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Vegetative Growth, Tuber Yield, and Yield Components of Potato (*Solanum tuberosum* L.) as Influenced by Earthing up and Inflorescence Removal

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ABSTRACT

Inappropriate agronomic practices, such as earthing up and inflorescence removal, contribute significantly to the gap between the potential and actual yields of potatoes in Ethiopia. To evaluate the combined effects of these practices on vegetative growth, tuber yield, and yield components, a factorial experiment was conducted. The treatments included four earthing-up rounds (no earthing up, one, two, and three rounds) and three levels of inflorescence removal (no removal, bud removal, and flower removal), arranged in a randomized complete block design with three replications. The combined effects of these factors significantly influenced key yield parameters, including the total number of marketable and unmarketable tubers hill^{-1}, marketable and unmarketable tuber weights hill^{-1}, and the number of small, medium, and large-sized tubers. The highest marketable tuber number hill^{-1} (10.07), marketable tuber weight (708.67 g hill^{-1}), medium-sized tuber number (6.95), large-sized tuber number (4.48), marketable tuber yield (31.49 t ha^{-1}), and total tuber yield (33.08 t ha^{-1}) were all achieved with the combination of bud removal and three rounds of earthing up. This combination of treatments is recommended for optimizing potato production in Ethiopia.

Introduction

The potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is the world's most important food security crop due to its ability to produce large yields in a short period and provide high nutritional value unit input^{-1} (Limenih and Tefera, 2014). In Ethiopia, it is the most significant crop in terms of both economic impact and food production (Degebasa, 2019). Ethiopia's climatic and edaphic conditions are ideal for high-quality potato production, giving the country the highest potential for potato cultivation in Africa. However, only 2% of Ethiopia's potential potato-producing land is currently utilized (Gebremedhin et al., 2008).

In 2020-2021, Ethiopia's average potato yield was 13.28 t ha^{-1}, with total production amounting to 11.15 million tons from 85,988 ha. This yield was lower than the African average of 15 t ha^{-1} and the global average of 21 t ha^{-1} (FAOSTAT, 2022). Several production constraints have been identified as causes of this low yield. The main challenges include the limited availability and high cost of seed tubers (Amede et al., 2006), the occurrence of diseases and insect pests (Guluma, 2020), and suboptimal agronomic practices, such as earthing up (Sakadzo et al., 2019) and inflorescence management (Tekalign and Hammes, 2005; Gebregwergis et al., 2021).

Earthing up is a row cultivation method that plays a vital role in increasing tuber production. It promotes root system expansion, weed removal, and the incorporation of soil nutrients, particularly when manure is applied (Khayatnezhad and Gholamin, 2011). Properly timed and executed earthing up enhances tuberization and increases total yields (Gutema, 2016). Additionally, this practice prevents tubers from greening, supports plant stability, captures runoff, aerates the rooting zone, and reduces resistance to root growth, all of which contribute to improved root development. The resulting better root growth enables more efficient utilization of newly added soil minerals, leading to enhanced plant growth, yield, and quality (Ren et al., 2017; Ebrahimi et al., 2021; Van Dijk et al., 2021; Arora et al., 2023).

Earthing up also helps maintain moderate soil moisture and temperature, conditions that support early tuberization and higher yields (Rykaczewska, 2015). By increasing soil depth, earthing up allows plants to extend their roots deeper and more widely, facilitating greater nutrient and water absorption. This process also conserves soil moisture and reduces the leaching of nutrients (Sakadzo et al., 2019). Exposed tubers are more vulnerable to pest attacks and greening, both of which reduce tuber quality (Svubure et al., 2015). Therefore, effective earthing up practices are crucial for maintaining soil health, protecting tubers, and promoting optimal growing conditions.

Another key factor influencing tuber yield is inflorescence management. The development of potato inflorescences (flowers and fruits) competes with tubers for assimilates, thereby limiting tuber growth. Removing the inflorescence shifts assimilate allocation toward the underground structures, increasing tuber yield (Tekalign and Hammes, 2005). Inflorescences serve as strong sinks for assimilates—such as mineral nutrients, sugars, and amino acids—which reduces the availability of these resources for tuber growth. Potato plants prioritize the distribution of assimilates among fruits, tubers, and other vegetative structures according to the relative strength of the sinks. Competition between these sink organs arises when assimilation is limited (Hassen et al., 2013). Removing inflorescences reduces this competition, allowing more assimilates to be directed toward tuber growth.

Given the significant influence of earthing up and inflorescence management on potato yield, it is essential to identify the optimal frequency of earthing up and the appropriate stage for inflorescence removal (flowers, buds, and fruits) to enhance tuber yield and quality. This is especially relevant under cool climatic conditions, where potato responses are strongly influenced by environmental variability. Therefore, the present study evaluated the combined effects of earthing up and inflorescence removal on the vegetative growth, tuber yield, and yield components of potato crops.

Materials and Methods

Description of the study area

The experiment was conducted under irrigation in the Debre Markos, East Gojjam Zone of the Amhara Regional State, Ethiopia (2022). The experimental location was at 10° 19' 43" North latitude and 37° 44' 43" East longitude, with an altitude of 2,446 m.a.s.l. The average annual rainfall at the experimental site was 1,628 mm in 2021. The mean minimum and mean maximum temperatures of the experimental area were 11 °C and 25 °C, respectively. The soil of the area was characteristically Nitosol and had a pH value of 5.6.

Experimental materials, treatments, design and procedures

The improved potato variety '*Gudenie*' was used for the experiment. It is a potential potato cultivar, with early maturation late blight tolerance and high yield. It has been the most commonly used variety by farmers in the study area. A factorial combination of four earthing up rounds (without, one, two, and three rounds) and three inflorescence removal stages (without removal, bud removal, and flower removal) were used in a randomized complete block design with three replications. The first earthing up treatment was applied on the 15th d after complete emergence, the second treatment was applied on the 30th d, and the third treatment was applied on the 45th d. The soil was earthed up around the plant up 15-20 cm high (Nyawade et al., 2018), except for the control. According to Sharma (2014), earthing up should start after full plant emergence when the shoot reaches 15 cm in height but before the start of tuber formation (Rodríguez et al., 2020) and it should be completed before the plant begins flowering. Bud and new leaf removal was performed early in bud formation, whereas flower removal and new leaf removal were performed at the beginning of blooming (Faramarzi et al., 2011). The inflorescence removal was performed daily until the plants ceased to have growing buds and flowers.

Data collection and analysis

To evaluate the combined influences of earthing up and inflorescence removal on vegetative growth, data on the tuber yield and yield components of potato were collected. Plant height (cm) was measured from the base to the tip of the main stem using a meter. The number of primary branches hill^{-1} was recorded by counting the primary branches arising only from the main stems. The number of leaves hill^{-1} was counted plant^{-1}. Leaf area (cm^2) was calculated from three randomly selected leaves from the lower, middle, and upper parts of the plants. The leaf area index (LAI) was determined by multiplying the leaf area by the leaf number to obtain the total leaf area. The total leaf area was then divided by the respective land area occupied by plants. LA = width (cm) × length (cm) × 0.674 and LAI = LA (cm^2) × LN/land area (cm^2). Where, LA is the leaf area (cm^2); LN is the number of leaves hill^{-1}; LAI is the leaf area index; land area is the land area covered by plants (75 cm × 30 cm); and 0.674 is the correction factor. The marketable tuber number (count hill^{-1}) was determined on the basis of its size category, which was greater than or equal to 25 g and free from disease and rot. The unmarketable tuber number (count hill^{-1}) was determined by counting the tuber size category (< 25 g), including disease and insect attacks. The marketable tuber weight (g hill^{-1}) was determined by measuring tubers free from mechanical, insect, and disease damage and weighing greater than or equal to 25 g. The unmarketable tuber weight (g hill^{-1}) was determined by weighing diseased, green, and small-sized (< 25 g) tubers. The marketable tuber yield (t ha^{-1}) was determined by measuring tubers that were free from damage, weighed greater than or equal to 25 g and converted into t ha^{-1}. The unmarketable tuber yield (t ha^{-1}) was determined by weighing diseased, green, and small (< 25 g) tubers and converting them into t ha^{-1}. The diameter of the tubers (cm) was measured using a calli m^{-1}. Tuber size distributions in terms of number were categorized into groups by considering the size of tubers: small (< 39 g), medium (40-75 g), and large (> 75 g) and the tuber number (count hill^{-1}) was determined by counting the tubers in each category (Lung'aho et al., 2007). Tuber dry matter content (%): ten randomly selected fresh tubers of different sizes were collected and weighed. After being cut into slices, the tubers were dried in an oven at 80 °C for 72 h. The dry weight was then measured. In accordance with Zelalem et al. (2009), the following formula was used for determining the dry matter percentage.

$$\text{Dry matter percentage} = \frac{\text{Tuber Dry Weight} \times 100}{\text{Tuber Fresh Weight}}$$

SAS version 9.2 statistical software (SAS, 2009) assisted in statistical analysis (ANOVA). Fisher's protected least significant difference (LSD) test at a 5% level of significance separated the mean values of significant treatment effects (Gomez and Gomez, 1984).

Results

Growth parameters of potato

Plant height (cm)

Different levels of earthing up and inflorescence removal had significant effects ($P < 0.01$) on the height of potato plants, whereas their combination had no significant influence ($P > 0.05$). The three rounds of earthing up treatments resulted in the tallest plant height (68.70 cm). Conversely, the control had the shortest plant height (60.96 cm) (Table 1). The plant that was left untreated (without inflorescence removal) had the greatest height (69 cm). However, the bud removal treatment resulted in the shortest plant height (61.26 cm) (Table 1).

Number of primary branches hill^{-1}

Inflorescence removal had a significant effect on the number of primary branches hill^{-1} on potato plants ($P < 0.01$). However, there was no significant difference between the combined effect and the earthing up treatments ($P > 0.05$). According to Table 1, when the buds were removed, the number of primary branches hill^{-1} increased even though the flowers did not produce more branches.

Leaf number hill^{-1}

The number of leaves hill^{-1} was significantly ($P < 0.01$) influenced by the combined effects of earthing up and inflorescence removal practices. Among all treatments, the combined effect of three rounds of earthing up and bud removal increased the leaf number hill^{-1} (772.30), which was statistically similar to the effect of two-round combinations of earthing up and bud removal (716.23). Comparatively, the lowest leaf number (436.37) was obtained from the control (Table 2).

Leaf area index

The combined effect of the earthing up and inflorescence removal practices significantly influenced the leaf area index ($P < 0.01$). The largest leaf area index (5.28) was obtained from the bud removal treatment combined with three rounds of earthing up, followed by bud removal combined with two rounds of earthing up (5.10), flower removal with two rounds of earthing up (4.74) and bud removal with one round of earthing up (4.60), whereas the lowest value (1.71) was recorded for the control (Table 2).

Table 1. Plant height and number of primary branches of potato plants as influenced by earthing up and inflorescence removal.

Treatments	Parameters	
Earthing up	**Plant height (cm)**	**Number of primary branches (count hill^{-1})**
No earthing up	60.96^{c}	7.67^{a}
One time	65.64^{ba}	7.44^{a}
Two times	64.69^{b}	7.52^{a}
Three times	68.70^{a}	7.97^{a}
Least significant difference (0.05)	3.58**	1.16^{ns}
Inflorescence removal		
Without removal	69.00^{a}	7.00^{b}
Bud removal	61.26^{c}	8.78^{a}
Flower removal	64.73^{b}	7.43^{b}
Least significant difference (0.05)	**	**
Coefficient of variation (%)	5.36	14.64

Means followed by different letter(s) per column are significantly different at $P < 0.05$, ** = highly significant, ^{ns} = nonsignificant.

Table 2. Leaf area, leaf number, and leaf area index of potato plants as influenced by the combined effects of earthing up and inflorescence removal.

Treatments		Parameters		
Inflorescence removal	**Earthing up**	**Leaf number (count hill^{-1})**	**Leaf area (cm^{2})**	**Leaf area index**
Without removal	No earthing up	436.37^{e}	8.80^{g}	1.71^{f}
	One time	459.90^{de}	9.47^{fg}	1.95^{ef}
	Two times	469.43^{de}	10.41^{ef}	2.19^{de}
	Three times	493.57^{dce}	10.92^{ef}	2.42^{d}
Bud removal	No earthing up	533.27^{dc}	12.10^{ed}	2.86^{dc}
	One time	677.27^{b}	15.38^{bac}	4.63^{ba}
	Two times	716.23^{ba}	16.03^{a}	5.10^{a}
	Three times	772.30^{a}	15.40^{ba}	5.28^{a}
Flower removal	No earthing up	554.67^{c}	13.47^{dc}	3.33^{c}
	One time	687.50^{b}	13.99^{bdc}	4.26^{b}
	Two times	689.53^{b}	14.02^{bdc}	4.30^{b}
	Three times	687.03^{b}	15.52^{ba}	4.74^{ba}
Least significant difference (0.05)		**	*	**
Coefficient of variation (%)		7.55	9.06	11.58

Means followed by different letter(s) per column are significantly different at $P < 0.05$, according to the LSD test, ** = highly significant, * = significant.

Yield and yield components of potato tubers

Number of marketable tubers hill^{-1}

The combined effects of the earthing up and inflorescence removal practices significantly differed among the treatments ($P < 0.05$). The maximum number of marketable tubers hill^{-1} (10.07) was recorded in response to bud removal combined with three earthing up treatments, whereas the minimum number of marketable tubers (2.77) was recorded in the control (Fig. 1).

Number of unmarketable tubers hill^{-1}

The number of unmarketable tubers hill^{-1} was significantly ($P < 0.05$) influenced by the interaction of earthing up and inflorescence removal. Accordingly, after three rounds of earthing up and flower removal, the lowest number of unmarketable tubers hill^{-1} (1.07) was observed. Conversely, the control group had the greatest number of unmarketable tubers hill^{-1} (6.03) (Fig. 1).

Marketable tuber weight (g hill^{-1})

The interaction effect of earthing up and inflorescence removal significantly affected the marketable tuber weight ($P < 0.05$). The marketable tuber weight increased to 708.67 g hill^{-1} after three rounds of earthing up combined with bud removal (Table 3).

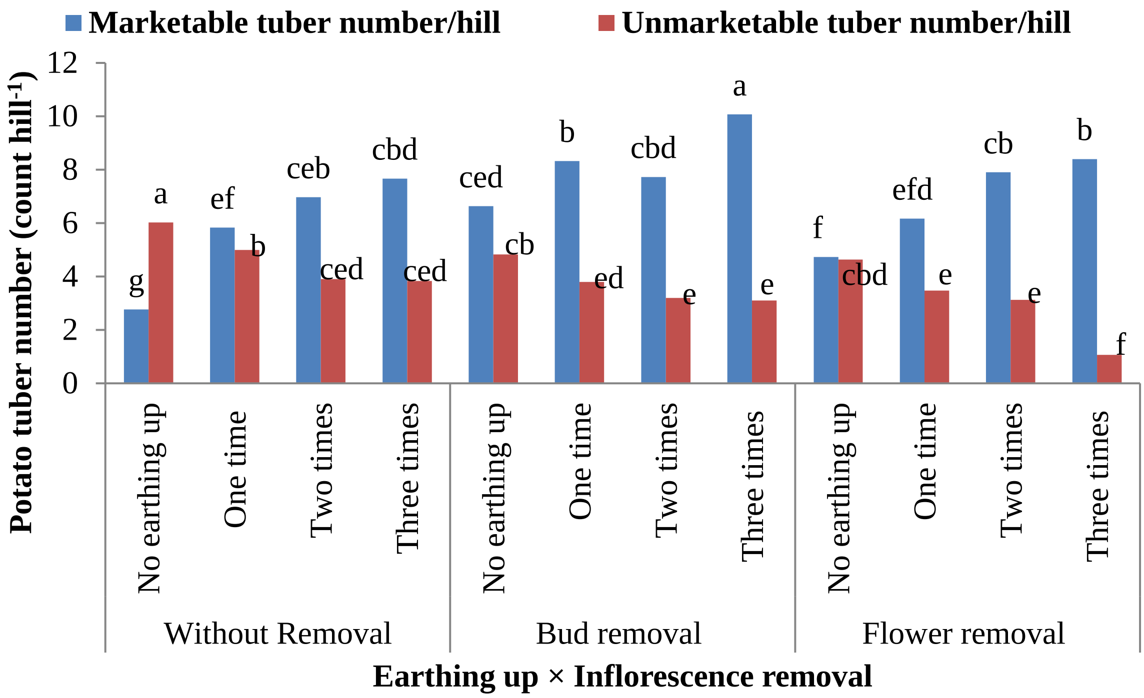

Fig. 1. Number of marketable and unmarketable tubers of potato as influenced by the combined effects of earthing up and inflorescence removal. Values marked by different letter(s) are significantly different at $P < 0.05$, according to the LSD test.

Table 3. The marketable and unmarketable tuber weights of potato as influenced by the combined effects of earthing up and inflorescence removal.

Treatments		Parameters	
Inflorescence removal	Earthing up	Marketable tuber weight (g hill^{-1})	Unmarketable tuber weight (g hill^{-1})
Without Removal	No earthing up	246.77^{g}	89.67^{a}
	One time	485.60^{fd}	73.27^{cb}
	Two times	527.87^{cbd}	55.87^{edf}
	Three times	558.73^{cbd}	49.60^{ef}
Bud removal	No earthing up	361.20^{f}	78.13^{b}
	One time	508.33^{cd}	57.40^{ed}
	Two times	591.40^{b}	46.60^{egf}
	Three times	708.67^{a}	35.73^{g}
Flower removal	No earthing up	408.87^{fe}	64.60^{cd}
	One time	528.73^{cbd}	56.87^{edf}
	Two times	571.67^{cb}	54.40^{edf}
	Three times	600.80^{b}	45.73^{gf}
Least significant difference (0.05)		*	*
Coefficient of variation (%)		9.48	11.47

Means followed by different letter(s) per column are significantly different at $P < 0.05$, according to the LSD test, * = Significant.

Unmarketable tuber weight (g hill^{-1})

There was a significant difference ($P < 0.01$) between the inflorescence removal and earthing up treatments in terms of unmarketable tuber weight hill^{-1}. A significant difference ($P < 0.05$) was shown by their interaction effect. Table 3 shows that potatoes without inflorescence removal and no earthing up produced the highest tuber weight (89.67 g hill^{-1}) among all treatments.

Marketable tuber yield (t ha^{-1})

There was a significant ($P < 0.05$) variation in the effect of the combination of earthing up and flower bud removal on the marketable tuber yield. Figure 2 shows that the combination of bud removal and three rounds of earthing up produced the highest marketable yield (31.49 t ha^{-1}) of all the treatment combinations. Conversely, the control plots produced the lowest marketable yield (10.7 t ha^{-1}).

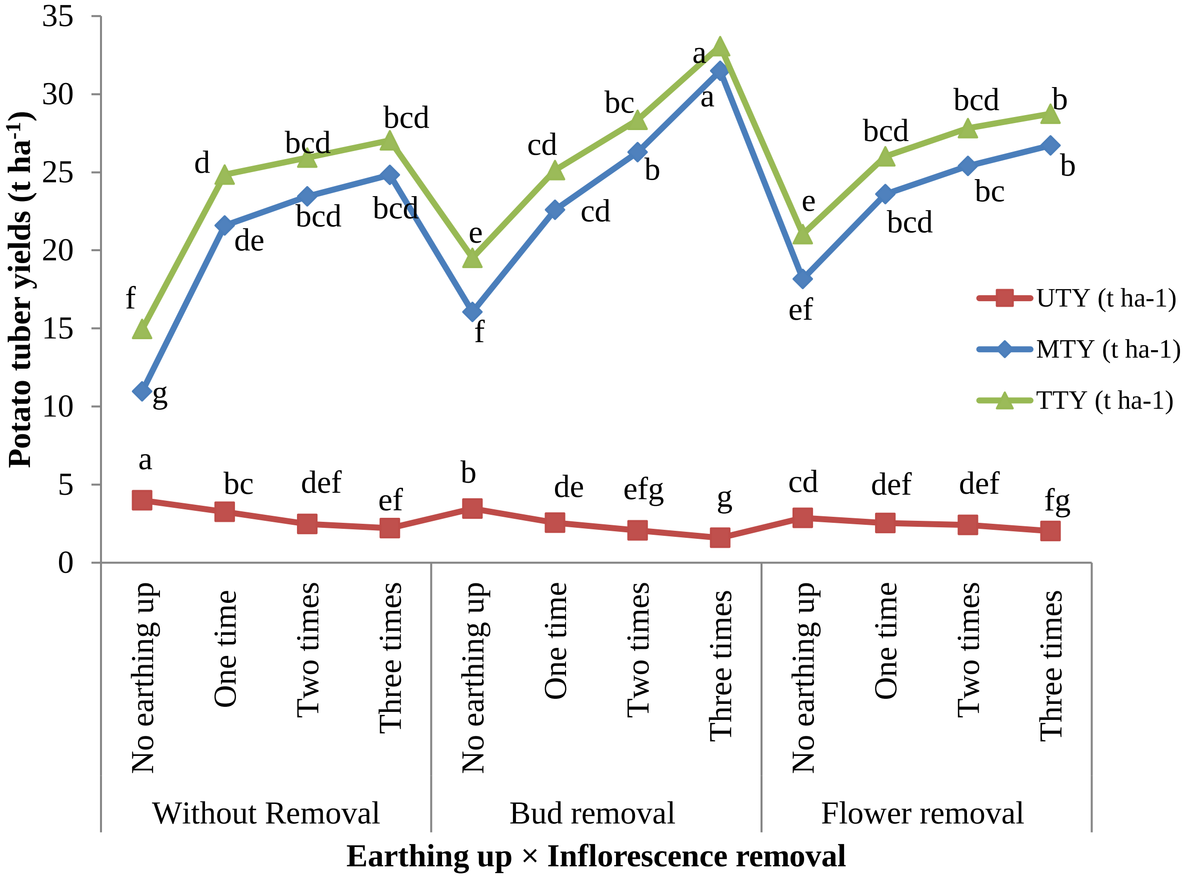

Fig. 2. Marketable, unmarketable, and total yields of potato tubers as influenced by the combined effects of earthing up and inflorescence removal. Values marked by different letter(s) are significantly different at $P < 0.05$, according to the LSD test. Where, MTY = marketable tuber yield, UTY = unmarketable tuber yield and TTY = total tuber.

Unmarketable tuber yield (t ha^{-1})

The unmarketable tuber yield was significantly ($P < 0.05$) affected by the combination of earthing up and flower bud removal. Figure 2 presents the highest unmarketable tuber yield (3.99 t ha^{-1}) in the control.

Total tuber yield (t ha^{-1})

There was a significant ($P < 0.05$) variation in the total yield of potato tubers among the combination treatments. The combined effect of bud removal and three rounds of earthing up produced the highest total tuber yield (33.08 t ha^{-1}), whereas the control had the lowest total tuber yield (14.96 t ha^{-1}) (Fig. 2).

Tuber size categories on the basis number hill^{-1}

Number of small-sized tubers

The combined use of inflorescence and earthing up practices resulted in statistically significant ($P < 0.05$) variation in the number of small-sized tubers hill^{-1}. Among all the treatments, the control group was particularly noteworthy since it had the maximum number of small tubers (Table 4).

Number of medium-sized tubers

The interaction effect of earthing up and inflorescence removal practices significantly influenced the number of medium-sized tubers hill^{-1} ($P < 0.05$). The highest number of medium-sized tubers hill^{-1} (6.95) was obtained in the three rounds of earthing up combined with bud removal, which was statistically similar to that in the two rounds of earthing up combined with flower removal treatment (6.08), while the control produced the lowest (2.20) number of medium-sized tubers, which was not significantly different from that of the no earthing up with flower removal (3.42) (Table 4).

Number of large-sized tubers

The results revealed that the combined effect of earthing up and inflorescence removal practices had a significant (*P* < 0.01) effect on the number of large-sized tubers hill^{-1}. When the potato buds were removed and earthed up three times, the highest number of large-sized tubers hill^{-1} (4.48) was obtained. The plots that were kept without inflorescence removal and without earthing up had the lowest (1.55) (Table 4).

Table 4. Number of small-sized tubers, the number of medium-sized tubers and the number of large-sized tubers of potato as influenced by the combined effects of earthing up and inflorescence removal.

Treatments		Parameters		
Inflorescence removal	Earthing up	Number of small-sized tubers (count hill^{-1})	Number of medium-sized tubers (count hill^{-1})	Number of large-sized tubers (count hill^{-1})
Without removal	No earthing up	5.05^{a}	2.2^{e}	1.55^{g}
	One time	5.67^{cb}	4.68^{bdc}	2.5^{ef}
	Two times	2.84^{ced}	4.99^{bc}	3.05^{cebd}
	Three times	2.48^{fed}	5.46^{bac}	3.56^{b}
Bud removal	No earthing up	5.08^{a}	4.07^{dc}	2.32^{f}
	One time	3.99^{b}	4.97^{bc}	3.17^{cbd}
	Two times	2.03^{fe}	5.41^{bc}	3.49^{cb}
	Three times	1.74^{f}	6.95^{a}	4.48^{a}
Flower removal	No earthing up	3.26^{cbd}	3.42^{ed}	2.68^{efd}
	One time	2.45^{fed}	4.77^{bdc}	2.42^{ef}
	Two times	2.02^{fe}	6.08^{ba}	2.9^{cefd}
	Three times	1.83^{f}	5.07^{bc}	2.57^{efd}
Least significant difference (0.05)		*	*	**
Coefficient of variation (%)		15. 58	18.42	12.77

Means followed by different letter(s) per column are significantly different at *P* < 0.05, according to the LSD test, ** = highly significant, * = significant.

Tuber diameter (cm)

Earthing up and inflorescence removal practices had significant (p< 0.01) effects on the diameter of the tuber. However, the interaction was not significant. The greatest tuber diameter (15.44 cm) was obtained in response to three rounds of earthing up, which was not significantly different from that of the two rounds of earthing up (14.22 cm), whereas the lowest tuber diameter (10.00 cm) was obtained in the control (Fig. 3). The greatest tuber diameter (15.46 cm) was recorded in response to flower removal. This diameter was statistically similar to that in the bud removal treatment (14.15 cm), whereas the lowest tuber diameter (9.23 cm) was recorded in plots without inflorescence removal (Fig. 3).

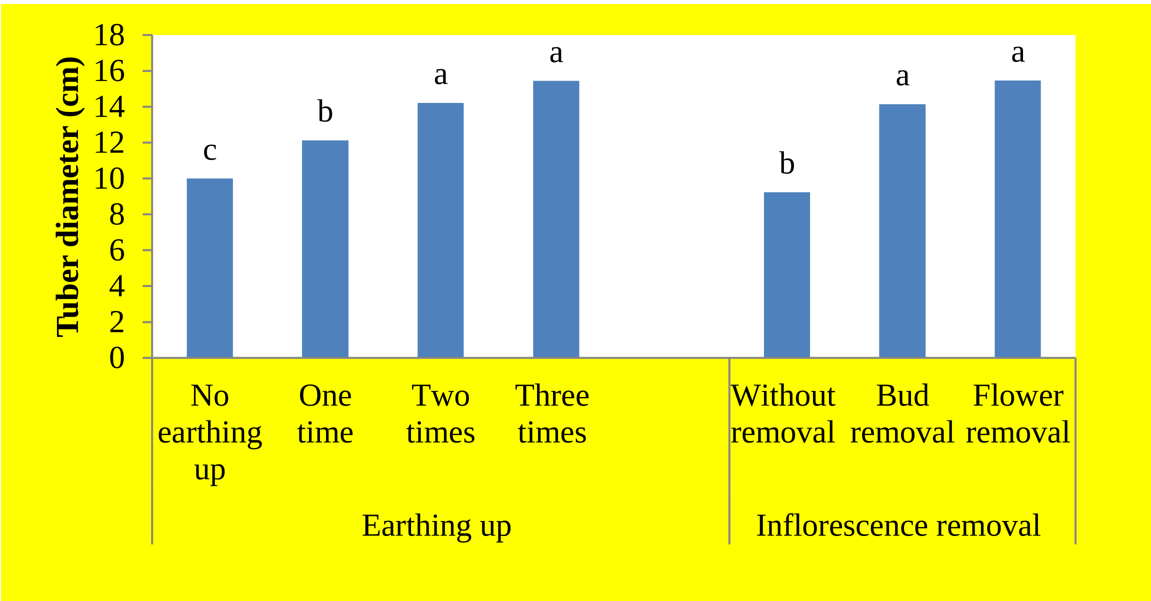

Fig. 3. Potato tuber diameter as influenced by earthing up and inflorescence removal. Values marked by different letter(s) are significantly different at *P* < 0.05, according to the LSD test.

Tuber quality parameter of potato

Dry matter content

According to the analysis of variance, the dry matter percentage was significantly ($P < 0.01$) influenced by earthing up and inflorescence removal practices. There was no small difference in dry matter content among the combination treatments ($P > 0.05$). The bud free potato had the highest dry matter content (29.04%) among all treatments. However, there was no discernible change in the potato treatment in which flowers were removed (27.6%), whereas the treatment in which no flowers were removed had the lowest (24.58%) tuber dry matter content (Table 5).

Table 5. Dry matter content of potato tubers as influenced by the earthing up and inflorescence removal practices.

Treatment	Parameter
Earthing up frequency	Dry matter content (%)
Without earthing up	24.18^{c}
One time	26.57^{b}
Two times	28.26^{ba}
Three times	29.82^{a}
Least significant difference (0.05)	2.19**
Flower bud removal types	
No removal	24.58^{b}
Bud removal	29.04^{a}
Flower removal	27.60^{a}
Least significant difference (0.05)	**
Coefficient of variation (%)	7.86

Mean values followed by different letter(s) per column are significantly different at $P < 0.05$, according to the LSD test, ** = highly significant.

In terms of earthing up, potatoes that had been earthed up three times had the highest dry matter content (29.28%), followed by potatoes earthed up twice (28.26%), whereas potatoes that had not been earthed up had the lowest (25.18%) percentage of dry matter content (Table 5).

Discussion

Increasing the frequency of earthing up resulted in taller plants due to improved soil conditions, enhanced root growth, and the increased scavenging of growth factors from the soil. These factors collectively contributed to greater plant height. Taller plants may support the emergence of new leaves, thereby increasing photosynthetic efficiency through enhanced light absorption. Getachew et al. (2012) observed that well-executed earthing up produced the tallest plants. However, the present study's findings differ from those of Gutema (2016), who reported that the tallest plants were observed in a single earthing-up plot, the shortest in a three earthing-up plot, and the second tallest in a no-ridging plot.

The removal of potato buds at emergence reduces plant height by preventing the development of apical dominance in the stems. This finding aligns with the suggestion of Chatfield et al. (2000), who reported that the shoot apical meristem maintains its role as the primary site of growth by inhibiting the development of axillary meristems. Inflorescence-removed plants appeared shorter due to reduced stem elongation, as reported by Tekalign and Hammes (2005) and Desta and Tsegaw (2008). In contrast, Faramarzi et al. (2011) found that inflorescence removal increased plant height. It appears that early removal of apical dominance allows lateral buds to grow, resulting in increased branching. This observation is supported by Ali (2016), who reported that the maximum number of branches occurred in plots where inflorescences were removed, while the control plots had the fewest branches.

The removal of inflorescences reduces the apical dominance of the stem by eliminating the auxin source, thereby promoting the growth of side buds and increasing the number of branches on the main stems. Similar findings were reported by Tekalign and Hammes (2005) and Nazari (2010), who observed a significant increase in the number of branches plant^{-1} following bud removal. The development of additional leaves was also noted after the removal of buds, which was facilitated by improved soil conditions. Early removal of apical buds stimulates the growth of lateral buds and leaves. This result aligns with the findings of Hasani and Karuniawan (2010) and Asl (2016), who reported that the elimination of inflorescences reduces apical dominance and increases the number of leaves, branches, and stems. The removal of flowers, buds, and leaves allows for increased light penetration, which enhances photosynthetic efficiency and subsequently improves vegetative growth (Preece and Read, 2005).

Yaroson et al. (2019) also investigated the response of potato to tillage practices and reported that soil management practices had a significant effect on the number of leaves, leaf area, and canopy cover. As the frequency of earthing up increased, the leaf area also increased. This increase is primarily attributed to reduced competition for assimilates between leaves and buds, as well as the availability of favorable growing conditions created by the larger volume of loose soil. Leaf area is one of the best indicators of a crop's capacity to produce dry matter since there is a positive correlation between dry matter accumulation and plant leaf area (Begum et al., 2015).

This finding is further supported by Tekalign and Hammes (2005) and Desta and Tsegaw (2008), who reported that pinching buds led to the expansion of larger leaves, thereby increasing the total leaf area. Getachew et al. (2012) also reported that potato plants subjected to earthing up had the largest leaf area, while the control plots had the smallest. The combination of earthing up and bud removal had a significant effect on the leaf area index. Potato crops that underwent three rounds of earthing up and bud removal displayed optimal foliage cover and a greater number of branches compared with crops grown without earthing up or bud removal. This could be due to the production of larger, more expanded leaves, which increased the leaf area index. These findings are consistent with those of Asl (2016), who reported that inflorescence removal in potatoes significantly increased the number of leaves and branches plant^{-1}, resulting in a higher leaf area index. Desta and Tsegaw (2008) also observed a higher leaf area index in plants where buds with younger leaves were removed, compared with control plants. Contrary to the current findings, Tafi et al. (2010) reported that earthing up had no significant effect on the leaf area index.

The number of tubers increases with higher earthing-up frequency combined with bud removal. This could be attributed to the redistribution of dry matter to the tubers and the preparation of the soil for healthy stolon development and early tuberization, leading to the formation of numerous high-quality tubers. This result aligns with that of Gebregwergis et al. (2021), who found that removing flower buds reduced competition for assimilates, thereby enabling most tubers to reach marketable size. Similarly, Chitsinde (2018) reported that earthing up three times created a well-drained, cool environment that produced the highest number of marketable tubers. Desta and Tsegaw (2008) observed that removing buds with younger leaves increased the number of marketable tubers by approximately 50%. Tekalign and Hammes (2005) also noted that potato plants from which flower buds were removed produced the highest number of marketable tubers.

The absence of earthing up exposes tubers to damage, resulting in smaller, deformed tubers. To enhance tuber assimilation, promote ideal soil conditions for tuber initiation and development, and prevent tuber damage, it is essential to remove flowers and apply earthing up three times. This finding is consistent with Gebregwergis et al. (2021), who reported a higher number of tubers affected by disease and sprouting in control plants compared to those that underwent earthing up. Potato plants that are not hilled have a weaker protective soil layer, leaving tubers more vulnerable to mechanical injury, pest attack, greening, and deformation (Montaldo, 1984; Svubure et al., 2015; Gutema, 2016; Ren et al., 2017; Van Dijk et al., 2021; Arora et al., 2023).

In contrast, Tekalign and Hammes (2005) and Desta and Tsegaw (2008) reported that flower bud removal had no significant effect on the number of unmarketable tubers. This difference may be attributed to the higher precipitation and cooler temperatures in the present study area, which may have influenced plant growth and tuber development. The highest increase in tuber weight recorded was 708.67 g hill^{-1}, a result likely due to the prevention of bud and flower development and the conservation of growing soil. The removal of flowers and newly growing leaves, which are strong consumers of assimilates, redirects assimilates to the underground tubers, promoting early tuberization, enhancing tuber growth, and ultimately increasing tuber weight. This observation aligns with the findings of Gebregwergis et al. (2021), who reported that combining bud removal with earthing up produced the highest number of marketable tubers. Similarly, Tsegaw (2007) and Faramarzi et al. (2011) noted that pruning flower buds and young leaves significantly increased tuber size and number.

Proper soil coverage provided by earthing up supports the development of marketable tubers, as it mitigates tuber damage (Chitsinde, 2018). The growth of inflorescences consistently reduces tuber size, as the developing inflorescences compete with tubers for nutrients and assimilates. Additionally, compacted soil limits nutrient uptake by growing tubers, leading to undersized tubers. This could be due to increased competition for assimilates, the formation of smaller tubers, greening, and mechanical or insect damage. Gebregwergis et al. (2021) similarly reported that potato crops grown without earthing up, and under normal conditions, produced the highest number of unmarketable tubers. Bernik et al. (2009) observed that earthing up reduced the percentage of green tubers due to better soil coverage of the tubers within the ridge. Sakadzo et al. (2019) also reported that tubers grown without earthing up were more vulnerable to pest attacks and exposure to light, which caused tuber greening and reduced tuber quality. Tafi et al. (2010) found that earthing up significantly reduced tuber greening compared to plots where no earthing up was done.

A significant increase in marketable tuber yield, ranging from 106% to 187%, was observed in response to bud removal combined with earthing up. This increase may be attributed to the elimination of competing plant parts and the creation of favorable growing soil conditions, which promote the synthesis and translocation of more assimilates to the tubers. As a result, most of the initiated tubers reached marketable size and were protected from damage and greening. This finding is consistent with Gebregwergis et al. (2021), who reported the highest marketable tuber yield (30.25 t ha^{-1}) following flower removal at the bud stage and earthing up after full emergence. Similarly, Faramarzi et al. (2011) found that the removal of inflorescences increased marketable tuber yield by up to 4.3 t ha^{-1}. In contrast, Tekalign and Hammes (2005) reported that the absence of inflorescence removal reduced the marketable tuber yield by approximately 22%. Likewise, Gutema (2016) observed a 27.5% yield increase in plots with three rounds of earthing up compared to control plots.

Potato hilling plays a critical role in preventing tuber greening, providing sufficient soil coverage for developing tubers, and promoting the production of uniformly sized, well-shaped, and less damaged tubers—key factors in marketable tuber yield (Bohl and Love, 2005; Xing et al., 2011; Sakadzo et al., 2019). Additionally, the process of breaking up compacted soil layers improves soil physical properties, such as bulk density, aggregate stability, and hydraulic conductivity, enhancing plant access to water and nutrients. These improvements support vegetative growth and contribute to higher yields (Ati et al., 2015).

The competition for assimilates between flower buds and tubers reduces the partitioning of assimilates to the tubers, promoting stolon elongation instead of tuber bulking. Consequently, most of the tubers remain undersized and are more prone to mechanical, insect, and disease damage, as well as greening caused by exposure to sunlight. This observation is consistent with Gebregwergis et al. (2021), who found that non-earthing up combined with the absence of bud removal produced higher unmarketable tuber yields than bud removal with earthing up. Similarly, Getachew et al. (2012) noted that inadequate earthing up exposed tubers to sunlight, extreme heat, diseases, and insect damage, all of which negatively impacted tuber quality and yield. Gutema (2016) also reported a significantly higher unmarketable yield in control treatments compared to those with earthing up and bud removal. In contrast, Tekalign and Hammes (2005) and Desta and Tsegaw (2008) observed no significant effect of flower bud removal on unmarketable tuber yield, suggesting that differences in precipitation and temperature in the present study area may explain the discrepancies.

The total tuber yield increased significantly, with an increase ranging from 68% to 121%, a result that may be explained by the larger volume of loose soil available and the absence of competition from other plant parts. This facilitated the synthesis and partitioning of additional dry matter into the tubers, resulting in the production of more and larger tubers. This finding is consistent with that of Gebregwergis et al. (2021), who reported an increase in total tuber yield with bud removal and earthing up. Similarly, Faramarzi et al. (2011) noted that removing inflorescences increased total tuber yield by up to 3.62 t ha^{-1}, while Nazari (2010) observed that inflorescence removal raised potato yield by 2.68 t ha^{-1} (8.9%). Tsegaw and Zelleke (2002) reported that flower and fruit removal increased total tuber yield by 2.2% and 17%, respectively, highlighting how reproductive growth can inhibit tuber growth and development. Conversely, Tekalign and Hammes (2005) and Asl (2016) reported that removing reproductive parts reduced total tuber yield by 13-19%, compared to plants that retained their reproductive structures. Gutema (2016) observed a 24.7% increase in total tuber yield in plots with three rounds of earthing up relative to control plots.

Soil compaction is known to affect potato growth negatively. Stalham et al. (2007) found that compacted soil delayed crop emergence, reduced root density, limited deep rooting, slowed leaf appearance and canopy cover expansion, and shortened the canopy cover duration. By contrast, Rodríguez et al. (2020) reported that two rounds of earthing up increased total tuber yield by 86.02%, underscoring the importance of proper soil management. Improved soil physical properties and higher moisture content create larger root systems, allow for greater root expansion, and enhance nutrient uptake, resulting in better vegetative growth, increased photosynthesis, and higher productivity (Moreno et al., 2008).

The intense competition for assimilates between developing inflorescences and tubers, coupled with poor soil conditions, often results in smaller, undersized tubers. This observation aligns with the findings of Tafi et al. (2010), who noted that earthing up impacts tuber development by modifying the ridge structure, which significantly influences tuber number and mass. Sakadzo et al. (2019) also highlighted that earthing up creates an optimal environment for tuber initiation and growth, enhancing tuber development and ultimately increasing yield.

The formation of inflorescences in potato plants negatively impacts tuber size. Removing inflorescences at the bud stage and performing three rounds of earthing up can reduce this effect, resulting in an approximate 215% increase in medium-sized tubers. This improvement is likely due to the creation of a favorable environment for rhizome growth and tuber initiation, as well as the enhanced rate of photosynthesis triggered by earthing up and flower removal. Taye et al. (2007) reported that frequent earthing up produces a higher number of medium-sized tubers. Similarly, Tafi et al. (2010) found that adding soil to plants improved potato tuber structure and increased the number of tubers bush^{-1}. The combined practices of earthing up and inflorescence removal improve soil conditions, enhancing nutrient absorption and the transfer of dry matter to underground structures. This leads to larger and more numerous tubers, a result consistent with the findings of Gebregwergis et al. (2021), who observed the greatest number of tubers in potato plants subjected to inflorescence removal and earthing up after full emergence.

Dry matter accumulation in potato plants is also enhanced by earthing up, as reported by Tafi et al. (2010). Their study attributed the increased dry matter content to the reduced stress on tubers when additional soil was applied, thereby increasing the ridge cross-section. Without a sufficient soil layer, tuberization rates may slow, and stolons may develop into aerial stems (Zierer et al., 2021). An increase in tuber diameter was observed in plots where earthing up was practiced, compared to control plots. Specifically, one, two, and three rounds of earthing up increased tuber diameter by 21%, 42%, and 54%, respectively (Fig. 3). This outcome is likely due to the enhanced source-to-sink relationship in potato plants created by earthing up. It is also possible that earthing up allowed stolons and tubers to grow more horizontally, unlike in control plots, where tubers grew more vertically, leading to increased tuber length rather than width. Chitsinde (2018) similarly reported that increased earthing-up frequency results in larger tuber sizes at harvest. Sakadzo et al. (2019) highlighted that timely earthing up supports tuber initiation, producing larger tubers with higher marketability. Henriksen et al. (2005) reported that adding soil to potato bushes influences tuber structure and productivity, significantly affecting the number and mass of tubers.

The removal of inflorescences further enhances tuber growth by diverting assimilates to vegetative and underground parts. Faramarzi et al. (2011) found that inflorescence removal increases the photosynthetic area of the plant and facilitates the transfer of assimilates to tubers, resulting in larger tubers. This observation aligns with the findings of Hassen et al. (2013), who reported that flower bud removal in anchote plants increased root diameter by 7.62%. The absence of reproductive parts in anchote facilitated the allocation of assimilates to vegetative structures, improving tuberous root growth.

Dry matter content in tubers also improves under bud- and flower-removal treatments compared to untreated plants. This improvement is linked to the cessation of flower and bud growth, which redirects nutrients previously used for shoot and root development toward tubers, leading to higher dry matter accumulation. Tekalign and Hammes (2005) found that tubers from potato plants with intact buds and flowers had 33.3% less dry matter than tubers from plants where these parts were removed. Desta and Tsegaw (2008) reported that removing young leaves and their associated buds increased dry matter content by 17.6% compared to untreated control plants. Additionally, studies by Hassen et al. (2013) and Gebregwergis et al. (2021) revealed that flower removal significantly increased tuber dry matter content by promoting the movement of assimilates to the sink.

Research on other crops also supports the positive effects of reproductive part removal. Hasani and Karuniawan (2010) found that pruning sink-reproductive parts in yam plants increased tuber fresh weight. Similarly, Wang et al. (2008) demonstrated that shoot apex removal in tobacco plants led to a reduction in the competition for assimilates, enhancing the growth of leaves and roots. In tobacco plants, shoot apices act as a strong sink, keeping assimilate levels in leaves and roots relatively low compared to plants where the apex was removed. Soil conditions play a vital role in potato crop establishment and tuber development. The improved soil environment created by earthing up facilitates better root establishment and supports tuber growth, resulting in higher carbohydrate accumulation. This finding aligns with Tafi et al. (2010), who reported that earthing up promotes dry matter accumulation in tubers while reducing drought-related stress due to improved soil moisture regulation. Gebregwergis et al. (2021) also observed that the highest dry matter content (26.3%) was achieved when earthing up was done 30 d after planting. Reduced soil tillage positively affects tuber quality in terms of specific gravity, dry matter, and starch content, as noted by Drakopoulos et al. (2016).

Conclusions

The findings of this study demonstrated that the combined practice of earthing up and inflorescence removal significantly enhances potato tuber yield components, leading to a substantial increase in total marketable tuber yield. The combined effect of these practices positively influenced critical factors such as tuber size, number, diameter, dry matter content, and overall tuber quality. These improvements are attributed to the creation of a more favorable soil environment, better nutrient allocation, and enhanced assimilate distribution toward tubers.

Earthing up, especially when conducted in three rounds, plays a crucial role in protecting developing tubers from damage caused by exposure to sunlight, pest attacks, and mechanical injury. It also reduces the likelihood of tuber greening, a condition that negatively affects marketability. Furthermore, the practice of earthing up improves soil aeration, enhances root penetration, and facilitates better water retention and drainage. Collectively, these factors create optimal conditions for stolon elongation, early tuberization, and tuber bulking, all of which contribute to higher tuber yield.

The removal of inflorescences complements the benefits of earthing up by redirecting plant assimilates from reproductive growth (flowers and berries) to vegetative and underground parts, specifically the stolons and tubers. This shift allows for more efficient dry matter accumulation in tubers, leading to larger, heavier, and higher-quality tubers. By eliminating the competition for resources between reproductive organs and tubers, the combined approach of earthing up and inflorescence removal ensures optimal resource partitioning, promoting the development of marketable tubers.

Based on the findings, it is recommended that farmers adopt the combined practice of removing inflorescences and conducting three rounds of earthing up for potato production. This integrated approach is shown to be an effective agronomic strategy for improving tuber size, quality, and yield. Implementing this practice may increase profitability for potato producers by enhancing marketable yield while reducing the risk of tuber loss due to greening, physical damage, and pest infestation. These findings highlight the importance of combining simple, cost-effective, and sustainable cultural practices to achieve higher productivity and marketable yield in potato farming.

Future research could explore the interaction of earthing up and inflorescence removal with other agronomic factors, such as soil type, irrigation frequency, and nutrient management. Additionally, studies could investigate the potential for mechanized implementation of these practices, which would reduce labor costs and enhance the scalability of these approaches and recommendations in commercial potato production systems.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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