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Effect of Sulphur and Irrigation Regimes on Potato Common Scab Development in Khartoum Area

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Authors' contributions

This work was carried out in collaboration between all authors. Author AIAI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SME and MYAA managed the analysis of the study. Author AMA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Potato common scab development was assessed under the traditional farming system (TFS) and modern farming system (MFS) using irrigation interval and side dressing of Sulphur-based fertilizer application along the ridge. The 4-day irrigation interval starting with the tuber formation suppressed the disease development significantly producing 33.6% and 22.2% reductions in scab incidence and severity, respectively. Sulphur applications [Wettable Sulphur and (NH_4So_4)] resulted in a significant decrease in incidence of 50 and 73% in TFS and MFS respectively; severity was also decreased by 44% and 60% in TFS and MFS respectively. The effect was particularly pronounced when Sulphur was applied at tuber initiation and to a lesser degree when it was applied at planting. The combined effect of short irrigation interval and Sulphur application under TFS had a synergistic significant impact on scab development resulting in ~ 60% and 55.6-58.3% reductions in incidence and severity, respectively. Significant increases in tuber yield of 138% and

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91-103% were obtained under TFS and MFS, respectively, when Sulphur was applied at planting. However, the yield was comparatively less when Sulphur was applied at tuber initiation. These results indicate that the common scab of potato in Sudan can practically be managed through short irrigation interval and application of Sulphur-based fertilizers during the early stages of tuber formation at planting or tuber initiation.

Keywords: Potato; Streptomyces; scab management; sulphur; irrigation regimes; centre pivot.

1. INTRODUCTION

The first introduction of potato to Sudan is reported to be during 1920s [1]. At present, the total area under potato production in Khartoum, River Nile and Northern states is estimated to have reached about 25000 ha. Potato is considered as one of the high-value crops that can play an important role in raising the socio-economic status of the Sudanese people. Along the River Nile, the crop has been produced by small farmers under a traditional farming system (TFS), which is characterized by small strips of land irrigated by surface irrigation. However, during the last two decades, high terraces in this region have been exploited for potato cultivation under modern farming system (MFS) with large potato fields (≥ 50 ha), center-pivot irrigation and mechanized cultural practices. Of all primary food crops, potato (*Solanum tuberosum* L.) suffers the greatest losses due to diseases of which common scab caused by the Actinomycete, *Streptomyces* spp. is economically important and occurs in most potato production areas of the world. It may be particularly destructive under favorable environmental conditions [2,3]. The disease has become increasingly important in Khartoum and River Nile states and is currently posing a serious threat to potato production as a sizable amount of the final tuber yield may remain unmarketable [4]. The pathogen is mainly soil-borne, and can also readily survive as a saprophyte in the soil and on plant debris [5,6]. Seed tubers can also serve as a source of inoculum with a great potential for long distance dissemination [7,8]. Thus common scab is influenced by many environmental factors such as soil pH, moisture, nutrients and texture [5,9] together with pathogen genetic variation and virulence [10].

Several methods have been tested for control of common scab in potato. Among these are breeding for resistance, crop rotation and biological control [11]. The most common methods, however, are irrigation to reduce aerobic soil condition during the early stages of tuber formation [12,13,14] and practices to maintain a low soil pH through application of Sulphur-based fertilizers [15,9]. Although these control measures seem to be practically feasible, but have not been previously attempted under Sudan conditions.

The objectives of this research were to evaluate the cultural management of potato common scab using irrigation regimes and application of sulphur-containing fertilizers under the TFS and MFS.

2. MATERIALS AND METHODS

2.1 Experimental Sites

The field experiment under TFS with surface irrigation were conducted at “Al Sheikh Al Tayeb” village on the western bank of the River Nile, 35 km north of Omdurman city (latitude 15°. 40" N, longitude 32°. 32" E, 280 m above sea level), Khartoum State, during season 2011. The soil was historically known to be infested with common scab organisms. So far, no center pivot type of irrigation is practiced in the traditional areas of potato production in Sudan, thus the experiments under MFS were conducted at WAS farm (~10 km west of Omdurman city, Khartoum State), during season 2011.

2.2 Plant Materials

The experiment was planted with moderately scab-infected potato seed tubers imported from Holland (predominantly with moderate scab inoculum load), cv. ‘Pekaro’ (scab-susceptible cv.) supplied by WAS Trading Company Ltd, Khartoum, Sudan.

2.3 Chemicals

In addition to the base line fertilizers of Urea (46% N) and Superphosphate (44% P), Sulphur-based fertilizers, namely Agricultural Sulphur (80% S) and Ammonium Sulphate (28% S) were used in the experiment. They were obtained from a chemical retail store in Khartoum North. Each fertilizer was applied as a side dressing along the ridge at a rate of 84 kg Sulphur per hectare [i.e. 105 kg Agricultural S and 300 kg (NH_4) So_4 per hectare].

2.4 Cultural Practices

Normal cultural practices routinely carried out by potato growers in the region were followed in the experiments conducted under TFS while under MFS, the experimental plots received the same amount of a daily watering received by the farm, in addition to fertilization and pesticide applications routinely given under MFS.

2.5 Parameters

The incidence and severity of the common scab as well as the final tuber yield were assessed at 10, 12 and 14 weeks after planting.

2.6 Procedure

2.6.1 Expt. 1. Effect of irrigation regimes and application of Sulphur on common scab development under TFS

A split-split plot design with 4 replications was used where irrigation intervals (every 8 days-W1 and every 4 day-W2) were assigned to the main plots. Combination of Wettable Sulphur and Ammonium Sulphate at planting and tuber initiation were randomized in the subplots.

Thus, the treatments at each of the two main plots (8-day and 4-day intervals) consisted of:

1- S0 AS0 ≡ no application of Sulphur fertilizers (control)
2- S P ≡ Wettable Sulphur at planting
3- S TI ≡ Wettable Sulphur at tuber initiation
4- S B ≡ Wettable Sulphur at both stages of growth.
5- ASP ≡ Ammonium Sulphate at planting
6- ASTI ≡ Ammonium Sulphate at tuber initiation
7- ASB ≡ Ammonium Sulphate at both stages of growth

Wettable Sulphur (S) and Ammonium Sulphate (AS) granules were applied at a dose of 84 kg S ha-1 by hand at three different times during the growing season: At planting only (P); at tuber initiation only (TI); and at both stages (B).

The same fertilizer dose was splited into two equal halves when added at both planting and tuber initiation stages.

Seed tubers were cut longitudinally into two halves and sown in plots consisting of four ridges; each 3 m long and spaced at 0.75 m apart. Seed pieces were spaced 0.2 m within the ridges. The experimental area was bordered by at least four untreated ridges. Phosphorous fertilizer (100 kg DAP ha-1) was applied before planting, while urea fertilizer was applied (360 kg) in equal split doses at planting and at the time of re-ridging. Five random plants were lifted from each plot after 10, 12 and 14 wks from planting, and the progeny tubers were examined for scab symptoms development (incidence and severity). Scab incidence was evaluated according to the following formula:

Scab incidence (%) = (Number of infected tubers × 100)/Total number of tubers inspected

Whereas common scab severity was rated on a scale of 0-4, where 0 ≡ tubers with no lesions; 1≡ superficial lesions occupying ≤ 12.5% of the tuber surface area; 2 ≡ slightly raised or slightly pitted lesions occupying > 12.5% - 25% of the tuber surface area; 3 ≡ moderately raised or moderately pitted lesions occupying > 25% - 50% of the tuber surface area; 4 ≡ severely raised or pitted lesions covering > 50% of the tuber surface area. Scab severity was calculated based on the formula:

Scab severity = [Σ (Number of infected tubers x corresponding severity scale)]/ Total number of tubers inspected

The sequential effect of the treatments on the final tuber yield was also assessed from an area of 1 m^2 harvested from the middle two ridges of each replication. The data were recorded and statistically analyzed according to the split-split plot design.

2.6.2 Expt. 2. Effect of application of sulphur fertilizers on potato common scab development under MFS

The centre pivot irrigation system was used in this experiment in West Omdurman where watering was almost daily, but the rate was manipulated as needed. The experimental design was a randomized complete block with four replications. All other experimental details were the same as for the experiment under TFS.

3. RESULTS

3.1 Effect of Irrigation Regime and Sulphur Fertilizers on Potato Common Scab Development under TFS

The results of the effects of watering regime and sulphur fertilizers application on scab incidence are presented in Table 1. At all sampling dates, the shorter irrigation interval (4-day) was associated with significantly (p ≥ o.o5) lower scab incidence as compared to the normal longer irrigation interval (8-day). For instance, an overall mean of scab incidence under 4-day interval at the last sampling date (14 wks after planting) was 28.8% compared to ~38% under long irrigation interval.

Sulphur fertilizers application, significantly (p ≥ o.o5) reduced scab incidence [was obtained in response to application of both sulphur fertilizers tested] under the two watering regimes at all sampling dates. In comparison, the application of sulphur at tuber initiation appeared more effective in reducing scab incidence than when applied at planting or at both planting and tuberization. The interaction of the watering regime and sulphur application was significant and also was the increase in scab incidence with time of sampling. Similar trends in the results were also observed with regards to scab severity (Table 2).

3.2 Effect of Sulphur Fertilizers Application on Potato Common Scab Development under MFS

Addition of sulphur fertilizers [Wettable Sulphur or $(NH_4)_2SO_4$] at the three times of application caused significant (p ≥ o.o5) reductions in scab incidence on progeny tubers assessed at 10, 12 and 14 wks after planting as compared to the non-treated control. For instance, the overall means of scab incidence were reduced to 13.9% and 13.8% in response to wettable sulphur and $(NH_4)_2SO_4$, respectively, relative to the non-treated control (51.8%) when assessed 14 wks after planting (Table 3).

The results shown on the effect of application of sulphur fertilizers on scab severity (Table 3) reflected the same trends of those recorded for scab incidence. Application of both Sulphur fertilizers either at planting or at tuber initiation produced the least scab severity but the differences were not significant between the different times of application.

3.3 Effect on Tuber Yield

The positive effects on scab development in response to the above treatments singly or combined were also accompanied with significant (p ≥ o.o5) increases in the final tuber yield (Table 4). With short irrigation interval under TFS, application of sulphur at planting resulted in significant (p ≥ o.o5) improvement in tuber yield (~ 138% increase) over the other times of application (~ 63-100% increase). All treatment interactions were significant under the traditional system. Addition of sulphur fertilizers (wettable sulphur and $(NH_4)_2SO_4$) under MFS, likewise resulted in significant (p ≥ o.o5) increases in the final tuber yield ranging from 53.7% - 103.4% in comparison with the non-treated control, irrespective of the application time (Table 4).No significant differences were found between the different application times, but remarkably greater increases in yield (~ 91-103.4%) were recorded when the fertilizers were added at planting as compared to the other two application times (Table 5).

4. DISCUSSION

The results indicated that the use of 4-day interval and the application of sulphur-containing fertilizers, particularly at planting or at tuber initiation significantly decreased the common scab disease development in TFS possibly by affecting the availability or efficacy of the initial inoculum. With regard to irrigation, several researchers have reported similar results indicating that maintaining high soil moisture levels during tuber initiation can inhibit potato common scab [16,17,14]. On the other hand, a close association between the incidence of scab and low soil moisture during the early stages of tuber formation has been observed [18,19], which necessitates control of common scab by appropriate irrigation. In Europe, common scab has been controlled largely by specified irrigation schedules furnishing excess soil moisture [20,21]. In addition, the growth of Actinomycetes might be retarded when soil pores become waterlogged, a condition that could suppress the development of common scab due to the increase of available manganese [22] or conversion of elemental sulphur to hydrogen sulphide [23].

Table 1. Effects of watering regime and sulphur fertilizers application on potato common scab incidence (%) under the traditional farming system in Khartoum area

	Assessment dates (wks after planting)									Irrigation regimes (starting 6 wks after planting)
	10			12			14			
Sulphur fertilizer and time of application[a]	**8-day**	**4-day**	**Mean**	**8-day**	**4-day**	**Mean**	**8-day**	**4-day**	**Mean**	**Overall mean of Sulphur/ irrigation**
S_0AS_0(control)	42.60a[*]	33.50b	38.1A	53.9a	37.60b	45.8A	66.30a	44.00b	55.2A	46.37A
SP	18.40cd	15.80ef		24.3d	17.90ef		33.20cd	26.20ef		22.63B
STI	17.90de	14.40f		24.0d	16.60f		32.60d	25.30f		18.82B
SB	18.70cd	17.40de		24.5d	19.40e		33.80cd	27.30e		23.57B
Means of (WS)	18.33A	15.87B	17.1B	24.27A	17.97B	21.1B	33.20A	26.27B	29.7B	
ASP	19.10cd	15.60ef		24.9cd	17.70ef		33.20d	26.00ef		22.77B
ASTI	17.90de	14.40f		23.90d	16.70f		32.40c	25.30f		21.80B
ASB	20.70c	17.40de		26.20c	19.40e		34.60c	27.30e		24.30B
Means of (AS)	19.23A	15.80B	17.5B	25.00A	17.93B	21.5B	33.40A	26.20B	29.8B	
Means of watering regime	22.19A	18.36B		28.81A	20.76B		38.02A	28.77B		
Mean of date of assessment			20.2C			24.79B			33.40A	

[a]: Fertilizers and time of application:S_0AS_0 ≡ no application of sulphur fertilizers (control); SP ≡ Wettable sulphur at planting; STI ≡ Wettable sulphur at tuber initiation; SB ≡ Wettable sulphur at both times (i.e. at planting and at tuber initiation); ASP ≡ Ammonium sulphate at planting; ASTI ≡ Ammonium sulphate at tuber initiation; ASB≡ Ammonium sulphate at both times. Fertilizers dose was splited into two halves when added at both planting and tuber initiation. Scabby seed tubers (12.5-25% tuber surface area) were used

[*]Means having the same letter within each column or row not significantly different at P=0.05 according to Duncan's Multiple Range Test

Table 2. Effects of watering regime and sulphur fertilizers application on potato common scab severity under the traditional farming system in Khartoum area

	Assessment dates (wks after planting)									Irrigation regimes (starting 6 wks after planting)
	10			12			14			
Sulphur fertilizers and time of application[a]	**8-day**	**4-day**	**Mean**	**8-day**	**4-day**	**Mean**	**8-day**	**4-day**	**Mean**	**Overall mean of sulphur/irrigation**
S_0AS_0 (control)	2.20a*	2.00a	2.10A	3.20a	2.50b	2.90A	3.60a	2.80b	3.20A	2.72A
SP	1.30bc	1.20bc		1.40de	1.3e		2.00c	1.50e		1.45BC
STI	1.30bc	1.10c		1.50cd	1.3e		1.90cd	1.50e		1.43C
SB	1.40b	1.30bc		1.60c	1.4de		2.00c	1.60e		1.55B
Means of (WS)	1.30A	1.20A	1.30B	1.50A	1.3B	1.40B	2.00A	1.60B	1.80B	
ASP	1.30bc	1.20bc		1.50cd	1.3e		2.00c	1.50e		1.47BC
ASTI	1.20bc	1.10c		1.50cd	1.3e		1.80d	1.50e		1.40C
ASB	1.40b	1.30bc		1.60c	1.4de		2.00c	1.60e		1.55B
Means of (AS)	1.30A	1.10B	1.20B	1.50A	1.3B	1.40B	1.90A	1.50B	1.70B	
Means of watering regime	1.44A	1.31B		1.76A	1.50B		2.19A	1.71B		
Means of date of assessment			1.38C			1.63B			1.95A	

[a]: Fertilizers and time of application: S_0AS_0 ≡ no application of sulphur fertilizers (control); SP ≡ Wettable sulphur at planting; STI ≡ Wettable sulphur at tuber initiation; SB ≡ Wettable sulphur at both times (i.e. at planting and at tuber initiation); ASP ≡ Ammonium sulphate at planting; ASTI ≡ Ammonium sulphate at tuber initiation; ASB≡ Ammonium sulphate at both times. Fertilizers dose was splited into two halves when added at both planting and tuber initiation. Scabby seed tubers (12.5-25% tuber surface area) were used

- Disease severity was rated on a scale of 0 - 4, where: 0 ≡ tubers with no lesions; 1 ≡ ≤ 12.5% of the tuber surface is occupied by superficial scab lesion and 4 ≡> 50% of the tuber surface is occupied by raised or pitted scab lesion. Mean disease severity was obtained by the expression: number of tubers in each severity scale × severity scale / total number tubers assessed

**Means having the same letter within each column or row not significantly different at P=0.05 according to Duncan's Multiple Range Test*

Table 3. Effect of application of sulphur fertilizers under modern farming system (MFS) on potato common scab development

Sulphur fertilizers[2] and time of application	Scab incidence (%)			Scab severity[1]		
	Assessment dates (wks after planting)			Assessment dates (wks after planting)		
	10	12	14	10	12	14
S_0AS_0 (control)	36.10a*	42.00a	51.8a	1.8a	2.40a	3.00A
SP	8.30b	11.40b	13.8b	1.0b	1.00b	1.10b
STI	8.70b	11.30b	13.7b	1.0b	1.00b	1.10b
SB	11.50b	13.40b	14.2b	1.1b	1.20b	1.30b
Mean(WS)	9.50B	12.00B	13.90B	1.00B	1.1B	1.20B
ASP	9.80b	11.80b	13.6b	1.0b	1.00b	1.10b
ASTI	8.50b	11.70b	13.6b	1.0b	1.00b	1.10b
ASB	11.50b	13.20b	14.2b	1.1b	1.30b	1.30b
Mean(AS)	9.90B	12.20B	13.80B	1.00B	1.10B	1.20B
Mean at (P)	9.10	11.60	13.70	1.00	1.00	1.10
Mean at (TI)	8.60	11.50	13.70	1.00	1.00	1.10
Mean at (B)	13.50	13.30	15.10	1.10	1.30	1.30
Overall Mean	9.72	12.13	13.84	1.03	1.08	1.17

[1]Disease severity was rated on a scale of 0-4, where: 0 ≡ tubers with no lesions; 1≡ ≤ 12.5% of the tuber surface is occupied by superficial scab lesion and 4= > 50% of the tuber surface is occupied by raised or pitted scab lesion.

[2]Fertilizers and time of applications: S_0AS_0 ≡ no application of sulphur fertilizers (control); SP ≡ Wettable sulphur at planting; STI ≡ Wettable sulphur at tuber initiation; SB ≡ Wettable sulphur at both periods of time (i.e. at planting and at tuber initiation); ASP ≡ Ammonium sulphate at planting; AS_1TI ≡ Ammonium sulphate at tuber initiation; AS_1B ≡ Ammonium sulphate at both periods of time. Fertilizers dose was splited into two halves when added at both planting and tuber initiation. –Scabby seed tubers (12.5-25% tuber surface area) were used.

** Means having the same letter within each column or row are not significantly different at P = 0.05, according to Duncan's Multiple Range Test*

Table 4. Effects of watering regimes and sulfur fertilizers application on potato tuber yield under the modern farming system (TFS) in Khartoum area

Sulphur fertilizer and time of application[1]	Yield (ton / ha)			
	8-day	% Increase	4-day	% Increase
S_0AS_0 (control)	10.00h*		12.50g	25.00
SP	16.20de	62.00	23.80a	138.00
STI	14.90ef	49.00	18.80bc	88.00
SB	13.60fg	36.00	16.30de	63.00
Mean (WS)	14.9B		19.60A	
ASP	16.30de	63.00	23.80a	138.00
ASTI	15.00ef	50.00	20.00b	100.00
ASB	13.80fg	38.00	17.50cd	75.00
Mean (AS)	15.00B		20.40A	
Mean regime	13.60B		19.00A	

[1]Fertilizers and time of applications: S_0AS_0 (control), SP≡ Wettable sulphur at planting, STI≡Wettable sulphur at tuber initiation, SB≡ Wettable sulphur at both stages (i.e. at planting and tuber initiation), ASP≡ Ammonium sulphate at planting, ASTI≡Ammonium sulphate at tuber initiation, ASB≡ Ammonium sulphate at both periods of time.

-Seed tubers with scab lesions (12.5-25% of the tuber surface area) were used.

-Surface type of irrigation was used in the traditional system, while centre pivot type of irrigation was used in the modern system.

**Means having the same letter within each column or row are not significantly different at P = 0.05, according to Duncan's Multiple Range Test*

Table 5. Effect of application of sulfur fertilizers under modern farming system (TFS) on potato tuber yield in Khartoum area

Sulphur fertilizer and time of application[1]	Yield (ton/ha)	% Increase
S_0AS_0 (Control)	23.30b*	
SP	47.40a	103.40
STI	40.90a	75.50
SB	36.90a	58.40
Mean (WS)	41.70A	
ASP	44.50a	91.00
ASTI	40.00a	71.70
ASB	35.80a	53.70
Mean (AS)	40.10A	

[1]Fertilizers and time of applications: S_0AS_0 (control), SP≡ Wettable sulphur at planting, STI≡Wettable sulphur at tuber initiation, SB ≡ Wettable Sulphur at both stages (i.e. at planting and tuber initiation), ASP ≡ Ammonium sulphate at planting, ASTI ≡Ammonium sulphate at tuber initiation, ASB ≡ Ammonium sulphate at both periods of time.

-Seed tubers with scab lesions (12.5-25% of the tuber surface area) were used.

-Surface type of irrigation was used in the traditional system, while centre pivot type of irrigation was used in the modern system

**Means having the same letter within each column or row are not significantly different at P = 0.05, according to Duncan's Multiple Range Test*

Various speculations have been suggested to explain the mechanism of scab control by irrigation. Firstly, there is a direct influence on tuber susceptibility as excess soil moisture cause susceptible lenticels to rapidly develop into resistant ones [24,5]. Secondly, there are direct effects on the growth of the pathogen due to lowering of the soil temperature and reduced oxygen availability. Thirdly, irrigation indirectly affects scab by providing an environment conducive to antagonism [25]. Fourthly, high moisture levels are thought to decrease calcium in tuber tissue and this leads to suppression of common scab. Conversely, other investigators [20,23] have noticed that an increase in calcium levels in tuber tissue may lead to increased scab susceptibility. However, controlling common scab by means of irrigation may not be equally effective under different farming systems or within the traditional system in different regions of potato production in the country since irrigation must commence at exact tuber initiation. This process occurs in a variable range of time depending on the potato cultivar and environmental conditions. Therefore, it is important to know exactly when this process occurs with each production cycle (early vs. optimum sowing dates) under the two different farming systems considered in this study.

The results also illustrated that sulphur could significantly suppress common scab and increase yield if applied at appropriate times, but without substantially lowering pH of slightly alkaline soil at the experimental sites. Pavlista [9] findings were in close accord with the data in the present study. He found that the S-containing fertilizers applied at planting and at tuberization reduced the incidence of common scab and promoted the tuber yield. Other investigators have noticed that commercial application of sulphur has suppressed common scab, mostly due to lowering of the soil pH [26,9]. However, Davis et al. [15] indicated that reduction in soil pH by sulphur was not sufficient to account for disease suppression and implicated the lower levels of calcium in peels of tubers as a reason for the reduction in scab. It is worth mentioning that instead of oxidation of sulphur to sulphuric acid leading to reduction in calcium in the tuber tissue, sulphur can be reduced anaerobically to hydrogen sulphide in the soil, which is toxic to *S. scabiei* [27,23] and to other forms of life.

It was evident from the study that the combined effect of irrigation and sulphur-containing fertilizers was compatible with the final tuber yield requirements. The improvement in tuber yield was significant producing an increase of 138% and 91-103.4% under TFS and MFS, respectively when sulphur was applied at planting, which was not significantly different from its application at tuber initiation.

However, the type of sulphur, its optimum rate and its timely application during the life cycle of the crop are deemed imperative and warrant further investigation. From a holistic point of view, only certified seed stocks that meet the allowed tolerance level of common scab should be admitted in the country and be grown in less contaminated soils using cultural practices that observe especial irrigation regime and timely applied sulphur fertilizers.

5. CONCLUSION

The irrigation regime (4-day interval) resulting in excess soil moisture starting during early tuber development proved to be an effective cultural practice for potato common scab management. Application of Sulphur-containing fertilizers (Wettable sulphur or Ammonium sulphate) in combination with the above irrigation regime resulted in further significant reduction of scab infection. However, optimum rates of Sulphur ($\geq$ 84 kg ha^{-1}) timely applied at planting or at tuberization deemed essential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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