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Effect of Soil Application of Stabilized Ortho Silicic Acid Based Granules on Growth and Yield of Rice (*Oryza sativa* L.)

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the most important cereal crops in Rwanda. Present study was aimed assessed the effect of stabilized ortho silicic acid (OSA) based granules on growth and yield of rice. Field experiments were conducted at Rwagitima, Gatsibo district in the Eastern province of Rwanda during two wet seasons in 2019, the first season was between February and May and the second one was from September to December. Two levels of recommended fertilizer doses (RDF; i.e., 200 kg ha^{-1} NPK as a basal fertilizer and 100 kg ha^{-1} urea as a top dressing fertilizer) were applied solely and along with different doses (10, 15 and 20 kg ha^{-1}) of OSA based granules. The treatments were: T_1 (100% RDF), T_2 (75% RDF), T_3 (T_1 +10 kgha^{-1} OSA), T_4 (T_1 +15 kgha^{-1} OSA), T_5 (T_1 +20 kgha^{-1} OSA), T_6 (T_2 +10 kgha^{-1}OSA), T_7 (T_2 +15 kgha^{-1} OSA) and T_8 (T_2 +20 kgha^{-1} OSA). Experiments were laid in a randomized complete block design (RCBD) with three replications. Results showed that the application of 100% RDF +20 kg ha^{-1} of OSA granules increased plant height (99.80 cm), tiller number (361) and root length (15.7 cm). Furthermore, yield increments of 28.4% and 19.9% for the first and second seasons, respectively, were obtained in treatments where 100% RDF +20 kgha^{-1} of OSA granules were applied. The rice yield in the treatment 75% RDF +20 kg/ha Silixol OSA granules was higher than that recorded with 100% RDF only. This indicates that use of Silixol OSA granules can result in 25% saving of fertilizer (NPK and urea) without compromising the yield. Conclusively, Silixol OSA granules offers good potential for yield increment of rice in Rwanda and, can minimize fertilizer use by 25%.

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Ortho Silicic Acid; OSA; recommended fertilizer dose; rice; Silicon

Introduction

Rice (*Oryza sativa* L.) is a staple food crop for millions of people globally, and is grown in more than 100 countries (Fukagawa and Ziska 2019). Rice was introduced in Rwanda in the late 1960's by Korean, Taiwanese and Chinese missionaries (MINAGRI 2013). Despite its late introduction in Rwanda, it has become one of the six priority crops under the Crop Intensification Program (CIP) established in 2007 (MINAGRI 2013). Rice production has gradually increased and an average yield of 3,532 kg ha^{-1} was obtained in 2018, ranked second to wheat (11,398 kg ha^{-1}) amongst cereals (NISR 2018). However, the rice yield is still low compared to the market demand, and this is largely attributed to poor soil fertility resulting from the intensive monocropping system that characterizes marshlands

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under rice production in Rwanda. In fact, almost half of the Rwandan soils have become acidic (pH < 5.2) resulting in higher levels of soluble and toxic aluminum (Beenart 1999).

The use of mineral fertilizers is the sole approach employed to manage soil nutrient deficiencies in Rwanda (MINAGRI 2014; NISR 2014). Nitrogen (N), phosphorous (P) and potassium (K) are commonly used fertilizers in rice production in Rwanda and NPK has been shown to significantly increase the yield (Cyamweshi, Kayumba, and Nabahunga 2017; Mukamuhirwa et al. 2018). Diagnostic treatment with NPK and additional 5, 15, 1.25, 0.25 and 0.5 kg ha^{-1} of Mg, Ca, S, Zn, B and Cu, respectively, in four agro-ecological zones of Rwanda resulted in a substantial increase in yield (Cyamweshi, Kayumba, and Nabahunga 2017). Apart from macronutrients and micronutrients, rice growth and productivity also is dependent on other beneficial nutrient elements such as silicon. Silicon exhibits synergistic interactions with several other nutrients, resulting in improved nutrient use efficiency (Rietra et al. 2017).

Silicon (Si) is the second abundant element in the earth's crust after oxygen (Wedepohl 1995). Plants absorb Si in form of monosilicic acid, and silixol OSA granules, a proprietary formulation, is one of the source of stabilized silicic acid. Although Si has been regarded as a non-essential element to plants (Epstein and Bloom 2005), perusal of literature highlights that Si plays a fundamental role in plant metabolism and productivity of crops including rice. Rice is one of the typical silicon accumulating plants (Hodson et al. 2005) and application of Si-containing fertilizers in crop production is commonly practiced in India, Brazil and Japan. In rice, silicon has also been identified as the stress alleviator for both abiotic and biotic stresses. Gokulraj et al. (2018) has reported the positive impact of OSA in alleviation of water stress imposed during the flowering stage of the rice crop. Heavy metal accumulation such as arsenic is another major concern for rice cultivation. Role of OSA in reducing the accumulation of arsenic in grains of rice has been studied by Dwivedi et al. (2020). Beneficial impact on agronomic parameters as well as yield and its attributes following application of Silixol OSA granules was previously reported (Jawahar et al. 2015; Lokadal and Sreekanth 2018). Fertilization with the Silixol OSA granules was also reported to significantly increase rice plant uptake of N, P and K (Karuku and Maobe 2018). Application of NPK fertilizer in combination with Si increased the total number of tillers by 28% (Cuong et al. 2017). In addition to the impact of silicon in alleviating the abiotic stresses, Si application also reduces the incidence of diseases by forming a protective layer within plant cells. Tripathy and Rath (2017), Jawahar et al. (2019) had reported the reduction in incidence of stem borer, leaf folder and blast in rice following application of Silixol OSA granules. Silixol OSA is a newly introduced Si-fertilizer in Rwanda and little is so far known on its impact on growth and yield of crops. The objective of the present study was to assess the effect of soil application of Si on growth and yield of rice.

Materials and methods

Study area

The study was conducted at Rwagitima-Ntende marshland, Gatsibo district (latitude 1°27"30""and 1° 52"50"“+ South and longitude 30°09"42"“+and 30°50"20"' East) in the Eastern province of Rwanda (Figure 1). The study site corresponds to the Eastern Agro-ecological zone according to Clay and Dejaegher (1987). The study site stands at 1364 m above sea level and receives a low precipitation (800–1000 mm/year. The study was conducted during two wet seasons in 2019. The first season was between February and May and the second was from September to December and their climatic data are described in Table 1.

Experimental design

The experiment was conducted in a randomized complete block design with three replications and 8 treatments. The treatments were: T_1 (recommended fertilizer dose (100% RDF); 200 kg ha^{-1} NPK

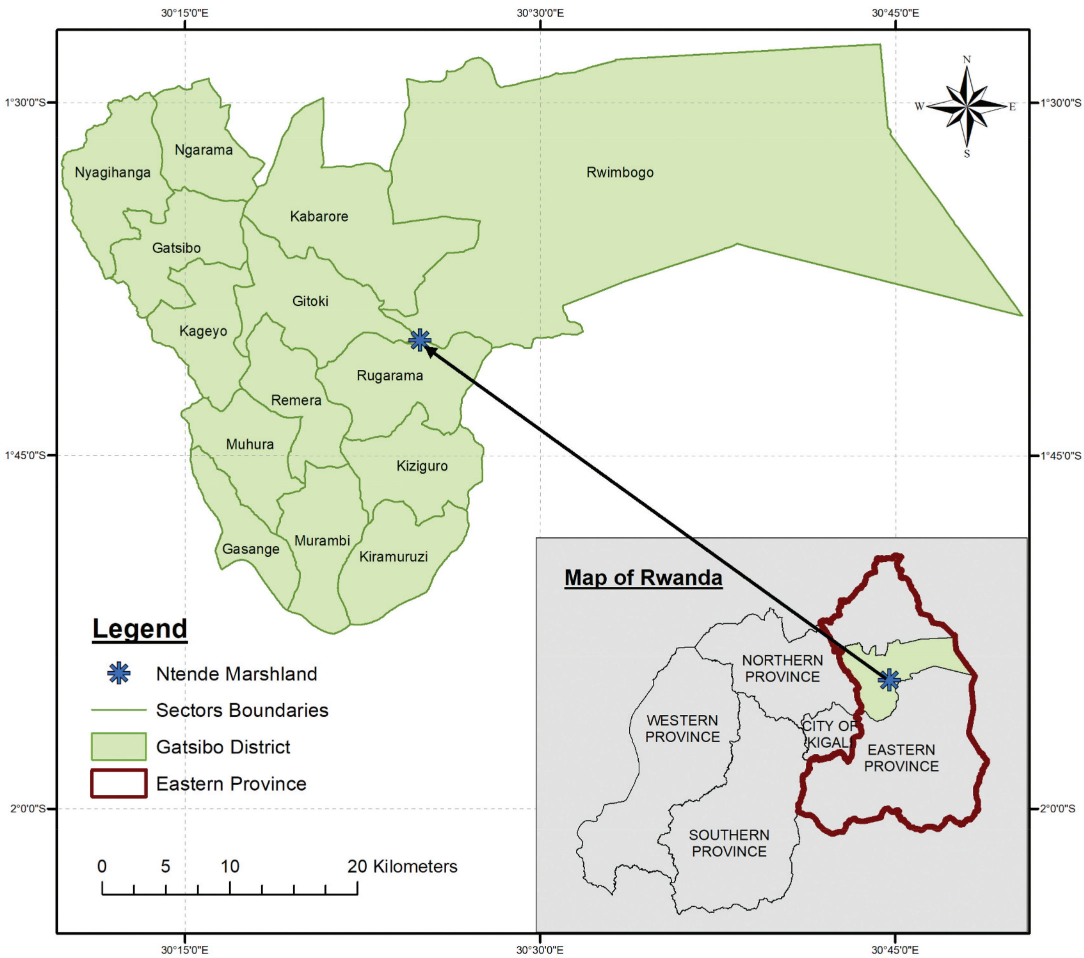

Figure 1. Location of the study site in Ntende marshland in Gatsibo district in Eastern province of Rwanda.

Table 1. Climatic data for the two cropping seasons in 2019.

Season	Month	Minimum temperature (°C)	Maximum temperature (°C)	Precipitation (mm)
I	February	15.6	28.9	65.6
	March	12.1	28.2	80.2
	April	17.0	26.8	113.7
	May	17.5	25.8	72.5
II	September	16.8	28.1	85.2
	October	16.6	25.5	175.5
	November	16.7	25.8	132.1
	December	16.9	25.9	125.6

Source: Rwanda Meteorology Agency.

(17.17.17) and 100 kg ha^{-1} Urea), T_2 (75% of RDF; 150 kg ha^{-1} NPK (17.17.17) and 75 kg ha^{-1} Urea), T_3 (T_1 +10 kg ha^{-1} of Silixol granules), T_4 (T_1 +15 kg ha^{-1} of Silixol granules), T_5 (T_1 +20 kg ha^{-1} of Silixol granules), T_6 (T_2 +10 kg ha^{-1} of Silixol granules), T_7 (T_2 +15 kg ha^{-1} of Silixol granules) and T_8 (T_2 +20 kg ha^{-1} of Silixol granules) (Table 2). NPK (17-17-17) was applied at planting and silixol granules were applied both at planting and at mid tillering stages, while Urea was applied both at mid tillering and at panicle

initiation stages. Silixol OSA granules, a commercial product, were obtained from Privi Life Science Limited (Rwanda). Seeds of the rice cultivar "YunYin 4" were obtained from Rwanda Agriculture and

Table 2. List of fertilizers applied and fertilizer application rates.

Treatment	1st application		2nd application		3rd application
	NPK (kg ha^{-1})	Silixol (kg ha^{-1})	Urea (kg ha^{-1})	Silixol (kg ha^{-1})	Urea (kg ha^{-1})
T1	200.0	0	50.0	0	50.0
T2	150.0	0	37.5	0	37.5
T3	200.0	10	50.0	10	50.0
T4	200	15	50.0	15	50.0
T5	200	20	50.0	20	50.0
T6	150	10	37.5	10	37.5
T7	150	15	37.5	15	37.5
T8	150	20	37.5	20	37.5

Animal Resources Board (RAB). The "YunYin 4" is the most commonly grown rice variety in most marshlands in the Gatsibo district. Transplanting was done at 21 days after seed sowing. Once seedling was transplanted in each hill at spacing of 20 cm x 20 cm. Irrigation was done at three days interval and weeding was done at 3-week interval after transplanting. Rice common pests such as rice fly were controlled using cypermethrin (20 ml/20 l of water). For prevention of rice blast and shealth blight, Dethane and Beam (50 g/20 l of water) were applied at mid-tillering stage. Harvesting was done at rice physiological maturity and the grains of each treatment were dried at 14% moisture content.

Soil sampling and analysis

The fields used for this study were soil sampled for site characterization prior to the start of the experiments. Soil samples (0–20 cm depth) were taken with an auger at the four corners of the field, mixed and a composite sample of approximately 1 kg taken for laboratory analysis. The soil samples were then air-dried in laboratory, crushed and ground, sieved using 2 mm sieve and analyzed for pH, N, P, K, electrical conductivity, organic carbon, calcium and magnesium. Soil pH was determined in a 1:2.5 soil: H_2O suspension with a glass electrode pH meter (Lierop and MacKenzie 1977). Available phosphorus was determined using Bray-1 method and the levels of Ca, Mg and K were analyzed using humid digestion method and measured with atomic absorption spectrophotometer (Okalebo, Gathua, and Woomer 2002). The SOC concentration was determined calorimetrically by measuring chromic ions after oxidation with sulfuric acid and potassium dichromate mixture while TN was determined using Kjeldahl digestion method (Anderson and Ingram 1993). Soil electrical conductivity was determined on a 1:2.5 soil: H2O suspension with a glass electrode Mas Scientific Lab. Digital Conductivity Pro Meter Model: MAS 966. Results for soil analysis are indicated in Table 3.

Growth parameters

To assess the effect of Si- fertilizer application on the growth, ten plants were randomly selected from each experimental plot and used to measure the following plant growth parameters; plant height from the bottom to the top most leaf, number of tillers were counted per hill, and root length was measured

Table 3. Soil analysis of the experimental site.

Parameters	Value
pH (water)(1;2.5)	6.2
EC (µS/Cm)	361
CEC(meq/100g)	23.4
Organic carbon (%)	3.04
Total Nitrogen (%)	0.17
Available Phosphorus (ppm)	1.9
Exchangeable Calcium (meq/100g)	4.92
Exchangeable Potassium (meq/100g)	0.31
Exchangeable Magnesium (meq/100g)	2.07

from the base of the plant to the tip of the longest root. Data on plant height and number of tillers were collected at two plant growth stages, at mid tillering stage (MT; 63 days after sowing) and at panicle initiation stage (PI; 93 days after sowing).

Yield and yield components

Yield components were determined based on ten randomly selected hills for each treatment in each replication and the following characteristics were measured; number of panicles, panicle weight, grain weight per panicle, 1000 grains weight and grain yield.

Statistical analysis

The experimental data were analyzed using ANOVA using R version 3.5.3 software (R Core Team 2019, Vienna, Austria). Treatment effects were significant at $p < 0.05$ and means were separated using the least significant difference (LSD) test and standard error of difference of the mean.

Results

Effect of Silixol OSA granules on growth attributes of rice

Soil application of Silixol OSA granules (20 kg ha^{-1}) in combination with RDF and 75% of RDF significantly increased the growth attributes of the rice plant (Table 4). Application of 100% RDF with 20 kg ha^{-1} of Silixol granules (T_5) resulted in significantly taller plants at panicle initiation stage (Table 4). 100% RDF +20 kg ha^{-1} also showed the highest values for number of tillers and root length, both at mid tillering and panicle initiation stages when compared to use of 100% RDF only. For instance, in season I, the number of tillers increased by 30.6% at mid tillering and 33.5% at panicle initiation. Root length significantly increased by 41.0% in season I, and 20.7% in season II. The treatments T_1 and T_2 for which no Silixol OSA granules were applied produced the lowest values for plant height, number of tillers and root length in both seasons. However, sometimes, T_6 (T_2 +10 kg ha^{-1} Si) and T_7 (T_2 +15 kg ha^{-1} Si) showed lower values than T_1 for three growth parameters (Table 4). Poor growth from use of T_6 and T_7 indicates that for 75% of RDF requires an addition of at least 20 kg ha^{-1} of Si to produce better crop growth.

Table 4. Effect of Silixol application on rice growth parameters in 2019.

	Plant height (cm)				Number of tillers				Root length (cm)	
	Season I		Season II		Season I		Season II		Season I	Season II
Treatment	MT	PI	MT	PI	MT	PI	MT	PI		
T1	80.00^{a}	90.70^{cd}	58.33^{a}	81.40^{bcd}	196^{a}	221^{bc}	271^{a}	321^{a}	11.13^{b}	11.09^{d}
T2	80.60^{a}	89.33^{d}	57.57^{a}	77.67^{d}	192^{a}	198^{c}	243^{a}	307^{a}	10.93^{b}	10.89^{d}
T3	82.19^{a}	92.96^{bcd}	60.70^{a}	83.63^{abc}	218^{a}	226^{bc}	304^{a}	334^{a}	11.93^{b}	11.89^{bcd}
T4	88.00^{a}	94.66^{bc}	61.27^{a}	83.80^{ab}	236^{a}	244^{b}	310^{a}	338^{a}	12.73^{b}	12.69^{ab}
T5	92.80^{a}	99.83^{a}	65.23^{a}	88.70^{a}	256^{a}	295^{a}	315^{a}	361^{a}	15.7^{a}	13.39^{a}
T6	88.60^{a}	93.93^{bc}	61.83^{a}	78.57^{cd}	193^{a}	218^{bc}	270^{a}	317^{a}	11.06^{b}	11.36^{cd}
T7	83.30^{a}	94.53^{bc}	61.20^{a}	81.63^{bcd}	195^{a}	220^{bc}	289^{a}	343^{a}	12.2^{b}	12.22^{bc}
T8	89.00^{a}	97.06^{ab}	62.40^{a}	83.37^{bc}	219^{a}	235^{b}	299^{a}	357^{a}	12.53^{b}	12.49^{ab}
P Value	0.264	0.002	0.55	0.011	0.072	0.016	0.821	0.92	0.032	0.002
LSD 5%	11.83	4.203	7.72	5.14	45.16	44.9	105.4	101.2	2.635	1.06
SED	5.52	1.96	3.601	2.396	21.06	20.94	49.1	47.2	1.229	0.497
CV%	7.9	2.5	7.2	3.6	12.1	11.1	20.9	17.3	12.2	5.1
SEM	3.90	1.39	2.55	1.69	14.89	14.83	34.80	33.40	0.87	0.35

Season I: February to May, Season II: September to December.
MT: Mid tillering, PI: panicle initiation.
Means followed by the same letter within a column are not significantly different at $p<.05$.

Table 5. Effect of Silixol application on yield components and yield in rice in 2019.

Treatment	Number of panicles		Panicle weight (g)		Grain weight per panicle (g)		1000 grain weight (g)		Yield (tons)	
	Season I	Season II	Season I	Season II	Season I	Season II	Season I	Season II	Season I	Season II
T1	207^{bc}	295^{bc}	4.73^{a}	3.21^{b}	4.32^{bc}	3.14^{b}	23.79^{a}	24.08^{c}	4.15^{a}	5.03^{a}
T2	177^{c}	252^{c}	4.56^{a}	3.11^{b}	3.46^{c}	2.95^{b}	23.08^{a}	23.90^{c}	4.04^{a}	4.92^{a}
T3	220^{bc}	297^{bc}	4.86^{a}	3.32^{b}	4.43^{ab}	3.12^{b}	24.13^{a}	24.98^{bc}	4.25^{a}	5.32^{a}
T4	236^{ab}	334^{ab}	4.91^{a}	3.46^{b}	4.79^{ab}	3.16^{b}	24.66^{a}	26.01^{ab}	4.53^{a}	5.40^{a}
T5	272^{a}	344^{a}	5.26^{a}	4.32^{a}	5.25^{a}	4.17^{a}	25.93^{a}	26.93^{a}	5.33^{a}	6.03^{a}
T6	198^{bc}	266^{c}	4.80^{a}	3.15^{b}	4.01^{bc}	2.98^{b}	23.90^{a}	24.58^{bc}	4.23^{a}	5.26^{a}
T7	217^{bc}	292^{bc}	4.96^{a}	3.16^{b}	4.36^{abc}	3.06^{b}	23.25^{a}	25.16^{bc}	4.38^{a}	5.30^{a}
T8	229^{ab}	315^{ab}	5.06^{a}	3.93^{a}	4.48^{ab}	3.44^{b}	24.76^{a}	25.33^{abc}	4.70^{a}	5.37^{a}
P value	0.024	0.01	0.89	<0.001	0.036	0.043	0.136	0.023	0.598	0.576
LSD 5%	46.48	1.838	1.037	0.397	0.911	0.714	2.003	1.632	1.398	1.608
SED	21.67	21.43	0.483	0.185	0.425	0.333	0.934	0.761	0.652	0.75
CV%	12.1	8.8	12.1	6.6	11.9	17.9	4.7	3.7	17.9	17.4
SEM	15.32	15.15	0.34	0.13	0.30	0.46	0.66	0.54	0.46	0.52

Season I: February to May, Season II: September to December.
Means followed by the same letter within a column are not significantly different at $p<.05$.

Effect of silicon on yield and yield attributes of rice

Yield attributes; number of panicles, panicle weight and 1000 grain weight were highest in treatment T_5 where 20 kg ha^{-1} of Si was applied with 100% RDF (Table 5). Treatment T_5 also produced the highest yield of 5.33 tons, and 6.03 tons for seasons I and II, respectively. Although, these values were not significantly different from the values of the other treatments, they numerically demonstrated yield increments of 28.4% and 19.9% for seasons I and II, respectively. Across both seasons, application of 75% RDF with 20 kg ha^{-1} of Si showed better growth and yield performance than 100 RDF only, thus that indicating use of Silixol OSA could save about 25% of fertilizer (NPK and Urea) (Table 5). Rice yield components and yield were generally lowest when no Silixol OSA granules was applied (T_1 and T_2) and when 75% RDF was used in combination with 10 kg ha^{-1} (T_6) and 15 kg ha^{-1} (T_7).

Discussion

The results obtained from this study demonstrated that soil application of Silixol OSA granules improved rice growth attributes. Applying 20 kg ha^{-1} of Silixol OSA with 100% RDF increased plant height, produced more tillers and longer roots in comparison with other treatments across the two cropping seasons (Table 4). The effect of Si on plant growth has been previously reported in several studies. Plant height is an important indicator of plant productivity potential (Saeed, Abbasi, and Kazim 2001). According to Yoshida, Navasero, and Ramirez (1969), Si deposition in the cell wall results in more erect leaves and stems, leading to an increase in plant height. The increased tiller number might be due to an increased nutrient uptake, especially nitrogen that often results from Si application (Singh et al. 2006). Improvement in tillering capacity has been associated with a high supply of silicon (Agostinho et al. 2017; Mbaraka et al. 2021). Si improves growth and morphology of roots in rice (Ju et al. 2017). The root growth could be attributed to improved nutrient (N, P and K) uptake, which could be as a result of application of Si (Pati et al. 2016).

Yield and yield attributes such as number of panicles, panicle weight and 1000-grain weight were significantly increased with application of Silixol OSA as compared to controls (RDF only) (Table 5). Similar results depicting positive effects of silicon application on yield and different yield components were previously reported in rice (Gokulraj et al. 2018; Jawahar et al. 2015; Mbaraka et al. 2021). The increase in yield attributes might be as a result of silicon improving plant growth, nutrient uptake and tolerance to abiotic and biotic stresses as reported by Tripathy and Rath (2017) and Cuong et al. (2017). Better growth performance in turn increases photosynthetic activity ultimately leading to high grain yield. However, it's important to note that paddy rice production nationally decreased by 12% in 2020 season (NISR 2020).

Besides rice, Si has also been reported to increase yield in soybean, common bean and peanut (Crusciol et al. 2013). Several studies have demonstrated the potential of silicon to enhance the plant's ability to overcome stress such as late blight in potato (Soratto et al. 2012), early blight in tomato (Gulzar et al. 2021), insect pest incidences in potato (Da Silva, Morales, and Melo 2010), and drought in sorghum (Hattori, Inanagaa, and Arakib 2005) and wheat (Ratnakumar et al. 2016). Silicon also improves fruit quality in grapes (Ramteke et al. 2012), mango (More et al. 2015) and apple (Javaid and Misgar 2017).

Conclusion

The results of our study highlight the impact of Silixol OSA granules on rice productivity in Rwagitima-Ntende marshland, Gatsibo district, Eastern Province of Rwanda. RDF applied with 20 kg/ha of Silixol OSA granules have been found to be the best application for yield increment of about 20%. The most important finding of the present study is that 75% RDF in combination with 20 kg/ha Silixol OSA granules have resulted in yield more than 100% RDF, this clearly indicates that use of Silixol OSA granules could be very beneficial to rice growers of Rwanda as they can save 25% fertilizer without compromising yield. The reduction in fertilizer use is highly beneficial for economy of Rwanda as well as the safety for the environment.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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