

Tuber 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, are responsible for the great discrepancy between the potential and achievable yields of potatoes in Ethiopia. To assess the effects of the combination on the tuber yield and yield components of potato, a factorial combination of four earthing up rounds (without, one, two, and three rounds) and three inflorescence removal levels (without removal, bud removal, and flower removal) was used in a randomized complete block design with three replications. The number of marketable, unmarketable and total tubers per hill; and the marketable, unmarketable, and total tuber yields significantly differed in terms of the combined effects of factors. The maximum marketable tuber number (10.07 count/hill), the maximum total tuber number (13.17 count/hill), the marketable tuber yield (31.49 t/ha), and the total tuber yield (33.08 t/ha) were associated with bud removal combined with three rounds of earthing up. Thus, this combination of treatments can be advised for potato production.

Keywords: Assimilates, Reproductive part, Stolons, Tuber initiation, Tuberization

INTRODUCTION

Potato (*Solanum tuberosum* L.) from the Solanaceae family is the world's most important food security crop, owing to its ability to produce large amounts of crops in a short period and high nutritional products per unit input (Limenih and Tefera, 2014). In Ethiopia, it is the most important crop in terms of both economic importance and food production (Degebasa, 2019). Ethiopia has ideal climatic and edaphic conditions for high-quality potato production; it may have the highest potential for potato production in all of Africa. However, potato production in Ethiopia currently occupies only 2% of its potential land (Gebremedhin *et al.*, 2008).

In 2020/2021, compared with the average yield of 15 t/ha in Africa and 21 t/ha globally, the average yield was 13.28 t/ha, with a total production of 11.15 million tons in 85,988 hectares of land (FAOSTAT, 2022). Several production challenges have been identified as the causes of the low national yield. The major challenges are the limited availability and high price of seed tubers (Amede *et al.*, 2006), the occurrence of diseases and insect pests (Guluma, 2020), and non-optimal agronomic practices, including earthing up (Sakadzo *et al.*, 2019) and inflorescence management (Tekalign and Hammes, 2005; Gebregwergis *et al.*, 2021). Earthing up is a row cultivation model that is essential for increased tuber production and root system expansion, weed removal, and soil–nutrient mixing (especially with manures) (Khayatnezhad and Gholamin, 2011). Adequate earthing up applied at the right time and in the right way

favours high tuberization and consequently an increase in total yields (Gutema, 2016). In addition, the earthing up practice keeps the tuber from greening, provides support for the plants, captures runoff, aerates the rooting zone, and improves resistance to growing roots, thereby creating conditions for better root growth and utilization of the newly added soil minerals for plant growth, yield and quality improvement (Ren *et al.*, 2017; Ebrahimi *et al.*, 2021; Van Dijk *et al.*, 2021; Arora *et al.*, 2023). Furthermore, earthing up the soil helps maintain moderate soil moisture and temperature and could be a strategy to increase potato yields. Higher moisture and a lower temperature in the soil lead to early tuberization and greater yield (Rykaczewska, 2015). Earthing up also increases the soil depth, allowing plants to extend their roots widely and deeply to absorb more nutrients and water, as earthing up conserves moisture and reduces the leaching of nutrients (Sakadzo *et al.*, 2019). Specifically, when tubers are exposed outside of the soil, they become more vulnerable to pest attacks and greening, both of which lower tuber quality (Svubure *et al.*, 2015).

Moreover, the development of potato inflorescences (flowers and fruits) has a detrimental effect on tuber development because growing tubers actively compete with inflorescences for assimilation. The removal of the inflorescence improves the distribution of assimilates into underground structures and increases tuber yield (Tekalign and Hammes, 2005). The inflorescences are strong sinks for assimilates (mineral nutrients, sugars, and amino acids), and there could be a corresponding decrease in the amounts available for tuber growth. Potato plants distribute assimilates to developing fruits, tubers, and other vegetative structures based on the strength of the sinks. There must be competition between sink organs when assimilation is limited (Hassen *et al.*, 2013). This requires the removal of inflorescences to eliminate competition among sink organs. Thus, identifying the optimum earthing up frequency and the right stage of inflorescence removal (flowers, buds and fruits) must be considered to ease the existing problems of increasing potato tuber yield, especially under cool conditions, because potato responses are strongly influenced by environmental variability. Therefore, the present study evaluated the combined influences of earthing up and inflorescence removal on the tuber yield and yield components of potato crops.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in the Debre Markos, East Gojjam Zone of the Amhara Regional State in 2022 under irrigation. The experimental area is located at 10° 19' 43" latitude North and 37°44' 43" longitude East, with an altitude of 2,446 m.a.s.l. The 2021 average annual rainfall at the experimental site was 1,628 mm. 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 its pH was 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 a high yield, and 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) was used in a randomized complete block design with three replications. The first earthing up treatment was applied on the 15th day after complete emergence, the second treatment was applied on the 30th day, and the third treatment was applied on the 45th day. 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 the flower and new leaf removal was performed at the beginning of blooming (Faramarzi *et al.*, 2011). The inflorescence removal was performed daily until the plants ceased growing buds and flowers.

Data collection and analysis

To evaluate the combined influences of earthing up and inflorescence removal, data on the tuber yield and yield components of potatoes were collected. The marketable tuber number per hill was determined based on its size category, which was greater than or equal to 25 g and free from disease and rot. The unmarketable tuber number/hill (count) was determined by counting the tuber size category (< 25 g), including disease and insect attacks. The total tuber number was determined as the sum of the marketable tuber number and the unmarketable tuber number per hill. The marketable tuber yield (t/ha) was determined by measuring tubers that were free from damage, weighed greater than or equal to 25 g and converted into tons per hectare. The unmarketable tuber yield (t/ha) was determined by weighing diseased, green, and small (< 25 g) tubers and converting them into tons per hectare (Lung'aho *et al.*, 2007).

SAS version 9.2 statistical software (SAS, 2009) was used to perform the statistical analysis (ANOVA). The Fisher-protected least significant difference (LSD) test at a 5% level of significance was used to separate the means of significant treatment influences (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Number of marketable tubers/hill

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 (10.07) was recorded from the bud removal combined with the three earthing up treatments, whereas the minimum number of marketable tubers (2.77) was recorded from the control (Table 1). The number of tubers increased when the earthing up frequency increased along with bud removal. This could be a result of the dry matter being distributed to the tubers and the soil being prepared for healthy stolon development and early tuberization, from which healthy and excellent superior tubers are formed. This result is consistent with that of Gebregwergis *et al.* (2021), who revealed that removing flower buds avoids competition for assimilation; as a result, most of the tubers reached marketable tuber size. Chitsinde (2018) reported that earthing up three times ensured a well-drained cool environment and produced the highest marketable tuber number. Removing buds with younger leaves increased the number of marketable tubers by approximately 50% (Desta and Tsegaw, 2008). Tekalign and Hammes (2005) also reported that potatoes whose flower buds were removed presented the greatest number of marketable tubers.

Number of unmarketable tubers/hills

The number of unmarketable tubers/hills 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 (1.07) was observed. Conversely, the control group had the greatest number of unmarketable tubers per hill (6.03) (Table 1). A lack of earthing up exposes tubers to damage, resulting in undersized and deformed tubers. To promote assimilation into tubers, create ideal soil conditions for tuber initiation and development, and prevent tuber damage, it was necessary to remove the flowers and earthing up the soil three times. This finding is consistent with that of Gebregwergis *et al.* (2021), who reported that a greater number of tubers were affected by disease, and sprouting was observed in control plants. Potato

plants that are not hilled have a poor protective and stabilizing soil layer, and tubers are more vulnerable to various types of damage (Montaldo, 1984; Svubure *et al.*, 2015; Gutema, 2016; Van Dijk *et al.*, 2021; Arora *et al.*, 2023). In contrast, a nonsignificant effect of flower bud removal on unmarketable tuber numbers was reported by (Tekalign and Hammes, 2005; Desta and Tsegaw, 2008). This difference is probably related to the higher precipitation and cooler temperatures in the current study area.

Number of total tubers/hill

Earthing up frequency, flower bud removal, and their interaction had highly significant effects on the number of tubers per hill ($p<0.01$). The maximum tuber number (13.17) was obtained from the combination of bud removal with three earthing up treatments followed by the combination of bud removal with one earthing up treatment (12.13), whereas the minimum (8.8) was obtained from the control (Table 1). It is assumed that the early growth of buds, flowers and fruits consumes the food materials necessary for tuber formation. A significant increase in the percentage ranging from 6.48% to 49.66% was observed in the response to bud removal and earthing up. This could be because of the development of more stolons and early tuberization, from which tubers are formed. The greater number of tubers in all the treatments than in the control group might be related to the increased initiation of stolons, which often results in increased tuber formation, development and tuber number (Van Dijk *et al.*, 2021). Similarly, more earthing up frequencies allow for the formation of more tubers on the buried stems (Khayatnezhad and Gholamin, 2011; Chitsinde, 2018). The number of tubers per plant significantly increased when the inflorescences were removed (Nazari, 2010; Asl, 2016).

Table 1. The number of marketable and unmarketable tubers of potato is influenced by the combined effects of earthing up and inflorescence removal practices.

Treatment		Parameter		
Inflorescence removal	Earthing up	Marketable tuber numbers/hill	Unmarketable tuber numbers/ hill	Total tuber numbers/ hill
Without removal	No earthing up	2.77 ^g	6.03 ^a	8.80 ^f
	One time	5.83 ^{ef}	5.00 ^b	10.83 ^{becd}
	Two times	6.97 ^{ceb}	3.90 ^{ced}	10.87 ^{becd}
	Three times	7.67 ^{cbd}	3.83 ^{ced}	11.50 ^b
Bud removal	No earthing up	6.63 ^{ced}	4.83 ^{cb}	11.46 ^b
	One time	8.33 ^b	3.80 ^{ed}	12.13 ^{ba}
	Two times	7.73 ^{cbd}	3.20 ^e	10.93 ^{bcd}
	Three times	10.07 ^a	3.10 ^e	13.17 ^a
Flower removal	No earthing up	4.73 ^f	4.63 ^{cbd}	9.37 ^{fe}
	One time	6.17 ^{efd}	3.47 ^e	9.63 ^{fecd}
	Two times	7.90 ^{cb}	3.13 ^e	11.03 ^{bc}
	Three times	8.40 ^b	1.07 ^f	9.47 ^{fed}
Least significant difference (0.05)		*	*	*
Coefficient of variation (%)		13.47	15.71	8.61

Values marked by a different letter(s) are significantly different at $p<0.05$, according to the LSD test.

Marketable tuber yield

There was significant ($p<0.05$) variation in the effect of the combination of earthing up and flower bud removal on the marketable tuber yield. Table 2 shows that the combination of bud removal and three rounds of earthing up produced the highest marketable yield (31.49 t/ha) of all the treatment combinations. Conversely, the control plots produced the lowest marketable yield (10.7 t/ha) (Table 2). A significant increase in

the percentage ranging from 106% to 187% was observed in the response to bud removal combined with earthing up. The increased marketable yield under conditions of bud removal and three rounds of earthing up could be due to the elimination of competitor parts and favourable growing soil conditions contributing to the synthesis of more assimilates and translocate to the tubers, so most of the initiated tubers reach a marketable size and are protected from damage and greening. Consistent with the present results, Gebregwergis *et al.* (2021) reported that the highest marketable tuber yield (30.25 t/ha) was obtained by removing flowers at the bud stage and earthing up after full emergence. The removal of inflorescences resulted in an increase in the yield of marketable tubers to as high as 4.3 t/ha (Faramarzi *et al.*, 2011). Compared with the inflorescence removal treatments, the control treatment (no removal) reduced the marketable tuber yield by approximately 22% (Tekalign and Hammes, 2005). Similarly, according to Gutema (2016), the yield increased by 27.5% under three rounds of earthing up compared with that of the control. Potato hilling prevents tuber greening and maintains adequate coverage for developing tubers, helping to guarantee that tubers are more uniformly sized, well-shaped, and less likely to sustain damage, all of which are components of marketable tuber yield (Bohl and Love, 2005; Xing *et al.*, 2011; Sakadzo *et al.*, 2019). Breaking the compaction of soil layers results in increased plant exploitation of water and improved soil physical properties (reducing bulk density and increasing aggregate stability and hydraulic conductivity), which are responsible for all vegetative growth and production properties (Ati *et al.*, 2015).

Unmarketable tuber yield

The unmarketable tuber yield was significantly ($p < 0.05$) affected by the combination of earthing up and flower bud removal. Table 2 presented the highest unmarketable tuber yield (3.99 t/ha) in the control. The flower buds and tubers may compete fiercely for assimilation, which reduces assimilate partitioning to tubers, encouraging stolon elongation instead of bulking, and most of the tubers are undersized and exposed to mechanical, insect, disease, and sunlight damage. This finding aligns with the findings of Gebregwergis *et al.* (2021), who reported that combining nonearthing up and without bud removal produced a greater unmarketable tuber yield than did bud removal and earthing up. Getachew *et al.* (2012) reported that inadequate earthing up may expose tubers to sunlight, extreme heat, disease, and insect damage, all of which could have an impact on tuber quality and yield. Gutema (2016) also reported a considerably greater unmarketable yield in the control treatment than in the other treatments. In contrast to the present results, Tekalign and Hammes (2005) and Desta and Tsegaw (2008) reported that flower bud removal did not significantly influence unmarketable tuber yield.

Total tuber yield

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), whereas the control had the lowest total tuber yield (14.96 t/ha) (Table 2). The total tuber yield increase ranging from 68% to 121% was likely facilitated by the greater volume of loose soil available and the absence of competitors. This allows the synthesis and partitioning of additional dry matter into the tubers. Consequently, it helped to produce more tubers that were better in terms of quantity and size, which ultimately increased the yield. The present result is in line with those of Gebregwergis *et al.* (2021), who stated that the total tuber yield is obtained by removing buds and earthing up. Faramarzi *et al.* (2011) reported that, as a result of removing inflorescences, the total tuber yield increased by as much as 3.62 t/ha. Nazari (2010) reported that removing the inflorescence increased the potato yield by up to 2.68

t/ha (8.9%). The removal of flowers and fruit increased the total tuber yield by 2.2% and 17%, respectively, suggesting that reproductive growth inhibited the growth and development of tubers (Tsegaw and Zelleke, 2002). The removal of the reproductive parts of potato reduced the total tuber yield by 13% -19%, compared with that of plants in which the reproductive parts were not removed (Tekalign and Hammes, 2005; Asl, 2016). Gutema (2016) reported that, compared with the control, three rounds of earthing up significantly increased the total tuber yield by 24.7%. In addition, Stalham *et al.* (2007) reported that compacted soil delayed emergence, reduced rooting density and deep rooting, slowed the rate of leaf appearance and ground cover extension, and shortened the canopy cover duration of crops. Rodríguez *et al.* (2020) reported that two rounds of earthing up increased the total yield by 86.02%. Improving the physical properties and moisture content of the soil results in larger roots, more space for the roots to spread out, better nutrient absorption, better vegetative growth characteristics, enhanced photosynthesis, and greater productivity (Moreno *et al.*, 2008).

Table 2. The marketable, unmarketable, and total yields of potato tubers is influenced by the combined effects of earthing up and inflorescence removal practices.

Treatment		Parameter		
Inflorescence removal	Earthing up	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ ha)
Without removal	No earthing up	10.97 ^g	3.99 ^a	14.96 ^f
	One time	21.58 ^d e	3.26 ^{bc}	24.84 ^d
	Two times	23.46 ^{bcd}	2.48 ^{def}	25.94 ^{bcd}
	Three times	24.83 ^{bcd}	2.21 ^{ef}	27.04 ^{bcd}
Bud removal	No earthing up	16.05 ^f	3.47 ^b	19.52 ^e
	One time	22.59 ^{cd}	2.55 ^{de}	25.14 ^{cd}
	Two times	26.28 ^b	2.07 ^{efg}	28.35 ^{bc}
	Three times	31.49 ^a	1.59 ^g	33.08 ^a
Flower removal	No earthing up	18.17 ^{ef}	2.87 ^{cd}	21.04 ^e
	One time	23.59 ^{bcd}	2.53 ^{def}	26.02 ^{bcd}
	Two times	25.41 ^{bc}	2.42 ^{def}	27.83 ^{bcd}
	Three times	26.71 ^b	2.03 ^{fg}	28.74 ^b
Least significant difference (0.05)		*	*	*
Coefficient of variation (%)		9.48	11.47	8.12

Values marked by a different letter(s) are significantly different at $p < 0.05$, according to the LSD test.

CONCLUSION

The results of the present study revealed that the combined effect of the earthing up and inflorescence removal practices significantly influenced the potato tuber yield components, contributing to an increase in the total marketable tuber yield. Based on the findings of the present study, the combination of the three rounds of earthing up and removing inflorescences can be recommended for the production of potato.

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