our finding the existence of some positive and negative interactions between soil nutrients for root growth, whereas they are recommended for rhizosphere development, respectively (Waraich et al., 2011).

Drought stress management

Treatments 2 and 3 are likely to be suitable for root development in mid-season drought-prone area. This is confirmed by their grain yields of about 2 t ha⁻¹ that were greater than the grand mean obtained during the experiment. However, the 1000-grain weight was lower in T2 than the observed values for the other treatments, revealing poorest grain filling, contrasting with T3. Therefore, the high yield in T2 could be a consequence of highest number of grains per panicle whereas T3 has higher correlation with plant height and panicles numbers than T2, respectively. The correlations in T3 justify the highest ability of rice grain production and evapotranspiration that is accounting for a water use indicator (Al-Kaisi and Broner, 2009). Rice vegetative growth can increase the evapotranspiration for the improvement of water uptake by root (Koné et al., 2008). The highest soil exploration rate by root in T3 during the experiment is an illustration of this analyse.

There was an unexpected result in treatment T4 including N, P and K, the common ternary fertiliser recommended around the world for most of the crop: despite of positive correlation between root depth and vegetative parameters in T4, it has induced poor root development and lowest grain yield differing with the study of wheat in water stress condition (Baque et al., 2006). The concentrations of these nutrients in the studied soil could contributed for this: K and N was the limiting nutrients for rice cultivation while P was at suitable level (Koné et al., 2009). Therefore, the correction of these deficiencies appears to be rational and was justified by the effects of T3 on the development of rice’s rhizosphere development, vegetative growth and grain yield in the studied ecology. It is, thus, from this analyses, necessary to correct soil nutrient deficiency for best fertiliser strategy in mitigating mid-season drought.

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Conclusion
This study revealed the ability of basal fertiliser composed of N and K to enhance rice vegetative growth and the root depth in mid-season drought-prone area. The nitrogen was an improver of root ramification for highest root length density and soil exploration rate. The improvement of these morphological traits could have improved the evapotranspiration and water uptake for high grain yield production.

Recommendation
Soil mineral diagnostic is recommended as basic concept for water stress management and a basal fertiliser composed of NK is suitable for foot slope soil in guinea savanna ecology of West Africa.

References
dosclim/rechfran/4them/cyclel’eau/moussonAfOuest.htm.[21 Novembre 2007].


