Islam, M. S., Khan, A. A., Rubayet, M. T., Haque, M. M., Karim, M. A., Mian, I. H. (2021): Effect of magnesium and sulfur fertilizer on yield, diseases and disorders of seed potato. Agriculture and Forestry, 67(1): 239-254

DOI: 10.17707/AgricultForest.67.1.20

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EFFECT OF MAGNESIUM AND SULFUR FERTILIZER ON YIELD, DISEASES AND DISORDERS OF SEED POTATO

SUMMARY

A study was undertaken to find out the effects of two major nutrient elements such as Magnesium (Mg) and Sulfur (S) on plant growth, tuber, and tuber disease incidence of potato **(***Solanum tuberosum* L.). Data were recorded on stem number/ten hills, plant height, canopy coverage, tuber number per ten plants, tuber weight per plot and incidence of diseases such as common scab (*Streptomyces scabis*), dry rot (*Fusarium sp.*) and soft rot (*Erwinia carotovora*) of potato. The doses of nutrients were Mg @ 0, 10, 15, 20 $kgha^{-1}$ and S @ 0, 10, 20, 30 $kgha^{-1}$. Every nutrient increased plant growth and tuber yield but decreased disease incidence considerably over control up to second highest dosage. The highest yield of 33.61 and 31.50 tha^{-1} were obtained with 15 $kgha^{-1}$ Mg and 20 $kgha^{-1}$ S. When the two elements were applied together at 15 $kgha^{-1}$ Mg and 20 $kgha^{-1}$ S independently, the highest tuber yield of 35.48 tha^{-1}, and the incidence of tuber diseases and disorders were also minimal. Based on findings of the present study it may be concluded that application of Mg, 21.11 kg and S, 4.28 $kgha^{-1}$ along with 140 kg N ha^{-1} are optimum for maximum plant growth, tuber yield and minimize incidence of disease and disorders of potato tuber.

Keywords: Magnesium, sulfur, potato, yield, quality.

INTRODUCTION

Potato **(***Solanum tuberosum* L.) is one of the most widely cultivated horticultural crops in the world and holds the 4th largest crop by global production volume (Marcomini et al., 2019). Now, it is cultivated and consumed more than

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.
Recieved:0707/2020 *Accepted:08/01/2021*

160 countries worldwide (Andre et al., 2014). On the other hand, it ranks next to rice and wheat in terms of production and internal demand in Bangladesh (Rubayet et al., 2017). It contains significant amount of Vitamin-B, C and minerals. The yield of the crop in Bangladesh is very low compared to other potato growing counties. The average yield of potato in Bangladesh is 19.6 tha^{-1} in 2014-15 which is much below the potential productivity of the crop (Anon, 2016). Many factors are responsible for low yield of potato such as seed quality, soil fertility, irrigation facilities, nutrient management, pest infestation, etc. (Iqbal et al., 2019). One of the majors constrains for potato cultivation is unavailability of quality and healthy seed tubers. Diseases and disorders are important for qualitative and quantitative tuber losses (Hossain et al., 2004). Among the diseases, tuber-borne diseases and disorders such as soft rot (*Erwinia* spp.), dry rot (*Fusarium* spp.), common scab (*Streptomyces scabies*) skin spot, black heart, heat injury, secondary growth, greening, etc., play important role in reduction of seed quality. Potato crops require a balanced fertilization for plant growth, and both yield and quality of tubers (Koch et al., 2020). One of the most important constrains of higher tuber yield is the lack of adequate balanced fertilizer application. Since 1980, farmers were using only NPK-fertilizers, but now they are applying S and Zn along with NPK. Many researchers are in opinion that application of minor nutrients such as S, Mg, Zn, B in addition to essential major elements can play a good role in increasing the yield of potato (Sharma *et al*., 2011).

Plants are deficit to Mg in the soil having low pH, sandy in nature and highly leached soil with low Cation Exchange Capacity. The most common symptom of Mg deficiency was observed in the potato field is plants showed interveinal chlorosis on the older leaves. Magnesium is an important constituent of chlorophyll molecule, therefore, essential for photosynthesis. Magnesium increase NPK uptake and thereby increase yield and promotes uptake and translocation of phosphorus (Guo *et al*., 2016). With NPK fertilizers supplemental Mg can increase yields and have tremendous effects on potato quality and net returns, even when soil test Mg levels seem adequate. Magnesium is also important in the activity of a large number of enzyme systems in plants, systems that are particularly important in the metabolism of carbohydrates. Magnesium plays a vital role in the adsorption of other nutrients especially phosphorous, potassium and calcium, acts as a catalyst, activators and co-factors in several enzymatic activities and participates in active protein and carbohydrate metabolism. Potatoes are highly sensitive to Mg nutrient deficiency than other crops. Mg deficiency is one of the most important factors for poor growth of potato in the peat and sandy soils. Mg deficiencies may be corrected through the use of magnesium sulfate (Epsom salts or Kieserite) in fertilizers.

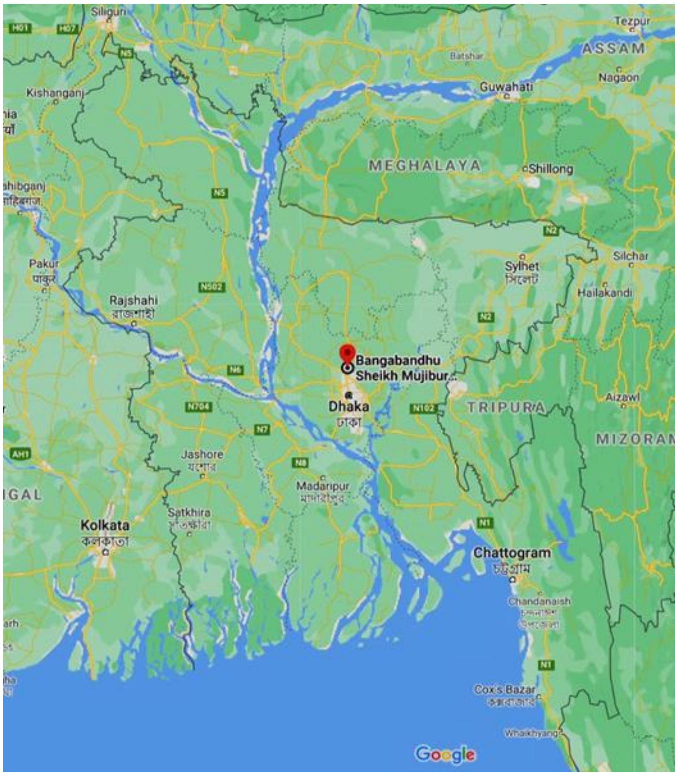
Sharma et al. (2011) observed that sulfur application in potato showed significant influence on quality and yield. The highest tuber yield, large size and medium size tuber yield, dry matter content, specific gravity, sugar content and starch content were found with application of sulfur. Sulfur helps to minimize the diseases, for instance common and powdery scab. This effect may be due to a reduction in the soil pH where elemental sulfur is used. However, a programme of foliar S, can also reduce infection (Brierley *et al*., 2008). Sulfur can reduce common scab, late blight, stem canker of potato. In additionally, Sulfur can balance other nutrients and make the environment less favorable for the pathogen. Applications of elemental S to soil would control potato scab. It appears that the mechanism for control comes from the reduction in soil pH. Elemental sulfur can aid in reducing the infection levels of common scab caused by the *S. scabies*. Best effects come from applying sulfur to the soil in a readily available form at planting. The application of sulfur significantly reduces the infection of *Rhizoctonia solani* and *Streptomyces scabies* and increase tuber yield. It may elucidate S-induced resistance mechanisms in plants (Hanna *et al*., 2006). Above discussion indicates that application of Mg and S may help in increasing production and quality of potato. Hence, to address these problems the study was undertaken with the major objective to investigate the effects of applying different levels of magnesium and sulfur on tuber yield and quality of seed potato.

MATERIALS AND METHODS

The experiment was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University farm, Gazipur, Bangladesh (Map 1) during 2014-2016 to find out effect of Magnesium (Mg) and Sulfur (S) on plant growth, tuber yield and tuber health. Mg was applied at 0, 10, 15 and 20 $kgha^{-1}$, which were designated as Mg_0, Mg_{10}, Mg_{15} and Mg_{20}. Sulfur was applied at 0, 10, 20, 30 $kgha^{-1}$, which were designated as S_0, S_{10}, S_{20} and S_{30}. In this experiment the treatment combinations were Mg_0S_0, Mg_0S_{10}, Mg_0S_{20}, Mg_0S_{30}, $Mg_{10}S_0$, $Mg_{10}S_{10}$, $Mg_{10}S_{20}$, $Mg_{10}S_{30}$, $Mg_{15}S_0$, $Mg_{15}S_{10}$, $Mg_{15}S_{20}$, $Mg_{15}S_{30}$, $Mg_{20}S_0$, $Mg_{20}S_{10}$, $Mg_{20}S_{20}$ and $Mg_{20}S_{30}$. Magnesium as magnesium chlorite ($MgCl_2.6H_2O$) and Sulfur as gypsum ($CaSO_4{\cdot}2H_2O$) were used in the experiment.

Experimental site: The soil of the experimental field belongs to Salna series under the Agro Ecological Zone AEZ-28, Madhupur Tract (24.05^0 N latitude and 90.16^0 E longitude) at an elevation of 8.4 m above the sea level. The texture of the soil was silty clay in surface layer and silty clay loam in subsurface layer. The results of soil test reveal that the soil contains 1.4% organic matter, magnesium 1.05 mE/100 g soil, sulfur 2.29 ppm and pH 6.7-6.9. Land of the experimental plots was prepared in the month of November using a tractor driven harrow and disk plough followed by laddering to obtain a good tilth. Weeds and other debris were removed. Before ploughing cowdung based compost was applied at 10 tha^{-1}. A blank dosage of N, P, K, Zn and B was used at 140-35-140-4-1.5 $kgha^{-1}$and applied as urea, TSP, MOP, zinc oxide and boric acid, respectively. One half dosage of NK and other nutrients were mixed with soil in furrows at the time of plantation of seed tuber. After final land preparation, experimental unit plots were prepared. The unit plot size was 2.25 m × 2.40 m. Plot to plot and block to block distance was 1 m. The experiment was laid out in

4 × 4 factorial design in randomized complete block with three replications. The potato seed tubers of variety Diamant (basic class) were collected from Bangladesh Agricultural Development Corporation (BADC). Seed tubers were kept under defused light for sprouting. Sprouted tubers were planted in 5-7 cm deep furrows in 3rd week of November. The planting spacing was 60 cm row to row and 15 cm tuber to tuber. Four lines were accommodated in each unit plot. Standard cultivation operations were followed to grow potato (Anon, 2008). First irrigation was applied one week after planting which was continued for several times as per requirement. After 20 days of planting weeding was done. To control the fungal diseases especially late blight, Dithane M-45 was applied at the rate of 2.5 kgha^{-1} and to control aphids, Admire was applied at the rate of 1Lha^{-1}. Both the pesticides were applied as foliar spray for six times at 10 days interval starting from 20 days of planting.



Map 1. Location of study area (24°02'15.1" N, 90°23'53.1" E, https://goo.gl/maps/ivZHT7iRS4j23wUq7)

Data recording

Plant growth parameters: At 45 days after planting of seed tuber under different experiments, 15 cm × 60 cm area was selected randomly and data on canopy coverage was recorded and expressed in percentage. At 60 days after planting 10 plants were selected randomly from each plot and data on plant growth attributes viz. number of stems per 10 hills and at 60 days after planting plant height was recorded. Stem killing was done on 80th day of after planting to avoid spread of viruses and for hardening of tuber skin. After ten days of stem killing potato tubers were harvested manually and care was taken to avoid tuber injuries at harvest. Seven days after air drying healthy tubers were sorted out and graded into four grades on the basis of tuber size. Grading of tuber was done following a standard grading system based on size according to Bangladesh Agricultural Development Corporation (BADC) the only Government's seed producing agency in Bangladesh (Anon., 2008). The grades were undersize (20 – 28 mm), grade A (28 – 41 mm), grade B (41 – 56 mm) and oversize (>56– 60 mm). Data on plant growth and tuber yield attributes in terms of stem number per ten plants, plant height, canopy coverage, number of tubers per ten plants and tuber yield per unit plot were recorded.

Data on disease: Data on diseases and disorders were taken after 7 days of harvest and expressed percentage (w/w) based on per plot yield of potato. The disease was identified based on visible symptoms. Whenever necessary, the identification was confirmed by laboratory tests. The data on incidence (%) of common scab, soft rot and dry rot were recorded. Data on different disease incidence were computed using a standard formula shown below:

$$\% \text{ incidence} = (\text{Weight of infected tuber}/\text{Weight of total tuber}) \times 100$$

Statistical analysis: Data were analyzed statistically using Statistix 10 analytical software (https://www.statistix.com/) for proper interpretation of results. The data recorded on different parameters were subjected to analysis of variance (ANOVA) and the means were compared using least significant difference (LSD) test at 5% level of significance. Graphs and figures were prepared as and when necessary for proper presentation of the data.

RESULTS AND DISCUSSION

Stem number per 10 hills

Main effect of Mg: The highest number of 53.3 stems per 10 hills was recorded at 10 kg Mg ha^{-1} (Mg_{10}), which was statistically similar to 15 kg (Mg_{15}) and 20 kg Mg ha^{-1} (Mg_{20}) but significantly higher compared to control. The lowest number of 47.5 stems per 10 hills was produced under control (Mg_0) (Fig. 1).

Main effect of sulfur: The highest number of 53.3 stems per hill was found at S_{20}, which was statistically similar to S_{10} and S_0. The lowest stem number of 48.3 per 10 hills was observed in S_{30}, which was statistically similar to S_0 and S_{10} (Fig. 2).

Interaction effect: The highest number of 56.7 stems per 10 hills was produced in treatment combination $Mg_{10}S_{20}$, which was statistically similar to $Mg_{20}S_{10}$, $Mg_{10}S_0$, $Mg_{10}S_{30}$, $Mg_{15}S_{10}$, $Mg_{15}S_{20}$, $Mg_{20}S_{20}$, Mg_0S_0, Mg_0S_{10}, Mg_0S_{20}, $Mg_{10}S_{10}$, $Mg_{15}S_0$, $Mg_{15}S_{30}$ and $Mg_{20}S_{30}$. The lowest stem number of 40.00 per 10 hills was recorded in Mg_0S_{30} which was statistically similar to $Mg_{20}S_0$ (Table 1).

Plant height

Main effect of magnesium: Significantly the highest plant height of 64.90 cm was recorded at 15 kg Mg ha^{-1}, which was statistically different from its other doses. The lowest plant height of 57.40 cm was produced in control (Fig. 1).

Main effect of sulfur: The highest plant height of 63.40 cm was found at 20 kg S ha^{-1}, which was statistically similar to 30 kg S ha^{-1}. The lowest plant height was observed in control (S_0) Application of caused significant increase in this parameter compared to control (Fig. 2).

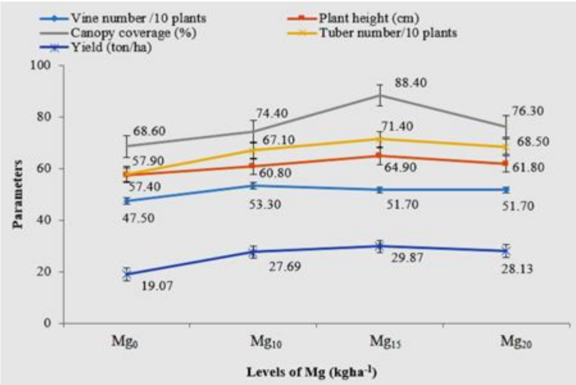


Fig 1. Effect of magnesium (Mg) on growth and yield attributes of potato at different levels under a constant level of NPKBZn [Mg_0 = No magnesium, Mg_{10} = 10 kg Mg ha^{-1}, Mg_{15} = 35 kg Mg ha^{-1}, Mg_{20} = 20 kg Mg ha^{-1}.]

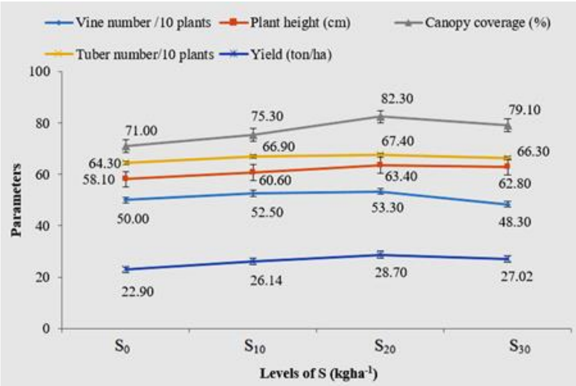


Fig 2. Effect of Sulfur (S) on growth and yield attributes of potato at different levels under a constant level of NPKBZn [S_0 = No sulfur, S_{10} = 10 kg S ha^{-1}, S_{20} = 20 kg S ha^{-1}, S_{30} = 30 kg S ha^{-1}.]

Interaction effect: Significantly the highest plant height of 69.0 cm was produced in $Mg_{15}S_{20}$ which was different from other treatment combinations. The lowest plant height of 54.3 cm was recorded in control (Mg_0S_0) (Table 1).

Table 1. Interaction effect of magnesium (Mg) and sulfur (S) on growth and yield attributes of potato at different levels under a constant level of NPKBZn

Level of Mg / Dose of S	Mg_0*	Mg_{10}	Mg_{15}	Mg_{20}
Stem number /10 plants				
S_0*	50.0 a[1]	53.3 ab	50.0 ab	46.7 bc
S_{10}	50.0 ab	50.0 ab	53.3 ab	56.7 a
S_{20}	50.0 ab	56.7 a	53.3 ab	53.3 ab
S_{30}	40.0 c	53.3 ab	50.0 ab	50.0 ab
Plant height (cm)				
S_0	54.3 k[1]	58.3 ij	61.0 efg	58.7 hij
S_{10}	57.3 j	60.0 ghi	63.7 cd	61.3 efg
S_{20}	57.3 j	63.0 cde	69.0 a	64.3 bc
S_{30}	60.7 fgh	61.7 defg	66.0 b	62.7 cdef
Canopy coverage (%)				
S_0	65.0 j[1]	67.0 i	82.0 de	70.0 h
S_{10}	66.7 ij	73.0 g	87.0 c	74.7 g
S_{20}	69.7 h	81.0 e	95.3 a	83.0 d
S_{30}	73.0 g	76.7 f	89.3 b	77.3 f
Tuber number/10 plants				
S_0	57.0 g[1]	63.8 f	68.4 cde	67.8 e
S_{10}	57.2 g	67.1 e	72.7 ab	70.6 bc
S_{20}	58.4 g	68.8 cde	74.4 a	68.2 de
S_{30}	58.9 g	68.8 cde	70.2 cd	67.2 e
Seed Potato Tuber Yield (ton/ha)				
S_0	16.41 j[1]	22.94 g	26.84 ef	25.39 f
S_{10}	18.30 i	28.26 de	29.83 bc	28.19 de
S_{20}	21.41 h	30.64 b	32.86 a	29.90 bc
S_{30}	20.15 h	28.93 cd	29.96 bc	29.04 cd

*Mg_0 = No magnesium, Mg_{10} = 10 kg Mg ha^{-1}, Mg_{15} = 15 kg Mg ha^{-1}, Mg_{20} = 20 kg Mg ha^{-1}. *S_0 = No sulfur, S_{10} = 10 kg S ha^{-1}, S_{20} = 20 kg S ha^{-1}, S_{30} = 30 kg S ha^{-1}. [1]Figures under the same parameter within row and column are averages of three replications and having a common letter(s) do not differ significantly (*P= 0.05*) by LSD test.

Canopy coverage

Main effect of magnesium: The maximum of 88.4% canopy coverage was recorded at 15 Kg Mg ha^{-1} (Mg_{15}), which was statistically different from other treatments. The minimum canopy coverage of 68.6% in control was also statistically different from other treatments (Fig. 1).

Main effect of sulfur: The maximum canopy coverage of 82.3% was recorded at 20 Kg S ha^{-1} (S_{20}) and the minimum canopy coverage of 71.0% were found in control, which was statistically different from other treatments (Fig. 2).

Interaction effect: The canopy coverage under different treatment combination of Mg and S ranged from 95.3% to 65.0%. The highest canopy coverage of 95.3% was found at $Mg_{15}S_{20}$, which was not significantly different from other treatment combinations. The lowest canopy coverage of 65.0% was found under control, which was statistically similar to Mg_0S_{10} (66.7%) (Table 1).

Tuber per ten plants

Main effect of magnesium: The minimum tuber number of 57.9 per 10 plants was recorded from control, which was significantly increased due to application of Mg at different levels. The maximum average number of 71.4 tubers per 10 plants was found at Mg_{15} (Fig. 1).

Main effect of sulfur: The maximum average number of 67.4 tubers 10 per plants was observed at S_{20}, which was statistically similar to S_{10}. The minimum tuber number of 64.3% per 10 plants was recorded under control (Fig. 2).

Interaction effect of Mg and S: The maximum average number of 74.4 tubers per 10 plants was obtained from $Mg_{15}S_{20}$, which was similar to $Mg_{15}S_{10}$. The minimum number of 57.0 tubers per 10 plants was found under control, which was statistically similar to Mg_0S_{10}, Mg_0S_{20} and Mg_0S_{30} (Table 1).

Seed Potato Tuber Yield (tha^{-1})

Main effect of magnesium: The lowest tuber yield of 19.07 tha^{-1} was produced in control plot, which was increased to 29.87 tha^{-1}. The highest yield per plot of 29.87 tha^{-1} was produced at Mg_{15} (Fig.1).

Main effect of sulfur: The significantly highest yield was obtained with served 28.70 tha^{-1} at 20 kg S ha^{-1} (S_{20}) and the lowest yield per plot was found 22.90 tha^{-1} under control, which was significantly different from other treatments (Fig. 2).

Interaction effect of Mg and S: The average highest yield of 32.86 tha^{-1} was found at $Mg_{15}S_{20}$, which was different from other treatment combinations and the lowest yield per plant was 16.41 tha^{-1} under control, which was statistically similar to Mg_0S_{10} and Mg_0S_{30} (Table 1).

Grading of healthy tubers: Healthy tubers were graded into four grades based on their size. These were Grade-A (diameter 28-41 mm), grade-B (diameter 41-55 mm), undersize (diameter 20-28 mm) and oversize (diameter 55-60 mm). Occurrence of tuber under each grade was expressed as percentage of total healthy tubers. Occurrence of grade-B tubers was maximal followed by grade-A, undersize and oversize tuber (Fig. 3).

Grade A (diameter 28-41 mm)

Main effect of magnesium: The highest grade-A seed tuber of 27.48% was recorded at 20 $kgha^{-1}$, which was statistically similar to 10 $kgha^{-1}$. The lowest Grade-A seed was produced at control (Mg_0) (Fig. 3).

Main effect of sulfur: The highest occurrence of grade A seed tuber of 27.41% was found at 30 kg S ha^{-1} which was statistically similar to 20 kg S ha^{-1}. The lowest occurrence Grade A seed was observed in control (S_0) which was statistically similar with 10 kg S ha^{-1}

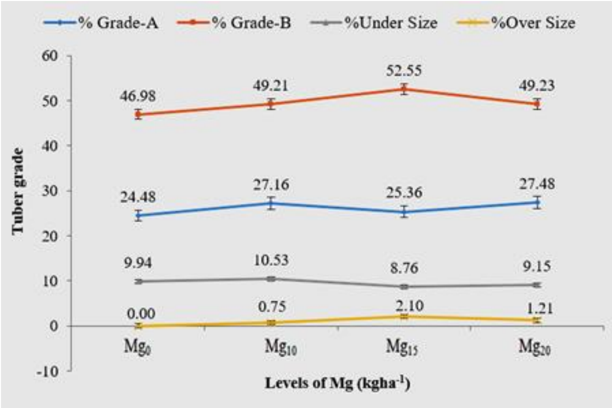


Fig 3. Main effect of Mg on occurrence of different grades of tubers under a constant level of NPKBZn [Mg_0 = No magnesium, Mg_{10} = 10 kg Mg ha^{-1}, Mg_{15} = 15 kg Mg ha^{-1}, Mg_{20} = 20 kg Mg ha^{-1}]

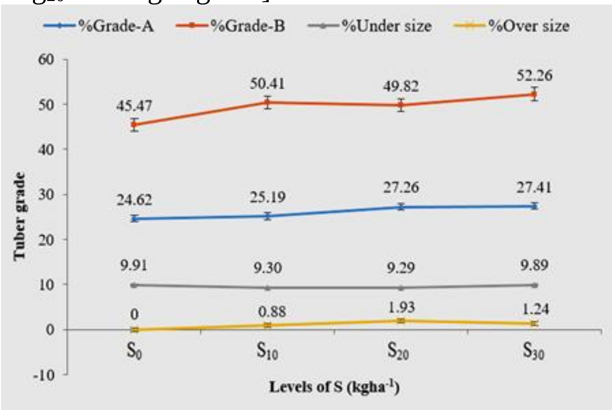


Fig 4. Main effect of S on occurrence of different grades of tubers under a constant level of NPKBZn [S_0 = No sulfur, S_{10} = 10 kg S ha^{-1}, S_{20} = 20 kg S ha^{-1}, S_{30} = 30 kg S ha^{-1}]

Interaction effect of Mg and S: The highest-Grade A seed tuber (29.41%) was produced in $Mg_{10}S_{20}$ which was statistically similar with $Mg_{10}S_{30}$, Mg_0S_{30}, $Mg_{20}S_{10}$, $Mg_{20}S_0$, $Mg_{20}S_{30}$ and $Mg_{20}S_{20}$. The lowest Grade A seed tuber (20.18%) was recorded in control (Mg_0S_0) which was statistically similar with Mg_0S_{10} (Table 2).

Grade B (diameter 41-55 mm)

Main effect of magnesium: The highest grade-B seed was found 52.55% at 15 kg Mg ha^{-1} (Mg_{15}), which was significantly different from other treatments. The lowest grade-B of 46.98% was recorded from control significantly higher compared to other treatments (Fig. 3)

Main effect of sulfur: The main effect was significant. The highest occurrence of 52.26% grade-B tubers was recorded at 30 kg ha^{-1} (S_{30}) and the lowest occurrence of 45.47% grade-B tubers was observed under control, which was significantly higher from other treatment combinations

Table 2. Interaction effect of magnesium (Mg) and sulfur (S) on tuber grade size at different levels under a constant level of NPKBZn

Level of Mg / Dose of S	Mg_0*	Mg_{10}	Mg_{15}	Mg_{20}
% Grade-A (28-41mm)				
S_0*	20.18 g[1]	25.70 cde	25.04 de	27.55 abc
S_{10}	22.44 fg	24.46 ef	26.17 cde	27.7 abc
S_{20}	26.77 bcde	29.41 a	25.72 cde	27.13 abcd
S_{30}	28.55 ab	29.07 ab	24.5 ef	27.52 abc
% Grade-B (41-55 mm)				
S_0	45.42 fg[1]	43.14 g	49.12 cde	44.2 g
S_{10}	48.03 ef	51.3 bcd	52.07 bc	50.26 cde
S_{20}	45.44 fg	48.62 de	53.82 ab	51.4 bcd
S_{30}	49.02 cde	53.77 ab	55.19 a	51.07 bcde
% Under size (20-28mm)				
S_0	7.93 e[1]	13.36 a	9.13 cde	9.2 cde
S_{10}	8.67 de	11.01 b	8.88 de	8.64 de
S_{20}	10.57 bc	8.87 de	8.57 de	9.14 cde
S_{30}	12.59 a	8.89 de	8.44 de	9.62 bcd
% Over size (>55-60mm)				
S_0	0 c[1]	0 c	0 c	0 c
S_{10}	0 c	0 c	2.74 b	0.80 c
S_{20}	0 c	0 c	4.51 a	3.19 ab
S_{30}	0 c	3.00 b	1.13 c	0.83 c

*Mg_0 = No magnesium, Mg_{10} = 10 kg Mg ha^{-1}, Mg_{15} = 15 kg Mg ha^{-1}, Mg_{20} = 20 kg Mg ha-1, *S_0 = No sulfur, S_{10} = 10 kg S ha^{-1}, S_{20} = 20 kg S ha^{-1}, S_{30} = 30 kg S ha^{-1}. [1]Figures under the same parameter within row and column are averages of three replications and having a common letter(s) do not differ significantly (*P= 0.05*) by LSD test.

Interaction effect: Interaction effect of Mg and S on grade-B tubers was significant. The highest grade-B 55.19% seed tubers were found at $Mg_{15}S_{30}$, which was statistically similar to $Mg_{15}S_{20}$ and $Mg_{10}S_{30}$. The lowest occurrence of 43.14% grade-B seed tuber was found at $Mg_{10}S_0$, which was statistically similar to $Mg_{20}S_0$, Mg_0S_0 and Mg_0S_{20} (Table 2).

Undersize (diameter 20-28 mm)

Main effect of magnesium: The highest occurrence of only 10.53% undersize seed tuber was produced due to application of Mg at 10 kg ha^{-1}, which was statistically similar to control (gha^{-1}). The lowest occurrence of 8.76% undersize seed tuber was recorded in 15 kg Mg ha^{-1} which was statistically similar to 20 kg Mg ha^{-1} (Fig. 3).

Main effect of sulfur: No significant different was observed in under size tuber due to sulfur. The highest under size seed tuber (9.91%) was observed in control (S_0) and the lowest under size seed tuber (9.29%) was in 20 kg S ha^{-1} (Fig. 4).

Interaction effect: The highest under size seed was found in $Mg_{10}S_0$ (13.36%) which was statistically similar with Mg_0S_{30}. On the other hand, the lowest healthy under size seed was recorded in control Mg_0S_0 (7.93%) which was statistically similar with $Mg_{15}S_{30}$, $Mg_{15}S_{20}$, $Mg_{20}S_{10}$, Mg_0S_{10}, $Mg_{10}S_{20}$, $Mg_{15}S_{10}$, $Mg_{10}S_{30}$, $Mg_{15}S_0$, $Mg_{20}S_{20}$ and $Mg_{20}S_0$ (Table 2).

Oversize (diameter >55-60 mm)

Main effect of magnesium: Oversize tubers were not produced in absence of Mg (control) and lowest level of the element. The maximum occurrence of 2.10% tubers was recorded at 15 kg Mg ha^{-1} of the element (Fig. 3).

Main effect of sulfur: The highest occurrence of only 1.93% oversize seed tuber was recorded at 20 kg ha^{-1} (S_{20}) and there was no oversize seed tuber was observed under control (Fig. 4).

Interaction effect: The highest occurrence of only 4.51% oversize seed tuber was found at $Mg_{15}S_{20}$, which was statistically similar to $Mg_{20}S_{20}$. Oversize seed tuber was not formed at the treatment combinations $Mg_{20}S_0$, $Mg_{15}S_0$, $Mg_{10}S_{20}$, $Mg_{10}S_{10}$, $Mg_{10}S_0$, Mg_0S_{30}, Mg_0S_{20}, Mg_0S_{10} and Mg_0S_0 which were statistically similar with $Mg_{20}S_{10}$, $Mg_{20}S_{30}$, $Mg_{15}S_{30}$ (Table 2).

Incidence of diseases: Like experiment 1, three important potato diseases were recorded from harvested tubers. The diseases were common scab, soft rot and dry rot.

Incidence of common scab

Main effect of Mg: Main effect of Mg on common scab was significant. The highest common scab incidence was 7.01% (w/w) was under control (Mg_0). Application of Mg caused significant decrease in disease incidence showing the lowest common scab incidence of 5.10% at Mg_{10} (Fig. 5).

Main effect of sulfur: The main effect of S on common scab was also significant. The highest incidence of 9.66% (w/w) of common scab was found under control (S_0). Application of S reduced the disease incidence significantly over control (S_0). The lowest incidence of 3.33% common scab disease was recorded under S_{30}, which was statistically similar to S_{20} (Fig. 6).

Incidence of soft rot and dry rot: The main effect of Mg and S on incidence of soft rot and dry rot was very low. The incidence soft rot and dry rot under Mg ranged 0.87-2.76% and 0.25-0.82%, respectively. Their incidence under S ranged 1.17-2.34% and 0.37-0.73%, respectively (Fig. 5 and 6).

Interaction effect of Mg and S on total disease incidence: The maximum total disease incidence was recorded under control (Mg_0S_0). Combined application of Mg and S caused significant decrease in disease incidence over control. The decreasing tendency incidence continued up to $Mg_{15}S_{20}$ (Fig. 7).

Incidence of disorders: Different disorders such as secondary growth and greening were found in harvested potato tubers, but their incidence was negligible (Fig. 8). So the details are not given.

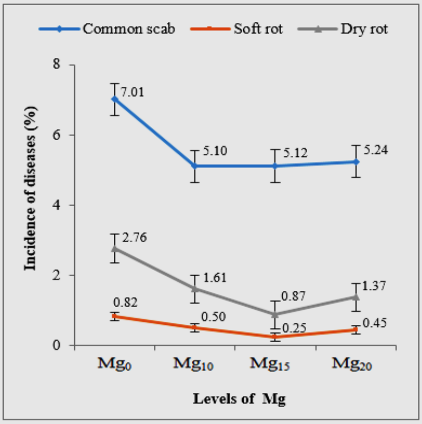


Figure 5. Incidence of common scab, soft rot and dry rot diseases at different levels of magnesium

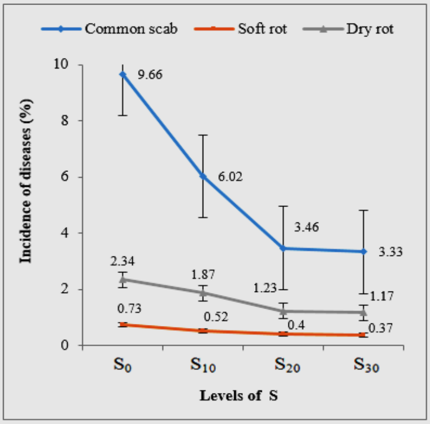


Figure 6. Incidence of common scab, soft rot and dry rot diseases at different levels of sulfur

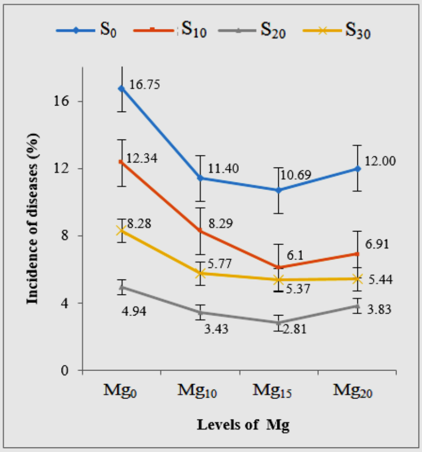


Figure 7. Interaction effect of Mg and S on incidence of total diseases

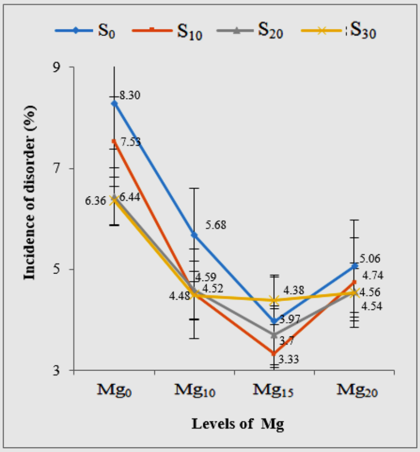


Figure 8. Interaction effect of Mg and S on incidence of total disorders

Estimation of optimum level of magnesium and sulfur

Regression analysis was done and optimum and economic dose of fertilizer were calculated using the formula Y = -b/2c from the response curve (Gomez and Gomez, 1984). Dobermann et al. (2000) stated that the optimal rate of fertilizer application to a crop is that rate which produces the maximum economic returns at the minimum cost, and this can be derived from a nutrient response curve. The large and significant R^2 value in case of Mg and S of regression indicates that the quadratic response fitted the data. Response curve shows that yield increased with the increasing of nutrients at certain level and thereafter yield was decreased. Results presented in Fig 9 shows that potato tuber yield increased with increasing level of Magnesium to a certain limit and then decreased with further increase of nutrients level. But the increment of yield was

prominent in case of Mg and the highest yield (29.87 tha^{-1}) was obtained from 15 kg Mg ha^{-1}. Magnesium has distinct effect on the yield. But further application of Mg yield began to decrease. It was indicating the detrimental effect of over fertilization. The reason might be medium Mg status in soil. From the regression equations optimum dose of Magnesium fertilizer is 15.28 kg ha^{-1} for better yield.
In case of sulfur, potato tuber yield was also increased with increasing level of sulfur fertilizer to a certain limit and then decreased with further increase of nutrients level (Fig. 20). The highest yield (28.70 tha^{-1}) was obtained from 20 kg S ha^{-1}. But further application of S yield began to decrease. The reason might be medium S status in soil. The regression equations suggested that optimum dose of sulfur fertilizer is 21.11 kg ha^{-1} for better seed tuber yield (Table 3).

The results of present experiment suggest that growth parameters, yield and yield components of potato are responded positively to Mg and S fertilizers either applied as sole or in combination. The average tuber weight, healthy seed tuber and total tuber yield was positively and significantly influenced by different levels of Mg and S fertilizer and their interaction. The highest tuber yield, average tuber weight, number of tubers per plant and number of stem per hill were obtained from application of Mg and S fertilizer in combination at the rate of 15 Kg Mg ha^{-1} and 20 Kg S ha^{-1}. Other researchers also found positive effect of Mg and S fertilizer on growth and yield. Talukder et al. (2009) tested 5 levels of magnesium viz., 0, 5, 10, 15, and 20 kg ha^{-1} to observe its effects on potato and to find out the optimum and economic dose of Mg for potato.

Table 3. Regression equation and Optimum dose of Magnesium and Sulfur fertilizer

Nutrients levels ($kgha^{-1}$)	Seed potato tuber yield (tha^{-1})	Yield increased over control (%)	Regression equation and R^2 value	Optimum dose of fertilizer (kg ha^{-1})
Magnesium Levels				
Mg_0	19.07	-	$y = -0.0443x^2 + 1.3538x + 18.999$ $R^2 = 0.9927$	15.28
Mg_{10}	27.69	45.24		
Mg_{15}	29.87	56.67		
Mg_{20}	28.13	47.53		
Sulfur Levels				
S_0	22.90	-	$y = -0.0123x^2 + 0.5193x + 22.717$ $R^2 = 0.9646$	21.11
S_{10}	26.14	14.19		
S_{20}	28.70	25.37		
S_{30}	27.02	18.01		

Mg_0 = 0 kg Mg ha^{-1}, Mg_{10} = 10 kg Mg ha^{-1}, Mg_{15} = 15 kg Mg ha^{-1}, Mg_{20} = 20 kg Mg ha^{-1}. S_0 = 0 kg S ha^{-1}, S_{10} = 10 kg S ha^{-1}, S_{20} = 20 kg S ha^{-1}, S_{30} =30 kg S ha^{-1}.

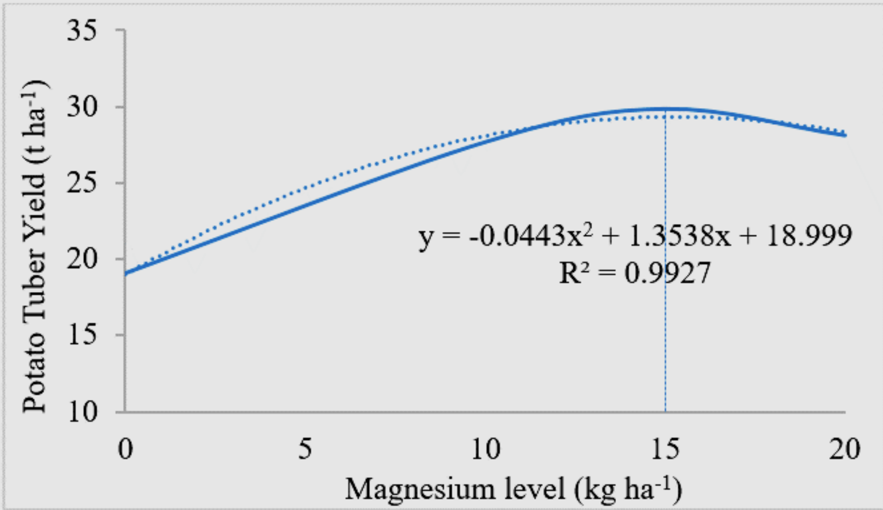


Figure 9. Relationship between magnesium levels with potato tuber yield

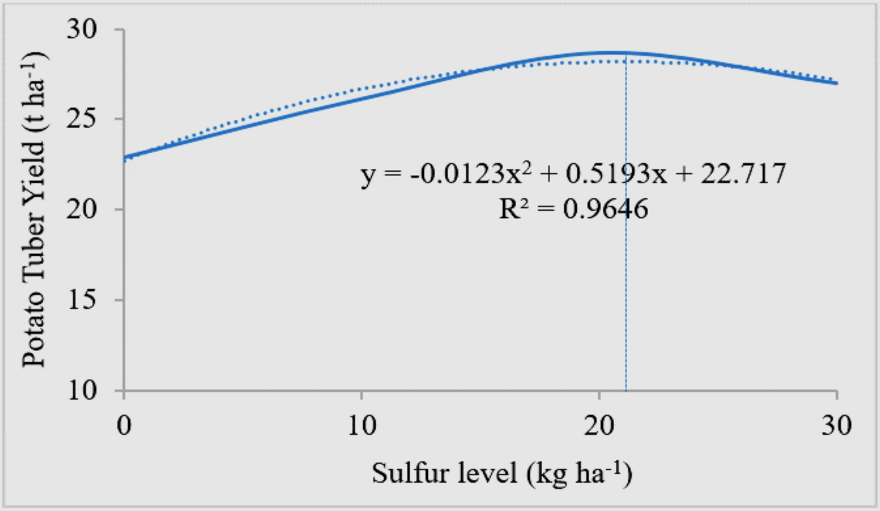


Figure 10. Relationship between sulfur levels with potato tuber yield

Tuber yield tended to decrease with increasing rate of Mg beyond 10 kg ha^{-1}. They suggested that maximum tuber yield (30.32 tha^{-1}) could be obtained at 13 kg ha^{-1} of Mg. Draycott and Allison (1998) recommended for potato to apply 15-20 kg Mg ha^{-1} to obtain higher tuber yield. The result of present study is very close to their findings. Sharma et al. (2011) showed that sulfur application in potato had significant influence on quality and yield. Highest tuber yield, large size and medium size tuber yield, dry matter content, specific gravity, sugar content and starch content were increased with increasing dose of sulfur.

Kristufek et al. (2000) observed that control of common scab is mainly caused by different soil amendments and breeding for disease resistance. One of the best methods for combating scab is the use of acid producing fertilizers, especially those that contain liberal amounts of sulfate of ammonia. Hanna et al. (2006) also found that the application of S can reduce bacterial and fungal diseases in potatoes at the rate of 25 kg S ha^{-1}. Soil characteristics greatly affect by the severity of potato scab in soils with pH 7. The use of acidifying fertilizers such as ammonium sulfate or diammonium phosphate or applications of sulfur that reduce the soil pH, can induce control of common scab disease (Wiechel and Crump, 2010). The results of present experiment partially support the findings of Kristufek et al. (2000) and Wiechel and Crump (2010). In present experiment, aggregate tuber yields increased quadratically with increasing Mg application rates up to 15 kg Mg ha_{-1}, reaching a plateau thereafter, yield was decreasing at the application of 20 kg Mg ha_{-1}. Similar result was found in case of sulfur application rates. Tuber yield increased quadratically with increasing sulfur application rates up to 20 kg S ha_{-1}, reaching a plateau thereafter, yield was decreasing at the application of 30 kg S ha_{-1}. Similar results also reported by Talukder et al. (2009); Barczak et al. (2013).

CONCLUSIONS

The present study revealed that, the incidence of common scab, soft rot and dry rot diseases of seed tuber reduces in application of Mg and S at the rate of 15 kg Mg ha^{-1} and 20 kg S ha^{-1}. The higher tuber yield was also obtained from this combination of Mg and S. However, regression analysis suggested that the maximum yield may obtain at a combination of Mg and S at the rates of 15.28 kg Mg ha^{-1} and 21.11 kg S ha^{-1} to the study area and other similar areas having alluvial soil. Therefore, it is suggested that farmers should apply 15.28 kg Mg ha^{-1} and 21.11 kg S ha^{-1} along with standard dose of NPK to obtain maximum yield and disease-free seed tuber of potato.

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