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Difference in blast development in upland rice grown on an Andosol vs a Ferralsol

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ABSTRACT

In the densely populated highlands of Madagascar, growing upland rice offers the opportunity to increase the total rice cropping area and to improve food security. However, rice blast was a major constraint for the first cultivars released in the 1990s and consequently limited the extension of upland rice. However, blast epidemics are much less intense in the region of Betafo, where the composition of the soil, an Andosol developed from volcanic rock, is different from the classical Ferralsol of the highlands. A 3-year field experiment (2009–2011) was conducted near Antsirabe to compare blast epidemics on rice grown in Ferralsol vs. an Andosol. Leaf and panicle blast development were monitored and the yield components of upland rice plants growing on the two different soil orders were measured. In 2009 and 2011, leaf and panicle blast development were significantly lower for plants grown on the Andosol compared to those grown on the Ferralsol (final panicle blast reduced by 40% in 2009 and 20% in 2011). The severity of blast was shown to be related to the concentrations of mineral elements in the plant, and the Si content was significantly higher in plants growing on the Andosol. In 2010, the differences of blast incidence between the two soils were less marked (14% reduction of panicle blast at the last scoring date). AUDPC were lower in the Andosol compared to the Ferralsol each year, for leaf and panicle blast. The yield components 1000 full grain weight, dry straw weight and the yield were higher in the Andosol compared to the Ferralsol in 2009 and 2010 but were not significantly different in 2011. These results clearly document that blast development may be impacted by the soil order in which rice is grown, and future agronomic management of blast should focus on improved soil mineral composition such as silicon.

1. Introduction

Blast, caused by the fungus *Pyricularia oryzae* Cavara [syn. *Magnaporthe oryzae* Couch], is one of the most widespread diseases of rice (*Oryza sativa* L.) and occurs in all rice growing regions in the world (Pennisi, 2010). The damage caused by leaf blast is due to the decrease in active photosynthetic area during the growing stage, which results in a decrease in tillering, in the number of panicles and in the number of grains per panicle (Bastiaans, 1991) and can kill the plants fully in severe situations. In terms of yield loss, panicle or neck blast is the most destructive form of the disease because it prevents grain filling (Ou, 1985).

Rice is the staple food crop in Madagascar with a consumption of 154 kg per capita per year in 2013 (FAOSTAT, 2018). The country needs to import rice to supply its own production. The traditional rice production in the lowlands is limited by the area that can be devoted to that cropping system. Upland rainfed rice is a recent crop in the densely populated highlands of Madagascar, whose altitude ranges from 1400 to 1800 m above sea level (m asl), making it possible to increase the area under rice production and to improve the food security of farm households. The first cultivars released to farmers during the 1990[s] were rapidly attacked by blast (Raboin et al., 2014) and the disease continues to be a constraint for any new cultivar developed and released in the region. Today, there is a race between breeders and blast: breeders have to rapidly produce new cultivars and find new sources of resistance, because blast rapidly adapts to any new resistant cultivars and is simultaneously becoming increasingly aggressive. Even the severity of blast on upland rice in farmer's field is low due to the tolerance

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of cultivars, blast pressure is still high and caused 50%–100% yield losses over the last 10 years at the experimental research station (Sester et al., 2014). There is thus an urgent need for other strategies to limit blast pressure and to delay the extension of virulent forms of the pathogen, thereby increasing the useful life of the new cultivars.

Blast management strategies usually involve cultivars and fungicide treatments, but this later practice is not sustainable and is too expensive for poor farmers in Madagascar, so agroecological management is necessary to reduce the propagation of the inoculum like crop rotations and residues destruction (Raveloson et al., 2018). Many studies have shown that the nutritional balance can be successfully used to limit blast epidemics, confirming that rice tolerance to blast can be enhanced by improving rice nutrition (Datnoff et al., 2007; Sester et al., 2014; Dusserre et al., 2017).

The soil characteristics (organo-mineral and biological content) are known by agronomists to play a key role in the development of blast epidemics but only a few experiments have demonstrated it at the field level. In 1981, Seguy et al. conducted an experiment to measure the impact of soil on rice susceptibility to blast and compared rice growing on a volcanic vs an hydromorphic soil from Cameroon, in pots placed outside in a place with a high blast pressure. The differences in blast severity they measured were spectacular. After analysis of soil mineral content, they concluded that the "natural fertility potential" of the volcanic soil explained why the level of blast was consistently lower on plants grown on that soil. A similar experiment was reported by Bonman (1992), with pots transferred from one region of the Philippines to another. In conclusion, the authors proposed that the term "disease potential" should be applied to each site depending on the soil type.

In Madagascar, epidemics of blast disease are much less intense in the region of Betafo, an important traditional rice production area located 22 km west from Antsirabe, which is characterized by Andosols developed on recent volcanic materials, than on the acid Ferralsols in the highlands. Based on those observations, we conducted a 3-year field experiment to compare blast disease in rice grown on a typical Ferralsol and on Andosol imported from the Betafo region, to investigate the ability of plants grown under specific soil fertility to improve their tolerance to blast disease in the field and to identify the relationship between the direct impact of soil on tolerance factors and the indirect impact through plant development. We hypothesized that cropping practices that restore soil fertility will improve rice tolerance to diseases in Ferralsol.

2. Materials and methods

2.1. Location

The experiment was conducted at Andranomanelatra (S 19°78′, E 47°11′, 1640 m asl.) in the Vakinankaratra region of the highlands of Madagascar. The tropical altitude climate is characterized by cool dry winter from May to September and warm wet summer from October to April, which is the rice cropping season. Average annual rainfall is 1460 mm.

2.2. Plant material

Two upland rice cultivars adapted for high altitude were used. Fofifa 152 (F152) is one of the first cultivars selected in the CIRAD-FOFIFA breeding program (Raboin et al., 2013). It was successfully released to farmers in the 1990s and was appreciated for its taste. However, in 2003 this cultivar resistance broke down and is now considered one of the most susceptible cultivars adapted to the rainfed conditions typical of the region. Fofifa 172 (F172) is a recent cultivar, and was seen to be resistant to nine differential strains of *P. oryzae* isolated from upland rice in Madagascar, after inoculation in a greenhouse (data not shown). It was used as a barrier between plots of F152.

2.3. Soil type

Two types of soil were compared in this study. The first type of soil, at Andranomanelatra, developed on volcano-lacustrine alluvia (Raunet, 1981). The second soil was transported from the village of Betafo, 18 km west of Antsirabe, in a region with recent volcanism. The type of soil at Andranomanelatra was classified as Geric Ferralsol according to the FAO soil classification (IUSS Working Group, 2014), using data collected by Razafimbelo et al. (2006). The soil texture is clayey with 66% clay, 17% fine silt, 3% coarse silt, 6% fine sand and 8% coarse sand. The soil is acidic (water pH 4.6) and the total carbon content is 46.9 g kg^{-1}. The soil from Betafo is classified as Silandic Andosol, and contains 12% clay, 39% fine silt, 12% coarse silt, 16% fine sand and 21% coarse sand (data from soil analysis performed in 2009).

2.4. Experimental design

The experiments were conducted in 2009, 2010 and 2011. The field was plowed manually and a fine seedbed prepared by secondary tillage. Six to eight rice seeds were sown manually in seed holes spaced 20 × 20 cm apart (25 hills per m^2). Before sowing, rice seeds were treated with Gaucho® (35% imidacloprid + 10% thiram) at a rate of 2.5 g per kg of seeds, as protection against insects. Weeds were removed by hand. The same amount of fertilizer was applied to each plot: cattle manure at a rate of 5 t ha^{-1} fresh weight plus NPK mineral fertilizer (11% N, 22% P_2O_5, 16% K_2O) at 300 kg ha^{-1}, dolomite ($CaMg(CO_3)_2$) at 500 kg ha^{-1} applied at sowing and two top-dressings of urea (46% N) at 50 kg ha^{-1} applied 30 and 70 days after sowing (beginning of tillering and beginning of the booting stage).

A randomized complete-block design was used for all three experiments with four replicates. Elementary plots containing the susceptible F152 variety (3 m × 3 m in 2009 and 2011, 3 m × 5 m in 2010) were separated by 3 m of F172 to avoid border effects. The basic rotation was two years, with upland rice followed by intercropping with pigeon pea (*Cajanus cajan*), sunnhemp (*Crotalaria grahamiana*) and finger millet (*Eleusine coracana)*. Two neighboring fields were cultivated by turns (one in 2009 and 2011, the other in 2010). In 2009, we removed 4 m^3 of Andosol from an upland rainfed field, cropped with rice the previous year, in the region of Betafo. The soil sample was placed in a cylindrical hole, 0.50 m in depth (depth of the major part of the roots, Dusserre et al., 2012) and 1.6 m in diameter (1 m^3), in the center of the elementary plots. In 2010 and 2011, 6 m^3 of soil from another field in Betafo were placed it in a rectangular 1.5 m × 2 m hole, 0.50 m in depth in the center of the elementary plots.

Three treatments were compared each year: rice growing on the local Ferralsol, rice growing on imported Andosol and, as a control of growth potential rice growing on Ferralsol with chemical treatment against blast: alternate fungicide treatments with Antracol® (70% Propineb, 3 kg ha^{-1}) and carbendazim (50% carbendazim, 1 l ha^{-1}) applied once a week in 2009 and twice a week in 2010 and 2011 from the first symptoms observation during tillering to the end of filling stage with a backpack sprayer (Cooper Pegler®, model CP15).

3. Measurements

3.1. Assessment of blast disease

Blast infection occurred naturally in our experiments. Leaf blast severity was estimated weekly from the first symptoms observation (in general during the first stage of tillering) to flowering stage (Dusserre et al., 2017), six times in 2009 and 2010 and seven times in 2011. The severity of leaf blast (LB) was assessed as follows: on 10 hills per experimental unit, the total number of tillers per hill and the number of tillers with at least one typical leaf blast symptom were counted; on three diseased tillers, the percentage of leaf area affected by blast symptoms was estimated visually on the four uppermost fully expanded