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ORIGINAL ARTICLE / ORIGINALBEITRAG

Effect of Phosphorus and Arbuscular Mycorrhizal Fungi (AMF) Inoculation on Growth and Productivity of Maize (*Zea mays* L.) in a Tropical Ferralsol

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Abstract

Soil fertility in the Lubumbashi region often proves to be limiting factor for crop production due to their low nutrient reserves. The objective of this work was to evaluate the impact of arbuscular mycorrhizae on phosphorus uptake by maize on Ferralsol. The trial was conducted in pots with 30 kg or 60 kg of P_2O_5 ha^{-1} and a control. These three levels of phosphorus were combined or not with arbuscular mycorrhizae. The combinations of 30 kg or 60 kg of phosphorus with the inoculum led to a male flowering of maize at 63 days after semi. Maize treated with 60 kg of phosphorus ha^{-1} formed very few or almost no blisters in the roots. Cob weight, length, diameter, number of rows and kernel weight varied significantly with phosphorus on both inoculated and uninoculated pots. The inoculated plants had high averages for these yield parameters. Due to the lack of phosphate fertilizer, inoculum alone can be an alternative to phosphorus provided that nitrogen and potassium are added, resulting in small but seed-filled ears compared to the phosphorus-free control without mycorrhizae, which resulted in empty ears. Yield varied significantly with the addition of phosphorus (0.3 to 6.1 tons ha^{-1}) and less significantly with inoculum (3 to 3.7 t ha^{-1}). The combination of treatments showed a significant difference in favour of the 60 kg of phosphorus or 60 kg of phosphorus associated with the inoculum. The highest phosphorus content was obtained on the inoculum treatment alone, which provided 1.4 mg phosphorus g^{-1} maize compared to other treatments, which provided 0.69 to 0.71 mg phosphorus g^{-1} maize.

Keywords Ferralsol · Arbuscular mycorrhizae · Phosphorus · Maize

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Wirkung von Phosphor und arbuskulären Mykorrhizapilzen (AMF) auf Wachstum und Produktivität von Mais (*Zea mays* L.) in einem tropischen Ferralsol

Zusammenfassung

Die Bodenfruchtbarkeit in der Region Lubumbashi erweist sich aufgrund der geringen Nährstoffreserven oft als einschränkender Faktor für die Pflanzenproduktion. Ziel dieser Arbeit war es, die Auswirkungen von AMF auf die Phosphoraufnahme von Mais zu bewerten. Der Versuch wurde in Töpfen mit 30 kg oder 60 kg P_2O_5 ha^{-1} und einer Kontrolle durchgeführt. Diese drei Phosphormengen wurden mit oder ohne AMF kombiniert. Die Kombinationen von 30 kg oder 60 kg Phosphor mit dem Inokulum führten zu einer männlichen Blüte des Maises 63 Tage nach der Aussaat. Mais, der mit 60 kg Phosphor ha^{-1} behandelt wurde, bildete sehr wenige oder fast keine Blasen in den Wurzeln. Das Kolbengewicht, die Länge, der Durchmesser, die Anzahl der Reihen und das Korngewicht variierten signifikant mit dem Phosphorgehalt sowohl in den beimpften als auch in den nicht beimpften Töpfen. Die beimpften Pflanzen wiesen hohe Durchschnittswerte für diese Ertragsparameter auf. Mangels Phosphatdünger kann Inokulum allein eine Alternative zu Phosphor sein, sofern Stickstoff und Kalium zugesetzt werden, was zu kleinen, aber samengefüllten Ähren führte, verglichen mit der phosphorfreien Kontrolle ohne Mykorrhiza, die zu leeren Ähren führte. Der Ertrag variierte signifikant mit der Zugabe von Phosphor (0,3 bis 6,1 t ha^{-1}) und weniger signifikant mit dem Inokulum (3 bis 3,7 t ha^{-1}). Die Kombination der Behandlungen zeigte einen signifikanten Unterschied zugunsten von 60 kg Phosphor oder 60 kg Phosphor in Verbindung mit dem Inokulum. Der höchste Phosphorgehalt wurde bei der Inokulation allein erzielt, die 1,4 mg Phosphor g^{-1} Mais lieferte, verglichen mit anderen Behandlungen, die 0,69 bis 0,71 mg Phosphor g^{-1} Mais lieferten.

Schlüsselwörter Ferralsol · Arbuskuläre Mykorrhizapilze · Phosphor · Mais

Introduction

Phosphorus (P) is an essential nutrient which is important for plant growth and many physiological processes such as metabolic energy transfers and nucleic acid metabolism (Chang et al. 2008; Eppendorfer and Eggum 1994; Grant et al. 2014; Martin-Prével and Montagut 1966). In tropical soils, the P concentration in the soil solution generally ranges between 0.1 and 10 µM (0.003 to 0.3 ppm) and is much lower than the adequate concentration for optimal growth of many crops (Liu et al. 2016). The orthophosphates, $H_2PO_4^-$ and HPO_4^{2-}, are the primary forms of phosphorus taken up by plants. However, these two forms are often in low concentration, mostly in highly weathered tropical soils. In general, the pH range of 6–6.5 is considered optimal for phosphorus uptake by the plant. In acidic soils (pH < 5.5), aluminium cations (Al^{3+}) are dominant in soil solution and they can immobilize P to form the poorly soluble $AlPO_4$ which can limit plant root growth. In basic soils, Ca^{2+} and Mg^{2+} dominate the cationic exchange capacity and the P immobilization becomes more important (Enita 2000; Oteino et al. 2015). The role of phosphorus (P) is yet crucial in plant production and it can be supplied as chemical fertilizers, but this is not generally possible for smallholder's farmers in tropics because of their low income. It is then useful to improve phosphorus (P) availability and one opportunity is provided by the inoculation of crops with arbuscular mycorrhizal fungi (AMF). The AMF make symbiosis with root plants and are able to secret phosphatase, which catalyze and release P for the benefit of plants (Grant et al. 2004; Tshibangu et al. 2020a). They also confer robustness to plants and they improve crop yields (Beaudin et al. 2008; Grant et al. 2014; Jan et al. 2014; Tshibangu et al. 2020b). AMF thus improves uptake of immobilized plant nutrients, especially P (Erdinc et al. 2017). The aim of this study was to assess the effects of AMF inoculum on P assimilation by maize and its impact on maize growth and productivity on an acidic and deficient in available phosphorus Ferralsols.

Material and Methods

Experimental Soil and Plant Material

The experimental soil was collected on an old maize farm located in the Luano area, Lubumbashi, DR Congo (–11,60233°S; 27,50897°E to –11,60234°S; 27,50908°E, altitude 1200 m asl). It is a red and deep sandy clay loam soil whose available laboratory data are summarized in Table 1.

Spores were extracted from a 100 g sample of soil by using the standard wet sieving and decantation method (45 µm and 1 mm mesh) followed by counting using an Olympus SZ61 stereo microscope according to Walker et al. (2006). AMF morpho-species identification was done under microscope of 40 and 100 X on three to five spores of similar morphology, assembled on a strip in the polyvinyl lacto-glycerol. Spore shapes, their colors and sizes, occurrence or not of pedicels, number of spore wall layers and wall surface ornamentation were main criteria used for identifi-

Table 1 Experimental chemical soil properties

pH(water)	Total nitrogen (%)	Organic carbon (%)	Available phosphorus (μg/g soil)	ECC (cmol (+) kg^{-1} soil)	Exchanges cations contents (cmol (+) kg^{-1} soil)		
					Calcium	Potash	Magnesium
6.3	0.09	0.97	10.3	0.43	6.38	0.52	1.9

ECC exchange cationic capacity, *cmol* centimol

cation (Oehl et al. 2011a; Trappe 1992). The mean density was of 150 spores 100 g^{-1} soil with predominance of genus belonging to *Gigaspora, Acaulospora* and *Archaeospora.* The maize variety "Katanga" was used as test crop in the experiment. This local variety blooms from 60 to 65 days after sowing and presents a maximal height of 191 cm depending on growing conditions. Grains are white and have a weight nearing 168 ± 25 g cob^{-1}, i.e. 380 g per 1000 grains. Before sowing, the grains were disinfected with sodium hypochlorite (1%) during 5 min, then with the alcohol (75%) and rinsed with tap water afterwards.

AMF Inoculum Production

The inoculum was obtained from red *Sorghum* (*Sorghum vulgare* L.) cultivated in pots, to have high AMF spore density and root colonization; as described by Mukerji *et al.* (2002), and Selvaraj and Chellappan (2006). The pots had 28 cm diameter (0.4396 m^2) and depth 28 cm. *Sorghum* was sown in a litter substrate at 25 to 30 plants per pot. At 3.5 months later, root and AMF spores from *Sorghum* crop were extracted and used as inoculum. The litter substrate was collected from Miombo woodland dominated by *Brachystegia* and *Julbernardia.* The choice of this substrate is justified by its high porosity. This is a reasonable method of AMF inoculum production contrary to the high cost of commercial inoculum and their scarcity in the Lubumbashi region. The inoculum produced had a spore mean density of 250. 100 g^{-1} of substrate and 10 g of colonized roots at the frequency of 70 to 80%. *Acaulospora* and *Ambispora* were the most dominant genera.

Chemical Fertilizers

Di-ammonium phosphate (DAP—18-46-0) and potassium chloride (KCl—60% K_2O) were used as basal fertilizers and urea (46% N) was added as top fertilizer to cover the N crop demand. The K and N were maintained constant while P was added as DAP in 3 doses: 60 kg P_2O_5 ha^{-1}, which is the normal dose, recommended for maize in tropical conditions (Raemaekers 2001), 30 kg P_2O_5 ha^{-1} as the half of recommended dose and 0 kg P_2O_5 ha^{-1} as the control.

Experimental Design

The experiment was conducted in pots of 28 cm diameter and 28 cm depth in a factorial design 2 × 3 with 5 replications. Two levels of AMF inoculation and 3 levels of phosphorus application were used as treatments:

- Control: unfertilized and un-inoculated
- 30 kg of P_2O_5 ha^{-1}, without AMF inoculum
- 60 kg of P_2O_5 ha^{-1}, without AMF inoculum
- 100 g AMF inoculum
- 30 kg of P_2O_5 ha^{-1}, 100 g AMF inoculum
- 60 kg of P_2O_5 ha^{-1}, 100 g AMF inoculum.

The maize plants were watered during the 3 first months (September to November 2017), every 2 days with 1 liter of tap water per pot having 1 plant each. The experiment took place in a shade house from September 2017 to January 2018. The last two months (December 2017 and January 2018) of experiment were rainy. During the experimental period, the prevailing temperature varied between 15 to 32 °C and a mean relative humidity of 79% and 12 h sunshine.

Measurements and Data Analysis

The plant height, the height at the insertion of panicle, days to the flowering, the number of leaves, the leaves chlorophyll content, the cob length, the cob diameter, the cob rows number, the seed weight per cob, the yield and the total P assimilated in grains were measured. The data were statistically evaluated by factorial analysis of variance with mycorrhizal inoculation and P application levels as factors. Means and standard errors were calculated for five replicate value. Means were compared by ANOVA and the Tukey-HSD test at significance level $P < 0.05$. The Minitab 16 software was used for the statistical analysis.

Results

Vegetative Growth Parameters and Root Colonization by AMF

The effect of inoculation and P application on maize was significant for the number of days before flowering. Plants

Table 2 Growth parameters and root colonization frequency (%) by AMF. SPAD units: soil plant analysis development. The means that do not share any letters in a group in each column are significantly different after ANOVA and the Tukey multiple comparison test ($P < 0.05$)

Treatments	Days before flowering	Final plant height (cm)	60 days after sowing		
			Number of leaves plant^{-1}	Leaves chlorophyll content (SPAD units)	Root colonization frequency (%)
Mycorrhizal inoculum (AMF)					
Without AMF	73 ± 14 a	149 ± 43 a	10 ± 2 a	41 ± 10 a	40 ± 20 b
With AMF	70 ± 13 a	158 ± 44 a	10 ± 2 a	43 ± 8 a	57 ± 25 a
Phosphorus (kg P_2O_5)					
0 kg P_2O_5 ha^{-1}	91 ± 3 A	102 ± 15 C	7 ± 1 B	31 ± 5 B	49 ± 27 AB
30 kg P_2O_5 ha^{-1}	63 ± 1 B	169 ± 22 B	11 ± 1 A	47 ± 4 A	31 ± 18 B
60 kg P_2O_5 ha^{-1}	61 ± 2 B	191 ± 21 A	11 ± 1 A	47 ± 4 A	65 ± 11 A
AMF × Phosphorus					
Without AMF 0 kg P_2O_5 ha^{-1}	93 ± 0 a	105 ± 3 b	7 ± 0 b	28 ± 3 b	25 ± 11 b
Without AMF30 kg P_2O_5 ha^{-1}	63 ± 0 b	171 ± 27 a	11 ± 1 a	46 ± 3 a	32 ± 13 b
Without AMF 60 kg P_2O_5 ha^{-1}	63 ± 0 b	197 ± 19 a	12 ± 1 a	46 ± 4 a	63 ± 8 a
With AMF 0 kg P_2O_5 ha^{-1}	88 ± 0 a	98 ± 21 b	7 ± 1 b	34 ± 5 b	73 ± 8 a
With AMF 30 kg P_2O_5 ha^{-1}	62 ± 0 b	166 ± 20 a	12 ± 1 a	47 ± 5 a	30 ± 23 b
With AMF 60 kg P_2O_5 ha^{-1}	59 ± 0 b	184 ± 23 a	11 ± 1 a	47 ± 5 a	68 ± 13 a

Table 3 AMF structures in root. AMF structures are present on 25% of root samples (+); mycorrhizae structures are present on 50% of root samples (++); mycorrhizae structures are present on 100% of root samples (++++); mycorrhizae structures are not present (–)

Treatments	AMF structures		
	Hyphae	Vesicles	Arbuscles
Without AMF 0 kg P_2O_5 ha^{-1}	++	–	–
Without AMF30 kg P_2O_5 ha^{-1}	++++	–	–
Without AMF 60 kg P_2O_5 ha^{-1}	++++	–	–
With AMF 0 kg P_2O_5 ha^{-1}	++++	+	+
With AMF 30 kg P_2O_5 ha^{-1}	++++	+	–
With AMF 60 kg P_2O_5 ha^{-1}	++++	–	–

that were inoculated with AMF flowered earlier than non-inoculated plants (Table 2). The combination of inoculation with P application increased maize flowering precocity while control plants were the latest to flowering. The effect of inoculation was not significant for plant height, number of leaves and chlorophyll content while, P application significantly increased the number of leaves per plant and leaves chlorophyll content. The effect of AMF inoculation and P application was significant on maize root colonization. Root colonization was more important on inoculated plants than on plants that were not inoculated. For non-inoculated plants, increasing P application proportionally increased their ability to be colonized by soil indigenous mycorrhiza. However, for inoculated plants, the maize which did not receive any P showed the highest rate of root colonization, followed by those that received 60 kg P_2O_5 ha^{-1} and the one that received 30 kg P_2O_5 ha^{-1} had the lower rate of colonization.

At 60 days after sowing, the most common mycorrhizae structures on all treatments were intra or extra-radical hyphae. Vesicles were found only on inoculated plants on which there was no P application and those that received 30 kg P_2O_5 ha^{-1}. In the same way, arbuscles were found only on plants that were inoculated and did not receive any P application (Table 3).

Yield Parameters

Yield results (Table 4) shows that the AMF treatments had a significant effect on yield parameters, except cob height insertion and cob length, which varied more with P treatments than with AMF inoculum. The height at the cob insertion, cob weight, cob length, cob diameter and the number of seed rows varied more with P than with AMF inoculum applied. Obtained averages under P influence were double or threefold higher than the control and AMF treatment alone. Cobs were then inserted between 73 and 103 cm height for 30 or 60 kg P_2O_5 ha^{-1}, whereas without P cob insertion was observed between 30 cm (for the control) and 40 cm (for inocula alone). The highest cob weight was obtained on treatments with 60 kg P_2O_5 ha^{-1} with or without inocula, i.e. 145 to 146 g. The length of these cobs measured on average 15 cm. A fertilization with 30 kg P_2O_5 ha^{-1} gave cobs weighing 79 to 107 g with a length of 12 to 13 cm. The lowest cob weight was obtained on inocula alone and the control, respectively 4 to 13 g, and a cob length of 6 to 7 cm. The cob diameter was the same for 30 kg and 60 kg P_2O_5 ha^{-1}, being 42 to 45 mm. The AMF only treatment had 24 mm of cob diameter, double compared to the control. Cobs from the 30 and 60 kg P_2O_5 ha^{-1} treatments without inoculum contained 13 seed rows, whereas they were empty for the control treatment. AMF combined to 60 kg P ha^{-1} had 13 seed rows followed by AMF combined with 30 kg P_2O_5

Table 4 Yield parameters and phosphorus content in maize grains. The means that do not share any letters in a group in each column are significantly different after ANOVA and the Tukey multiple comparison test ($P < 0.05$)

Treatments	Cob insertion height (cm)	Cob weight (g)	Cob length (cm)	Cob diameter (mm)	Seed raw number	Grain weight (g)	Yield of grains tons/hectare	Grain phosphorus content (mg of phosphorus g^{-1})
Mycorrhizal inoculum								
Without AMF	70 ± 35a	76 ± 82a	11 ± 4a	33 ± 15a	13 ± 1a	86 ± 33a	3.0 ± 2.6a	0.70 ± 0a
With AMF	67 ± 27a	89 ± 60a	11 ± 4a	36 ± 11a	10 ± 3b	71 ± 48a	3.7 ± 2.5a	0.97 ± 0a
Phosphorus (kg P_2O_5)								
0 kg P_2O_5 ha^{-1}	35 ± 13C	9 ± 6C	6 ± 1C	18 ± 9B	7 ± 0B	12 ± 1C	0.3 ± 0.3C	0.71 ± 0A
30 kg P_2O_5 ha^{-1}	76 ± 19B	93 ± 23B	12 ± 2B	41 ± 3A	12 ± 3A	71 ± 21B	3.7 ± 1.1B	0.72 ± 0A
60 kg P_2O_5 ha^{-1}	96 ± 18A	146 ± 22A	15 ± 3A	45 ± 2A	13 ± 1A	116 ± 17A	6.1 ± 0.9A	0.73 ± 0A
AMF × Phosphorus								
Without AMF 0 kg P_2O_5 ha^{-1}	30 ± 3b	4 ± 2c	6 ± 1b	12 ± 4c	–	–	–	–
Without AMF30 kg P_2O_5 ha^{-1}	78 ± 26a	79 ± 22b	13 ± 2a	42 ± 2a	13 ± 1a	59 ± 20b	3.1 ± 1.0b	0.69 ± 0b
Without AMF 60 kg P_2O_5 ha^{-1}	103 ± 12a	145 ± 19a	15 ± 2a	44 ± 2a	13 ± 1a	114 ± 15a	6.0 ± 0.7a	0.71 ± 0b
With AMF 0 kg P_2O_5 ha^{-1}	40 ± 17b	13 ± 6c	7 ± 1b	24 ± 8b	7 ± 0b	12 ± 1c	0.6 ± 0.0c	1.42 ± 0a
With AMF 30 kg P_2O_5 ha^{-1}	73 ± 12a	107 ± 16b	12 ± 1a	40 ± 4a	11 ± 4a	83 ± 15b	4.4 ± 0.8b	0.74 ± 1b
With AMF 60 kg P_2O_5 ha^{-1}	89 ± 23a	146 ± 26a	15 ± 3a	45 ± 3a	13 ± 1a	118 ± 20a	6.2 ± 1.0a	0.75 ± 0b

ha^{-1} with 11 seed rows, cobs from the AMF only treatment had 7 rows. The comparison of the treatments 30 kg P_2O_5 ha^{-1} with AMF and 30 kg P_2O_5 ha^{-1} without AMF considering grain weight, grain yield and grain phosphorus content parameters shows better the influence of AMF on P uptake. The addition of 30 kg P_2O_5 ha^{-1} produced 59 g of grains per cob, the AMF inoculation offer 12 g of grains per cob, whereas the control treatment had cobs without grains. The results found indicate that the AMF treatments had a highly significant effect on P uptake. The P treatments and their interaction with AMF also had a strong effect. Grains from inoculated plants had a double content of phosphorus in comparison with un-inoculated plants. The highest phosphorus content in maize grains was 1.41 mg phosphorus g^{-1} obtained on AMF inoculation alone followed by inoculum +60 kg of P_2O_5 ha^{-1} and inoculum +30 kg of P_2O_5 ha^{-1}.

Discussion

Vegetative Growth Parameters

Plaxton and Tran (2011) and Stigter and Plaxton (2015) have shown the phosphorus implication in plant physiology already which lead to the amine acid and protein constitution; and its deficiency in the soil can reduce severely the grain's production. AMF contribution to maize growth was strongly observed on male precocity on the plants inoculated and fertilized (59 and 62 days after sowing) in comparison to the control (93 days after sowing). Inoculating crops conferred an advance of 30 days duration at flowering, which is explained by P acquiring which is the first benefit of the symbiosis. Oehl et al. (2011b) demonstrated that for plants inoculated with AMF and fertilized, flowering occurred earlier compared to those that were not inoculated. The same average was obtained for plant height, leaves number and chlorophyll rate in leaves especially on treatments inoculated and fertilized with 30 or 60 kg P_2O_5 ha^{-1}. This joins the allegations of Davies and Linderman (1990) and Aguegue et al. (2017) showing that the only micro-doses of chemical fertilizers (half of the crop demand) are sufficient to promote plant growth when AMF have been applied. Munir et al. (2003) also showed that the addition of phosphorus decreases the mycorrhizal symbiosis because the plant's growth depends on the chemical fertilizer.

Phosphorus Fertilizer Effect on Root Colonization

Root colonization was very intense (73%) on inoculated plants without P addition and less intense (25%) on control plants, the difference being 48%. The inoculated plants were more colonized (57%) than un-inoculated plants, which had a mean of 40% root colonization rate. This root colonization rate can be explained by AMF previously existing in the experimental soil. As shown in the methodology, the experimental soil harboured 150 mycorrhizae spores per 100 g soil, a spore density sufficient to colonize the roots of a given crop. This is sufficiently proving the ubiquist character of AMF in soils as underlined by Liu et al. (2016), Cozzolino et al. (2013) and Ambrosini et al. (2015). Although most soils contain AMF, inoculation is still very important because it provides new AMF propagules capable of colonizing the newly established crop as quickly as possible. While assessing the root colonization, fungal hyphae as primary structure of symbiosis were present in all treatments. However, vesicles were only found in treatments with inoculum alone or combined to the small dose of 30 kg P_2O_5 ha^{-1}. The dose of 60 kg P_2O_5 ha^{-1} seemed to compromise the vesicle formation on roots. The highest dose of P_2O_5 (60 kg ha^{-1}) reduces fungi activity in the root and compromises arbuscles or vesicles formation, as was also observed by Braunberger et al. (1991).

Yield Parameters and Grains Phosphorus Content

The height at the cob insertion, the weight of cobs, their length and diameter were not directly influenced by AMF inoculum but rather by phosphorus applications. Fertilization with 30 kg P_2O_5 ha^{-1} seemed to be sufficient to improve the nutritional status of the Ferralsol used as substrate for this experiment, compared to the dose of 60 kg P_2O_5 ha^{-1} which is low cost effectiveness. These results are nearing those found by Aguegue et al. (2017) in Ferralsol in southern Benin, indicating that *Glomus cubens* species combined to a half dose of chemical fertilizers of NPK (7.5 P_2O_5 kg ha^{-1}) allow to get an equivalent production of maize to that obtained using the recommended dose of NPK (15 P_2O_5 kg ha^{-1}) alone. The AMF inoculum alone given cobs well filled with grains, thus much better than plants of the control (without phosphorus neither AMF inoculum) given cobs without grains. The AMF showed P efficiency in the experimental soil; this induced the fruition. Several researchers such as Pandey et al. (2005) and Huang et al. (2017) have demonstrated the mycorrhiza efficiency in plant production. Grain P concentration increased with both inoculation and P fertilization. The highest P concentration was obtained with the treatment of inocula alone. This proves that mycorrhizae can be used as biofertilizers as confirmed by Miransari (2011) and Zhang et al. (2017), and that these fungi enhance chemical P uptake through fungal hyphae. Results of this study showed that the grain P concentration was 2 to 3 times lower than the standard P concentration (210 mg 100 g^{-1}) contained in maize grains (Messiaen and Fakorede 2006). This gap could be explained by root concentration in the pot experiment culture that uptakes only mineral fertilizers than field experiments which benefit also the soil minerals.

Conclusions

The results of this research have shown that the use of 30 kg P_2O_5 ha^{-1} (i.e. half of the recommended dose of 60 kg P_2O_5 ha^{-1}) in the tropical soil like Lubumbashi's Ferralsols, combined with AMF was sufficient to obtain a good maize production. The combination of AMF with a low dose of P fertilizers (30 kg P_2O_5 ha^{-1}) or the recommended dose of 60 kg P_2O_5 ha^{-1} were the best treatments making the flowering duration short, but also allowing to obtain sturdy plants and a production of cobs with a considerable length and diameter. However, economically, it would be recommendable to use the dose of 30 kg P_2O_5 ha^{-1}. AMF used alone appeared to be an alternative to the lack of P in poor soils, provided that N and K were preliminary added to the soil.

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Conflict of interest A. Tshibangu Kazadi, J. Lwalaba Wa Lwalaba, B. Kirika Ansey, J. Mavungu Muzulukwau, G. Manda Katabe, M. Iband Karul, G. Baert, G. Haesaert and R.-P. Mukobo Mundende declare that they have no competing interests.

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