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Effect of Integrated Disease Management (IDM) Practices on Disease Severity and Incidence of Common Scab of Potato

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Abstract
Common scab is a disease caused by *Streptomyces* spp. that can significantly reduce potato crop yield and quality, affecting marketability. Traditionally, pesticides have been used to prevent this disease, but this approach has several drawbacks, including the development of pesticide resistance and negative effects on the environment and human health. Therefore, it was essential to develop eco-friendly Integrated Disease Management (IDM) strategies for common scab management. In this study, we evaluated 13 different treatments in various combinations with three replications each. We found that treatment T_2 (soil amendments with gypsum at 2.0 t/ha + tuber treatments with *Trichoderma harzianum* at 5 g/kg + foliar spray of copper oxychloride with streptocycline in a 3:1 ratio) showed the highest reduction in disease severity (3.63%) and incidence (1.79%) compared to the control (46.60% and 34.57%, respectively). Moreover, IDM practices also altered the physiochemical properties of the soil. T_2 treatment resulted in the highest pH value of 5.86 after planting and 5.30 after harvesting, with the minimum Electrical Conductivity (EC) value estimated to be 0.089 S/m after planting and 0.087 S/m after harvesting. After planting, T_2 treatment showed a soil content of 2.12 mg/kg zinc, 3.41 mg/kg copper, and 38.83 mg/kg iron, which increased to 2.42 mg/kg zinc, 3.27 mg/kg copper, and 38.39 mg/kg iron after harvesting. T_4 treatment (soil amendments with elemental sulphur at 0.5 t/ha + tuber treatments with *T. harzianum* at 5 g/kg + foliar spray of copper oxychloride with streptocycline in a 3:1 ratio) showed the highest sulphur content, estimated at 47.69 mg/kg after planting and 48.43 mg/kg after harvesting, and reduced the disease severity and incidence by 10.89% and 7.19%, respectively. T_3 treatment ($MnSO_4$ at 15 kg/ha + *T. harzianum* at 5 g/kg + copper oxychloride with streptocycline in a 3:1 ratio) resulted in the highest soil content of manganese, with 96.47 mg/kg after planting and 98.84 mg/kg after harvesting. Overall, T_2 treatment showed the most effective control against common scab disease and is recommended as the best IDM strategy for potato common scab management.

Extended author information available on the last page of the article

Keywords Disease incidence · Disease severity · Gypsum · Physiochemical properties of soil · *Streptomyces scabies*

Introduction

Potato (*Solanum tuberosum* L.) is a vital and versatile vegetable crop that holds significant global importance. The Food and Agriculture Organization (FAO) estimates that in 2020, over 359 million metric tonnes of potatoes were harvested from more than 17 million hectares of land worldwide. China remains the top potato producer globally, followed by India, the Russian Federation, and Ukraine (FAOSTAT, 2022). India produced 53.58 million metric tonnes of potatoes in an area of 2.20 million hectares, with an average yield of 24.35 t/ha in 2022 (Kumar et al. 2022a, b). With the increasing population pressure in the country, the demand for potatoes is continuously rising. Therefore, there was an urgent need to enhance the production per unit of usable land.

The potato crop has a short growing time and can be produced economically, making it an ideal crop to fulfil the demand. However, potato production and yield potentials are challenged by various factors, including fungal and bacterial diseases, temperature changes, soil conditions, and water availability (Majeed and Muhammad 2020). In most potato-growing zones in India, abiotic issues such as soil quality, temperature stress, salt, and lack of irrigation water are prevalent, whilst biotic issues like viral, bacterial, and fungal diseases, and nematodes pose significant challenges. Due to both biotic and abiotic factors, the productivity rate per unit area of land is lower in India compared to other countries, although the potato yield is steadily increasing (Mishra and Srivastava 2001). One of the significant challenges faced by potato farmers is common scab disease caused by various species of *Streptomyces*, including *Streptomyces scabies*, *S. europaeiscabiei*, *S. acidiscabiei*, *S. turgidiscabiei*, and *S. stelliscabiei*.

The pathogen is found in the soil and plant debris and is known to be highly destructive to potato tubers. Amongst the various species, *S. scabies* is considered the most dangerous due to its ability to produce thaxtomin A, a plant phytotoxin (Sarwar et al. 2018). *S. scabies* is a gram-positive filamentous bacterium that causes scabby lesions on potato tubers by producing thaxtomin A, which deteriorates cortical and epidermal tissues (Braun et al. 2017a, b). This leads to the development of superficial or deep corky stains on the tubers, which can negatively affect their quality. The production of thaxtomin disrupts the outer cells of the tuber, leading to additional layers and skin lesions (Wanner et al. 2014). Although the disease does not have a significant impact on potato yield and production, it can result in considerable economic losses due to the rejection of scab-damaged potatoes. The severity of the losses can vary depending on factors such as location, pathogen aggressiveness, potato cultivar susceptibility, soil conditions, and control techniques.

The pathogen is both seed- and soil-borne and can survive in the soil for many years, making it extremely difficult to reduce its population once it establishes itself in the field (Sharma and Sharma 1989; Braun et al. 2017a, b; Mishra and Srivastava 2001; Majeed and Muhammad 2020). McRae (1929) was the first to record the disease in the Khasi Hills (Meghalaya), India. By 1960, it had become prevalent in the hilly regions of Uttar Pradesh, Meghalaya, and West Bengal, and its severe form was observed in the Lahaul Valley (Himachal Pradesh). Subsequently, it spread to the plains during 1960–1980, and Sharma (1984) reported multiple sightings. Al-Mughrabi et al. (2016) reported that the potato industry in New Brunswick, Canada, experiences annual losses of $1.2 million due to common scab. Kapuria et al. (2016) found that common scab of potato reduces the market grade of tubers and causes losses ranging from 1.5 to 34.6% in the potato-growing district of Gujarat, India. Ahlawat et al. (2021) reported that moderate to severe forms of the disease occur annually in eastern Uttar Pradesh and neighbouring areas. Mishra and Srivastava (1999) also confirmed this observation. In the last two decades, the disease has spread throughout most of India's potato-growing regions, posing a significant threat to the success of potato farming. Scab has become a problem in nearly all potato-growing regions across the country. Considering the devastating effects of common scab disease, it was imperative to develop improved Integrated Disease Management (IDM) strategies for the control of potato common scab.

Common scab disease management strategies include the use of resistant varieties, cultural practices, organic manure, inorganic pesticides, and biological soil amendments. For instance, Mishra and Srivastava (2001), Graily-Moradi et al. (2021), Bhardwaj et al. (2019), and Maroufpoor et al. (2019) have all implemented these strategies with varying degrees of success. Wang et al. (2019) found that a rhizosphere-derived microbial product containing a consortium of *Bacillus subtilis* and *Trichoderma harzianum* was effective in controlling common scab disease and increasing tuber production. The product achieved this by promoting the growth of beneficial bacteria in the rhizosphere. Additionally, Arseneault et al. (2015) demonstrated that *Pseudomonas fluorescens* LBUM223 inhibited the development of common scab under controlled conditions by producing phenazine-1-carboxylic acid (PCA). This resulted in decreased thaxtomin A production by the pathogen, which is a key pathogenicity and virulence factor. In another study, four *Pseudomonas* strains were applied with or without vermicompost amendment to evaluate their effects on potato plant development, yield, and reduction of common scab disease (Arseneault et al. 2016). To manage common scab disease of potato, various biocontrol agents have been explored, including *Pseudomonas* strains, *Streptomyces* strains, and *Lactobacillus plantarum*. However, the emergence of resistant strains of the pathogen can make disease management challenging.

Therefore, this study aimed to develop an eco-friendly Integrated Disease Management (IDM) strategy for common scab of potato. The study evaluated a total of 13 treatments in different combinations with three replications. These treatments included soil amendments with gypsum, elemental sulphur, and manganese sulphate; tuber treatments with *T. harzianum*; and foliar sprays with copper oxychloride and streptocycline in varying ratios. The study monitored disease severity and incidence, as well as the physiochemical properties of the soil, to determine the most effective IDM strategy for controlling the common scab of potato.

Material and Methods

Collection of Organic, Inorganic, and Bio-fertilizers

For the experimentation, various materials were obtained from different sources. Vermiculite, neem cake, gypsum, manganese sulphate, elemental sulphur, single super phosphate, and boric acid powder were obtained from M/s Agriculture Seed Store located in Kanpur, Uttar Pradesh, India. Farm yard manure (FYM) and vermicompost were obtained from the Department of Animal Husbandry and Livestock Production Management at Chandra Shekhar Azad University of Agriculture & Technology (CSAUA&T), Kanpur, Uttar Pradesh, India. Bio-agents including *T. harzianum*, *B. subtilis*, *P. fluorescens*, Azotobacter, and Phosphorus Solubilizing Bacteria (PSB) were obtained from the Biocontrol Laboratory of the Department of Plant Pathology and the Department of Soil Science and Agriculture Chemistry at CSAUA&T, Kanpur, Uttar Pradesh. The experimentation was carried out on the Student Instructional Farm (SIF) of CSAUA&T, Kanpur, Uttar Pradesh during the *Rabi* seasons of 2019–2020 and 2020–2021, using the aforementioned organic manures, inorganic chemicals, and bio-agents as soil amendments.

Tuber Treatment

To conduct the experiments, seed tubers of the "Kufri Chandramukhi" variety were collected from the Vegetable Research Farm at CSAUA&T, Kanpur, Uttar Pradesh, India. The collected tubers were then subjected to treatment with *T. harzianum* at a rate of 5 g/kg. This treatment was administered by dipping the tubers in the prepared solution for 4 h, followed by shade drying.

Effect of Integrated Disease Management (IDM) Approaches on the Severity of Common Scab, Physiochemical Properties, and Nutritional Status of Soil

The experimental soil was treated with a variety of organic, inorganic, and biological soil amendments, each separately. The seed tubers of the potato crop were planted at a depth of 15 cm in ridges with row-to-row and plant-to-plant distances of 60 cm and 20 cm, respectively, in plots measuring 4 × 3 m. Each plot was planted with 80 potato tubers. The experiment was laid out using a Randomized Block Design (RBD), with three replications per treatment. Additionally, three pots were planted with untreated seed tubers to serve as a control. The specific treatments applied were as follows:

T_1 = neutral sandy loam soil treated with *B. subtilis* + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_2 = neutral sandy loam soil treated with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_3 = neutral sandy loam soil treated with manganese sulphate at 15 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_4 = neutral sandy loam soil treated with elemental sulphur at 0.5 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_5 = neutral sandy loam soil treated with single super phosphates at 1.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_6 = neutral sandy loam soil treated with *P. fluorescens* + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_7 = neutral sandy loam soil treated with *Azotobacter* at 12.5 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_8 = neutral sandy loam soil treated with boric acid powder at 3 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_9 = neutral sandy loam soil treated with vermicompost at 20 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_{10} = neutral sandy loam soil treated with farm yard manure at 25 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_{11} = neutral sandy loam soil treated with neem cake at 2.5 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_{12} = neutral sandy loam soil treated with phosphorus solubilizing bacteria at 12.5 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1)

T_{13} = control

Incubation of Plant in Culture Suspension of *S. scabies*

The observations were taken on disease incidence and disease severity at 45, 60, 75, and 90 days after planting and changes in macro-micronutritional status and physio-chemical properties of soil due to the application of IDM were estimated after harvesting of the crop.

Measurement of Scab Incidence

Scab incidence in all the treatments was calculated by recording the number of healthy and diseased tubers in each plot. Tubers were examined after the inoculation of *S. scabies*. Finally, the percentage of scab incidence was calculated by using the formula given below:

$$Scab\ incidence\% = \frac{Number\ of\ tubers\ exhibiting\ scab\ symptoms}{Total\ number\ of\ tuber\ observed} \times 100$$

Measurement of Disease Severity

To assess the severity of the common scab disease in potato, the depth of the lesion and the percentage of the surface area of the tubers affected by scab lesions were observed. The disease severity was measured using the rating scales of 0–5 based on the system proposed by Driscoll et al. (2009): 0 indicated no visible scab lesion (healthy), 1 indicated very small lesions covering less than 10% of the surface area of the tubers with a depth of less than 1 mm, 2 indicated small superficial lesions covering 11–25% of the surface area of the tubers with a depth of 1–2 mm, 3 indicated periderm broken with lesions covering 26–50% of the surface area of the tubers and a depth of 2–3 mm, 4 indicated light pitting with lesions covering 51–75% of the surface area of the tubers and a depth of 3–5 mm, and 5 indicated deep pitting with lesions covering 76–100% of the surface area of the tubers with a depth of 5 mm or greater.

According to Raupach et al. (1996), disease severity was calculated by using the given formula:

$$Disease\ severity\ \% = \frac{\left[\Sigma(rating\ no. \times no.of\ tubers\ in\ rating)\right]}{(total\ no.of\ tubers \times highest\ rating)} \times 100$$

Change of Nutritional Status and Physiochemical Properties of Soil Due to Application of IDM Practices

Soil samples for analysis of pH, organic carbon (OC), electrical conductivity (EC), sulphur (S), boron (B), zinc (Zn), manganese (Mn), copper (Cu), and iron (Fe) were collected from the Student Instructional Farm (SIF) of CSAUA&T, Kanpur.

Soil Sampling

Soil samples were collected from each plot by taking small portions of the soil with a suitable sampling tool up to the desired depth (0–15 cm or more) and placing them in polythene bags. Surface litter was removed before sampling, and samples were taken in a zig-zag manner from each sampling site. In fields with standing crops, samples were taken in between the rows.

Once collected, soil samples were placed in a clean area within each plot and mixed thoroughly by hand. The mixed soil was then divided into four quarters, and two opposite quarters were discarded. The remaining two quarters were remixed, and the process was repeated until the bulk was reduced to about 500 g using the quartering process. Finally, the soil samples were transferred to clean bags and labelled properly for identification.

Drying and Sieving of Soil Samples for Analysis

After collecting the soil samples in polythene bags, the samples were air-dried in shade. Plant residues, gravels, and other materials were removed from the soil samples. Soil clods were lightly crushed and then ground with a wooden pestle and mortar. The entire quantity of soil was passed through a 2-mm stainless steel sieve. For specific analyses such as organic carbon, the soil was further ground to pass through 0.2- to 0.5-mm sieves. The entire quantity of sieved soil was remixed thoroughly before analysis.

Estimation of Available Micro-Macronutrient and Physiochemical Properties of Soil

Various methods, predominantly colorimetric, are commonly used for estimating most micronutrients such as Zn, Cu, Fe, and Mn through the DTPA method (Lindsay and Norvell 1978). The available sulphur content was determined using a colorimetric method with barium chromate (Palaskar et al. 1981), whilst boron content was determined using the Berger and Truog method. Soil pH was determined using a digital soil pH meter, whilst soil EC was determined using a digital electrical conductivity meter. Soil organic carbon content was determined using the Walkley and Black titration method.

Statistical Analysis

The experiments were conducted using Randomized Block Designed with three replications and analyses were performed using SPSS software (IBM® SPSS® Statistics). The data that is presented in the manuscript is the mean of the two consecutive years (2019–2020 and 2020–2021).

Results and Discussion

Effect of IDM Approaches on the Number of Leaves Per Plant and Plant Height Under Field Conditions During 2019–2020 and 2020–2021

In this field study conducted during 2019–2020 and 2020–2021, the combined effects of soil amendment, tuber treatment, and foliar fungicide spray on the number of leaves and plant height of potato plants were investigated. Data were collected at 15, 30, 45, 60, and 75 days after planting (DAP) and analysed using SPSS software. As shown in Fig. 1, all treatments resulted in an increase in the number of leaves compared to the control. The number of leaves of potato plant was found maximum in treatment T_2 where treatment was given as soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1), representing 3, 10, 16, 22, and 25 in the number of leaves at 15, 30, 45, 60, and 75 days after planting (DAP) against 16 in case of control which is increased by 56.25% over control at 75 DAP followed by

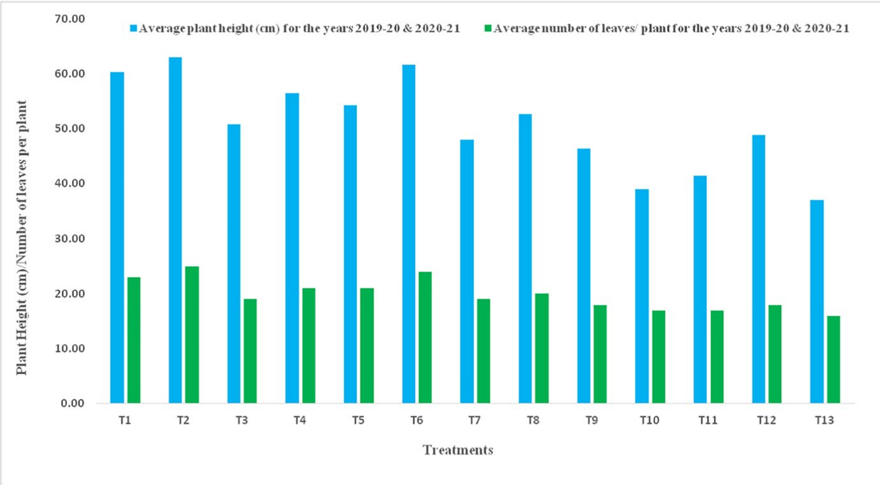

Fig. 1 Effect of Integrated Disease Management (IDM) practices on plant height and number of leaves in field conditions during 2019–2020 and 202–2021

the T_6 treatment as soil treated with *P. fluorescens* + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline (3:1), showing value of 3, 9, 15, 21, and 24 number of leaves at 15, 30, 45, 60, and 75 days after planting (DAP), representing 2nd largest number of leaves amongst the treatments. Similarly, the maximum plant height was recorded in T_2 treatment representing 6.16-, 22.50-, 37.33-, 50.50-, and 63-cm plant height at 15, 30, 45, 60, and 75 days after Planting (DAP) against 37 cm in the case of control which is increased by 70.27% over control followed by T_6 treatment, showing values of 5.50-, 20.66-, 35.00-, 50.00-, and 61.66-cm plant height at 15, 30, 45, 60, and 75 days after planting (DAP) against 37 cm in case of control which is increased by 66.64% over control, representing 2nd highest amongst all the treatments. In a study conducted by Kumar et al. (2019), they found that a combination treatment consisting of soil application of FYM at a rate of 125 g/pot, waste of mushroom cultivation, treatment of tubers with Azotobacter at a concentration of 5%, and foliar spray with Ridomil at a concentration of 0.25%, along with the addition of *T. harzianum* at a rate of 5 g/kg, was the most effective in reducing the severity of late blight disease. The treatment showed a disease severity of only 9.16%, compared to 76.40% in the control after 21 days of observation. Additionally, the treatment led to an increase in tuber germination and plant height of potato, with values of 100% and 44.5 cm, respectively, at 30 days of age. In another study by Wang et al. (2019), a microbial product composed of a consortium of a strain of *B. subtilis* and a strain of *T. harzianum* was investigated for its ability to suppress common scab disease and increase tuber yield. The product effectively established a high relative abundance of beneficial bacteria in the rhizosphere, leading to a reduction in the incidence of common scab disease and an increase in tuber yield.

IDM Practices and Their Effect on Physiochemical Properties of Soil

pH Values

Table 1 presents data on the pH values of the soil before planting, after planting, and after harvesting, following the adaptation of IDM practices. Before planting, the pH values were similar across all treatments. However, after the implementation of IDM practices, the pH values ranged from 5.86 to 6.95 after planting and 5.30 to 6.48 after harvesting. Treatment T_2 showed the maximum change in pH values, with a value of 7.4 before planting, 5.86 after planting, and 5.30 after harvesting, which was the lowest amongst all the treatments. Treatment T_4, which included neutral sandy loam soil amendments with elemental sulphur at 0.5 t/ha, tuber treatments with *T. harzianum* at 5 g/kg of tuber, and foliar spray of copper oxychloride with streptocycline (3:1), showed the second lowest pH value with 7.38 before planting, 6.08 after planting, and 5.41 after harvesting. The minimum change in pH after planting and after harvesting was found in T_{13} (control) with values of 6.95 and 6.48, respectively. Previous studies have shown that disease incidence and severity can increase with increasing soil pH in the range of 5.0–8.0 (Lambert and Manzer 1991). Therefore, the use of elemental sulphur fertilizers and adequate irrigation during tuber formation can help to reduce soil pH (<5.2) and minimize the incidence and severity of common scab (Pavlista 2005; Lacey 2001).

Table 1 Impact of Integrated Disease Management (IDM) strategies against common scab of potato and consequent changes in physiochemical soil properties under field conditions in 2019–2020 and 2020–2021

Treatment	pH			EC (S/m)			OC (%)		
	BP	AP	AH	BP	AP	AH	BP	AP	AH
T_1	7.40	5.99	5.75	0.134	0.104	0.098	0.52	0.62	0.70
T_2	7.40	5.86	5.30	0.130	0.089	0.087	0.49	0.68	0.72
T_3	7.42	6.26	5.64	0.143	0.141	0.120	0.37	0.40	0.49
T_4	7.38	6.08	5.41	0.133	0.130	0.106	0.41	0.47	0.57
T_5	7.41	6.00	5.45	0.129	0.123	0.113	0.46	0.51	0.55
T_6	7.43	5.90	5.60	0.132	0.103	0.091	0.50	0.65	0.73
T_7	7.40	6.54	5.95	0.136	0.129	0.125	0.51	0.84	0.95
T_8	7.39	6.10	5.49	0.130	0.123	0.117	0.32	0.36	0.40
T_9	7.45	6.67	6.00	0.135	0.132	0.123	0.48	0.87	0.98
T_{10}	7.41	6.80	6.23	0.143	0.141	0.134	0.53	0.89	0.99
T_{11}	7.45	6.74	6.13	0.140	0.138	0.129	0.50	0.84	0.96
T_{12}	7.42	6.39	5.89	0.141	0.140	0.118	0.47	0.71	0.80
T_{13}	7.46	6.95	6.48	0.145	0.143	0.140	0.33	0.35	0.38
SE (m)	0.031	0.040	0.070	0.0070	0.0064	0.0044	0.048	0.051	0.063
SE (day)	0.044	0.057	0.099	0.0115	0.0080	0.0063	0.068	0.073	0.089
CD at 5%	0.089	0.121	0.205	0.0223	0.0170	0.0135	0.140	0.154	0.187

BP (before planting), AP (after planting), and AH (after harvesting)

Electrical Conductivity (S/m)

Table 1 presents the results of the study, indicating that the highest values of EC before planting, after planting, and after harvesting were recorded in the control treatment (T_{13}), with values of 0.145, 0.143, and 0.140 S/m, respectively. On the other hand, the lowest EC values were recorded for the T_2 treatment, which involved neutral sandy loam soil amendments with gypsum at a rate of 2.0 t/ha, tuber treatments with *T. harzianum* at a rate of 5 g/kg of tuber, and foliar spray of copper oxychloride with streptocycline (3:1), with values of 0.130, 0.089, and 0.087 S/m, respectively. T_6 treatment, which involved neutral sandy loam soil treated with *P. fluorescens*, tuber treatments with *T. harzianum* at a rate of 5 g/kg of tuber, and foliar spray of copper oxychloride with streptocycline (3:1), showed the second lowest EC values of 0.132, 0.103, and 0.091 S/m, respectively. A high EC content in the soil can restrict nutrient availability for plants and reduce microbial activities in the soil. According to Yoshida (1997), a low EC of the soil solution around the potato tuber can suppress common scab disease, as the activity of Al^{3+} ions remains high, ultimately reducing the pH of the soil. Shiga et al. (2004) also reported a negative correlation between scab severity in soil and the concentration of exchangeable Al^{3+} in the soil solution around the potato tuber. They further explained that the effect of Al in soils is highly dependent on the pH of the soil.

Organic Carbon (%)

The findings from Table 1 suggest that the organic carbon content in all the treatments was similar before planting. However, there were significant changes observed after implementing Integrated Disease Management (IDM) practices. The organic carbon content ranged from 0.35 to 0.89% after planting and 0.38 to 0.99% after harvesting. These results indicate that the IDM practices implemented in the study may have contributed to an increase in the organic carbon content of the soil. Organic carbon is an important component of soil health as it contributes to soil fertility, structure, and water-holding capacity. Therefore, an increase in organic carbon content can have positive effects on crop growth and yield.

Based on the results presented in Table 1, the treatment T_{10} (neutral sandy loam soil amendment with FYM at 25 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) had the maximum increase in OC (%) value changes before planting, after planting, and after harvesting. The values recorded were 0.53, 0.89, and 0.99, respectively. The second highest increase in OC (%) value changes before planting, after planting, and after harvesting was observed in T_9 (neutral sandy loam soil amendment with vermicompost at 20 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), with values of 0.48, 0.87, and 0.98%, respectively. These findings suggest that up to a certain level of organic carbon content in the soil, it can be beneficial in reducing disease severity and increasing crop yield. Organic carbon plays a crucial role in soil health and fertility, as it contributes to the availability of nutrients and water-holding capacity of the soil. Therefore, increasing the organic carbon content through the use of organic amendments such as FYM and vermicompost can have positive effects on crop growth and yield. The findings presented by Ajitmal et al. (2002) suggest that factors such as soil pH, moisture content, and organic matter levels may have a significant impact on the severity of soil-borne diseases like a common scab in potatoes. Lazarovits et al. (2001) also reported that organic amendments can effectively control the severity of such diseases. In line with these findings, Furnakoshi and Matsuura (1983) noted that the application of compost at a rate of 2.0 t/ha can help control *S. scabies* and increase potato yield. They further suggested that the combination of soil amendment with compost and sulphur (3 t/ha) can be an effective approach to managing common scabs, as it reduces insoluble soil manganese to soluble forms which are toxic to *S. scabies*. The use of green manure has also been found to provide considerable control of common scab, even when heavy applications of lime are used, according to comprehensive studies.

Boron Content (mg/kg)

Boron plays an important role in the translocation of sugars and the regulation of potassium and calcium within plants. The results from Table 2 suggest that amongst all the treatments the maximum boron (mg/kg) content after planting and after harvesting was recorded in T_8 treatment (neutral sandy loam soil amendments with boric acid powder at 3 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), which represent as 78.91 and 71.84, respectively. The second highest boron (mg/kg) content after

Table 2 Impact of Integrated Disease Management (IDM) against common scab of potato and, subsequently, its effect on macronutrient status in soil under field conditions in 2019–2020 and 2020–2021

Treatment	Boron (mg/kg)			Sulphur (mg/kg)		
	BP	AP	AH	BP	AP	AH
T_1	45.89	53.68	49.93	26.85	31.67	30.21
T_2	48.39	54.21	51.50	27.70	35.86	36.47
T_3	47.94	57.28	52.19	25.69	32.49	32.61
T_4	45.75	51.39	47.61	26.85	47.69	48.43
T_5	48.63	54.76	50.14	27.59	34.78	35.16
T_6	48.71	56.49	50.42	26.93	33.27	31.69
T_7	44.16	49.53	46.61	26.50	30.25	27.47
T_8	46.47	78.91	80.15	25.37	31.89	29.60
T_9	42.69	45.79	41.81	24.49	28.62	26.21
T_{10}	43.48	46.63	42.54	25.94	28.79	25.48
T_{11}	41.98	43.74	38.35	24.14	30.64	25.68
T_{12}	40.59	48.68	43.50	25.18	29.42	27.75
T_{13}	40.19	39.47	37.36	24.80	26.78	23.56
SE (m)	0.8002	1.3011	0.6408	0.4803	0.6726	0.5138
SE (day)	1.1315	1.8398	0.9061	0.6791	0.9510	0.7265
CD at 5%	2.3363	3.7987	1.8708	1.4024	1.9637	1.5006

BP (before planting), AP (after planting), and AH (after harvesting) planting and after harvesting was recorded in T_3 (neutral sandy loam soil amendments with manganese sulphate at 15 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), which as 57.28 and 52.19, respectively, followed by T_6 (neutral sandy loam soil treated with *P. fluorescens* [1% W.P., cfu count: 2 × 10 cfu/g] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), representing as 56.49 and 50.42 after planting and after harvesting, respectively. Volvik et al. (1980) conducted a study and found that a soil application of boric acid at a rate of 2.5 kg/ha, in a mixture including KCl and manure (60 t/ha), reduced the infection from common scab and increased potato yield. Arora and Sharma (2014) reported that seed treatment with 3% boric acid and soil application of gypsum at a rate of 0.8 t/ha reduced scab incidence by 42.70% and 54.50%, respectively. Chaudhari et al. (2003) observed that the lowest disease incidence and index were obtained by soaking seeds in a 3% boric acid solution for 30 min.

Sulphur Content (mg/kg)

The application of sulphate fertilizers enhanced biodiversity and antibiosis. Common scab severity was also negatively correlated with sulphur content in the soil. The data presented in Table 2 revealed that the maximum increase of sulphur content in the soil before planting, after planting, and after harvesting was recorded in soil treated with T_4 treatment (neutral sandy loam soil amendments with elemental sulphur at 0.5 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), which represent as 26.85, 47.69, and 48.43, respectively. The second highest sulphur (mg/kg) content in soil is also significantly increased before planting, after planting, and after harvesting was recorded in T_2 treatment (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), which show as 27.70, 35.86, and 36.47, respectively. Amongst the treatments, the minimum sulphur (mg/kg) content significantly reduced after planting and after harvesting was recorded in T_{13} (control) which represents 26.78 and 23.56, respectively. Singh and Suzuki (2004) found that soil treatment with gypsum at 5.0 t/ha gave significant control of the common scab of potatoes and also increased the yield. Klikocka et al. (2005) observed that the application of sulphur significantly increased tuber yield and improved tuber quality and resistance against *Streptomyces scabies.* Arora and Sharma (2014) reported that the soil pH of the sulphur treatment plot continuously declined from 5.13 at tuber initiation time to 5.01 at harvest and disease severity of sulphur-treated plot was relatively low (22.8%) and the marketable yield of that was high (90.5%).

Zinc Content (mg/kg)

The finding of the experiment presented in Table 3 showed that amongst all the treatments, the zinc (mg/kg) content in soil significantly increased after planting and harvesting over control was recorded in T_2 treatment as neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg

Table 3 Impact of Integrated Disease Management (IDM) against common scab of potato and, subsequently, its effect on micronutrient status alterations of soil under field conditions in 2019–2020 and 2020–2021

Treatment	Zn (mg/kg)			Cu (mg/kg)			Fe (mg/kg)			Mn (mg/kg)		
	BP	AP	AH	BP	AP	AH	BP	AP	AH	BP	AP	AH
T_1	1.32	2.00	2.16	2.77	3.39	3.14	29.12	37.13	37.00	49.35	58.33	50.52
T_2	1.36	2.12	2.42	2.80	3.45	3.28	29.43	38.83	38.39	49.91	61.19	50.68
T_3	1.29	1.87	2.04	2.66	3.01	2.83	26.21	36.22	36.10	47.70	96.47	98.84
T_4	1.28	1.98	2.27	2.75	3.35	3.12	28.91	37.61	37.16	48.87	57.73	49.37
T_5	1.27	1.95	2.19	2.75	3.20	2.87	28.37	36.84	36.51	48.45	56.19	49.21
T_6	1.31	2.09	2.39	2.79	3.41	3.17	29.40	38.01	37.43	49.78	60.81	51.01
T_7	1.98	1.84	1.88	2.68	2.97	2.72	25.17	34.93	34.59	47.95	54.12	48.27
T_8	1.28	1.90	2.13	2.71	3.24	3.06	27.88	35.78	35.41	48.10	55.94	49.00
T_9	1.23	1.81	1.96	2.64	2.85	2.64	27.61	34.41	34.05	47.04	53.75	47.92
T_{10}	1.21	1.37	1.77	2.61	2.80	2.59	25.56	33.79	33.27	46.11	51.91	47.00
T_{11}	1.89	1.79	1.89	2.66	2.90	2.73	26.10	34.09	33.86	47.79	53.51	47.74
T_{12}	1.97	1.86	1.99	2.71	3.10	2.79	27.83	35.26	35.08	47.93	55.69	48.45
T_{13}	1.19	1.21	1.59	2.62	2.69	2.57	25.39	32.70	32.21	46.36	51.18	44.05
SE (m)	0.05	0.07	0.04	0.07	0.07	0.09	0.52	0.67	0.53	0.55	1.53	0.87
SE (day)	0.07	0.09	0.06	0.10	0.10	0.13	0.73	0.95	0.74	0.78	2.17	1.24
CD at 5%	0.14	0.19	0.13	0.20	0.21	0.27	1.50	1.96	0.53	1.62	4.47	2.55

BP (before planting), AP (after planting), and AH (after harvesting)

of tuber + foliar spray of copper oxychloride with streptocycline (3:1), representing as 2.12 and 2.42 mg/kg, respectively. The second highest zinc (mg/kg) content in soil was recorded in T_6 (neutral sandy loam soil treated with *P. fluorescens* [1% W.P., cfu count: 2×10^8 cfu/g] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), treatment as 2.09 and 2.39 mg/kg after planting and after harvesting, respectively, followed by T_4 treatment (neutral sandy loam soil amendments with elemental sulphur at 0.5 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatment which represents as 1.98 and 2.27 mg/kg after planting and after harvesting, respectively. The lowest zinc (mg/kg) content in the soil after planting and after harvesting was recorded in T_{13} (control) which represents 1.21 and 1.59, respectively. Marschner (1986) reported that iron, zinc, copper, boron, and manganese are involved in lignin synthesis in plants reported to minimize disease.

Copper Content (mg/kg)

The IDM practices can change the copper content in the soil. The data presented in Table 3 revealed that amongst all the treatments, the maximum copper (mg/kg) content was recorded in soil treated (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) with T_2 treatment, where copper content was 2.80 mg/kg before planting, 3.45 mg/kg after planting, and 3.28 mg/kg after harvesting, followed by T_1 (neutral sandy loam soil treated with *B. subtilis* [Baciforte, cfu count: 1×10^9 cfu/mL] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatment as 2.77, 3.39, and 3.14 mg/kg before planting, after planting, and after harvesting, respectively.

Fe Content (mg/kg)

Fe serves as a co-factor of many enzymes, such as cytochromes of the electron chain. It is also involved in the synthesis of chlorophyll and is essential for the maintenance of chloroplast structure and function. The data presented in Table 3 reveal that amongst all the treatments, the maximum Fe (mg/kg) content in the soil after planting and after harvesting was recorded in T_2 (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatments which represented as 38.83 and 38.39 mg/kg, respectively. The second highest Fe (mg/kg) content in the soil after planting and after harvesting was recorded for T_6 (neutral sandy loam soil treated with *P. fluorescens* [1% W.P., cfu count: 2×10^8 cfu/g] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatment which represents as 38.01 and 37.43 mg/kg, respectively. The enrichment of Fe in the soil was increased directly or through a decrease in soil pH which suppressed common scab severity. This indicates that Fe supports plant defence and reduces pathogen virulence rather than eliminating the pathogen population. The availability of Fe seems to be the most overlooked factor in the protection of potato plants from different diseases, but particularly common scab, because the pathogenic *Streptomyces* are well equipped to compete with the plants for Fe supplies. The deficiency is likely in alkaline soil but also in soils with low microbial activities. Thus, the availability of Fe can be improved by supplementation with organic matter which increases microbial activities but also by fertilization by organically bound Fe.

Manganese Content (mg/kg)

High Mn content was strongly correlated with low common scab disease severity in potatoes. The finding of the experiment presented in Table 3 showed that the Mn (mg/kg) value in all the treatments is almost the same, but the Mn value changed after the adaptation of IDM practices which ranged from 51.18 to 96.47 mg/kg after planting and 44.05 to 80.84 mg/kg after harvesting. Amongst all the treatments maximum Mn (mg/kg) changes occurred in the treatment T_3 (neutral sandy loam soil amendments with manganese sulphate at 15 kg/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatments which represented as 96.47 and 80.84 mg/kg, after planting and after harvesting, respectively. The second highest Mn (mg/kg) content in the soil after planting and after harvesting was recorded in T_2 (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatments, which represent as 61.19 and 50.68, respectively. The addition of Mn^{2+} ion in the form of manganese sulphate to soils in reducing the incidence of scab has been widely discussed with variable results by different scientists. McGregor and Wilson (1966) found that potatoes grown on natural soil and soil treated with $MnSO_4^-$ at 12.5 kg/ha mixed with fertilizer at the time of planting reduced the scab incidence and also increased the tuber yield. Mishra et al. (2009) observed that the addition of 0.05% $MnSO_4^-$ to 1% boric acid solution with tubers dipped for 30 min was also found effective against common scab. McGregor and Wilson (1966) found that potatoes grown on natural soil and soil treated with $MnSO_4^-$ at 12.5 kg/ha mixed with fertilizer at the time of planting reduced the scab incidence and also increase the tuber yield.

Disease Severity

The effect of IDM practices significantly reduced the disease severity of common scab of potatoes as compared to controls under field conditions during 2019–2020 and 2020–2021. The data represented in Table 4 showed that amongst all the treatments, the minimum disease severity of common scab of potato with the values of 0.41, 1.58, 2.74, and 3.63% at 45, 60, 75, and 90 DAP, respectively, was recorded in T_2 (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) treatment which was followed by T_6 treatment (neutral sandy loam soil treated with *P. fluorescens* [1% W.P., cfu count: 2×10^8 cfu/g] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), representing 0.77, 2.44, 4.40, and 5.79% disease severity at 45, 60, 75, and 90 DAP, respectively. Amongst all the treatments, the maximum disease severity of the common scab of potatoes with values of 15.63, 26.03, 39.49, and 46.67% was recorded in T_{13} (control) treatment at 45, 60, 75, and 90 days after planting (DAP). Both tuber treatment and foliar spray using salicylic acid as an inducer resulted in a disease index of 4.45%, lower than the control of 9.52–11.71%. The plants treated with salicylic acid had a yield of 74.21% and 83.26%, respectively, for a total of 446.85 g per plant in comparison to the control. Inducers sprayed on leaves before a pathogen was introduced helped the plant resist infection, resulting in a lower disease index (Baboo et al. 2021).

Disease incidence

Similarly, the minimum disease incidence of common scab of potato with the value of 1.79% was recorded in T_2 (neutral sandy loam soil amendments with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of

Table 4 The effect of using an Integrated Disease Management (IDM) approach on the disease severity and incidence of common scab of potato under field conditions in 2019–2020 and 2020–2021

Treatment	Disease severity				Total no. of tubers at the time of harvesting	Infected no. of tubers at the time of harvesting	Disease incidence at the time of harvesting
	45 DAP	60 DAP	75 DAP	90 DAP			
T_1	1.21	2.72	5.71	8.45	513	29	5.65
T_2	0.41	1.58	2.74	3.63	502	9	1.79
T_3	3.76	9.80	14.78	19.39	522	67	12.83
T_4	1.64	5.53	8.26	10.89	514	37	7.19
T_5	2.48	6.78	10.52	13.13	517	46	8.89
T_6	0.77	2.44	4.40	5.79	508	17	3.34
T_7	6.62	13.64	19.46	26.74	520	99	19.03
T_8	2.89	8.41	12.96	16.32	520	54	10.38
T_9	8.53	15.69	22.83	29.14	516	112	22.48
T_{10}	12.47	22.12	29.53	37.73	516	157	30.42
T_{11}	10.37	18.96	26.48	33.71	533	137	25.70
T_{12}	4.62	11.28	17.36	22.62	522	79	15.13
T_{13}	15.63	26.03	39.49	46.67	509	176	34.57
Mean	5.49	11.15	16.50	21.09	Mean		15.185
CV	3.20	3.57	2.59	1.20	CV		9.846
SE (m)	0.10	0.23	0.25	0.15	SE (m)		0.863
SE (day)	0.14	0.33	0.35	0.21	SE (day)		1.221
C.D.	0.30	0.67	0.72	0.43	C.D.		2.534

Table 5 Correlation between the severity of common scab disease and the physiochemical poil

Treatment	Disease severity	pH AH	EC AH	OC AH	B AH	S AH	Zn AH	Cu AH	Fe AH	Mn AH
T_1	8.45	5.75	0.98	0.70	49.93	41.43	2.158	3.138	37.00	50.52
T_2	3.63	5.30	0.87	0.72	51.50	34.47	2.421	3.275	38.39	50.68
T_3	19.39	5.64	1.20	0.49	52.19	31.69	2.036	2.825	36.10	80.84
T_4	10.89	5.41	1.06	0.57	47.61	30.21	2.267	3.119	37.16	49.37
T_5	13.13	5.45	1.13	0.55	71.84	29.53	2.189	2.874	36.51	49.21
T_6	5.79	5.60	0.91	0.73	50.42	32.16	2.394	3.167	37.43	51.01
T_7	26.74	5.95	1.25	0.95	46.61	27.47	1.879	2.719	34.59	48.27
T_8	16.32	5.49	1.17	0.40	50.14	29.60	2.125	3.055	35.41	49.00
T_9	29.14	6.00	1.23	0.99	41.81	26.21	1.960	2.638	34.05	47.92
T_{10}	37.73	6.23	1.34	0.99	42.54	25.48	1766	2.585	33.27	47.00
T_{11}	33.71	6.13	1.29	0.96	38.35	25.68	1.898	2.732	33.86	47.74
T_{12}	22.62	5.89	1.18	0.80	43.50	27.75	1.985	2.790	35.08	48.45
T_{13}	46.67	6.48	1.40	0.38	37.36	23.56	1.594	2.574	32.21	44.05
SE (m)	0.150	0.070	0.0447	0.0632	0.6408	0.5138	0.0408	0.0913	0.5235	0.8731
SE (day)	0.210	0.099	0.0632	0.0894	0.9061	0.7265	0.0577	0.1291	0.7402	1.2346
CD	0.431	0.205	0.1358	0.1870	1.8708	1.5006	0.1248	0.2684	1.5281	2.5493
Correlation		0.989**	0.950**	−0.210	−0.636	−0.807*	0.379	−0.930*	−0.983*	−0.228

The disease severity with pH, electrical conductivity (EC), organic carbon (OC), boron (B), sulphur (S), zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) due to effect of Integrated Disease Management (IDM) practices

AH (after harvesting)

Table 6 Positive and negative correlations between the severity of common scab disease and the physicochemical parameters of the soil

Serial no.	Positive correlation			Negative correlation					
	Zn (mg/kg)	EC (S/m)	pH	OC (%)	Mn (mg/kg)	B (mg/kg)	S (mg/kg)	Cu (mg/kg)	Fe (mg/kg)
1	0.379	0.095	0.989	−0.21	−0.228	−0.636	−0.807	−0.93	−0.983

The severity of the disease and the levels of zinc (Zn), electrical conductivity (EC), pH, organic carbon (OC), manganese (Mn), boron (B), sulphur (S), copper (Cu), and iron (Fe) in the soil at the time of harvesting as a result of the effect of Integrated Disease Management (IDM) practices

copper oxychloride with streptocycline [3:1]), treatment at the time of harvesting. The T_6 treatment (neutral sandy loam soil treated with *P. fluorescens* [1% W.P., cfu count: 2×10^8 cfu/g] + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]), showing 3.34% disease incidence representing second lowest amongst the treatment. Members of *B. subtilis*, *P. fluorescence*, and *T. harzianum* have been demonstrated to suppress several soil-borne pathogens, including *Streptomyces scabies*, and have also been shown to promote plant growth. Al-Mughrabi (2010) reported that a microbial product composed of a consortium of *B. subtilis* and *T. harzianum* is known to be antagonistic against *S. scabies* and significantly reduced the severity of common scab and increased yield. Davis et al. (1974) found that the application of gypsum and sulphur at 672.5 kg/ha and Terractor and Terrachlor super-X at 28 kg/ha are used to reduce the incidence of common scab which has also significant changes in pH (0.1–0.4) of soil. Arora and Sharma (2014) reported that seed treatment with 3% boric acid and soil application of gypsum at 0.8 t/ha reduce scab incidence by 42.70 and 54.50%, respectively.

Correlation Between Disease Severity and pH, EC (S/m), OC (%), B, S, Zn, Cu, Fe, and Mn of Soil at the Time of Harvesting

The data presented in Tables 5 and 6 show that disease severity correlated positively with pH, EC, and Zn, representing the values (0.989**), (0.950**), and (0.379), respectively, but negatively correlated with OC, B, S, Cu, Fe, and Mn representing the values (−0.210), (−0.636*), (−0.807**), (−0.930**), (−0.983**), and (−0.228), respectively, during 2020–2021.

Conclusion

Common scab, caused by the *Streptomyces* spp., is a global problem with significant economic consequences. It is a major concern for nearly all of India's potato-growing regions as it has the potential to severely affect crop health, tuber quality, and yields. The disease can cause significant damage to the quality and marketability of the potato crop, resulting in substantial economic losses. Disease severity is affected by several factors, including weather, potato cultivar susceptibility, soil quality, and farming practices. Whilst using chemical treatments to amend soil and treat seeds can reduce disease severity, it cannot completely eradicate pathogens. Furthermore, these chemicals pose health and environmental risks, polluting the environment. Therefore, adopting integrated control measures such as crop rotation, soil care, biocontrol agents, and natural chemicals is crucial in potato-growing regions to reduce the usage of pesticides and promote sustainable farming practices. The study presented an IDM system that aimed to explore alternative, eco-friendly strategies for plant disease management. The results showed that the IDM practices employed in the study led to a significant increase in growth parameters and yields whilst reducing the severity and incidence of common scab of potato in treatment T_2 (neutral sandy loam soil treated with gypsum at 2.0 t/ha + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]) followed by T_6 treatment (neutral sandy loam soil treated with *P. fluorescens* + tuber treatments with *T. harzianum* at 5 g/kg of tuber + foliar spray of copper oxychloride with streptocycline [3:1]). The results of this study suggest that the IDM practices tested can be recommended as effective and eco-friendly strategies for managing common scab disease in potato crops. These practices include treating the soil with gypsum and using tuber treatments with *T. harzianum*, as well as foliar spraying with a mixture of copper oxychloride and streptocycline. The combination of these treatments resulted in improved growth parameters, higher yields, and reduced disease severity and incidence compared to untreated controls. These practices can be a valuable addition to the existing Integrated Disease Management strategies for potato growers and may help reduce the reliance on harmful pesticides and chemicals.

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Declarations

Ethical Approval This manuscript does not contain studies on human or animal participants.

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Conflict of Interest The authors declare no competing interests.

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