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Assessing the potential of earthing up and integrated nutrient management on Irish potato (*Solanum tuberosum* L.) productivity in smallholder farming systems

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Abstract

Irish potato (*Solanum tuberosum* L.) is a strategic food security crop in Zimbabwe which is a good source of carbohydrates. This has created the need to increase research so as to increase potato productivity. The aim of the study was to assess the effects of earthing up and nutrient management on potato growth and yield. The study was carried out in Masvingo district of Masvingo Province. The experiment was laid out as a 2*3*3 factorial design with 18 treatments replicated three times to give 54 plots. Days to maturity were observed when potato plant leaves turned yellow and 85% of the tubers were ready for harvest at physiological maturity. Results show that plant height was not significantly affected ($p<0.05$) by earthing up. Nutrient management significantly influenced ($p<0.05$) plant height with highest (31.2 ± 0.97 cm) observed from 5 t ha^{-1} cattle manure + 50 kg ha^{-1} potassium fertiliser. Days to maturity were statistically affected ($p<0.05$) by tillage type and nutrient management. Days to maturity increased statistically ($p<0.05$) with increase in application rates of cattle manure + potassium fertiliser irregardless of tillage type. Earthing up considerably influenced potato yield, with highest yields obtained from earthing up treatments amended with cattle manure + potassium fertiliser. Combining 5 t ha^{-1} cattle manure and + 50 kg ha^{-1} potassium fertiliser have the potential to improve potato growth and yields. It can be concluded that farmers adopt the use of earthing up integrated with cattle manure + potassium fertiliser at a rate of 5 t ha^{-1} + 50 kg ha^{-1}can be a better option to improve potato production in smallholder farming systems.

Keywords

Cattle manure, Earthing up, Nutrient management, Potato, Smallholder, Farming systems

Introduction

Potato (*Solanum tuberosum.* L), is an edible plant which belongs to family Solanaceae and originated from South America where it was first grown in Peru (Quin, 2011; Sakadzo *et al*., 2020). Potatoes are used as food by many people world-wide because of its high carbohydrate content and edibility (Muhammad *et al*., 2013; Svubure *et al*., 2015). The plant produces a range of flowers which include white, pink, and red, blue or purple (Amador *et al*., 2003). Potatoes with white flowers produce tubers with white skin (Winch, 2006). When young potato tubers are green, they are like young tomatoes (Karam*et al*., 2009). Propagation of potatoes is mainly done with tuber seeds (Amador*et al*., 2003). The plant has capacity to grow up to 1m or above depending on soil fertility (Gusha, 2014). Maturity of potatoes depends on variety with many varieties maturing 120 days after planting (Kugedera, 2019).

Low soil fertility and moisture stress has affected potato production in most dry regions in Zimbabwe. Most farmers grow potato in home gardens which have poor soils due to monoculture and continual mining of

nutrients by crops grown in these gardens. Integrated nutrient management is one of the options which can be adopted by farmers (Vanlauwe *et al*., 2015; Nyambati *et al*., 2020) to improve productivity. Nutrient management has been seen as an option to increase nutrient availability, increase crop yields and reduce leaching in most arable lands (Shumba *et al*., 2020). It has been highly appreciated that the use of nutrient management through combining mineral fertilisers and cattle manure can improve soil fertility (Shumba *et al*., 2020) but soil fertility improvement alone cannot achieve higher yields. There is need to combine nutrient management with water and soil conservation techniques such as earthing up (Masvodza, 2015) to increase potato production. Potassium has been seen as one of the major nutrient needed in potato production (Kumar *et al*., 2012) to increase yield and quality of tubers. Potato production has been also decreasing due to reduced use of potassium fertiliser by poor resources farmers in many countries in Africa (Karam *et al*., 2009). Balancing potassium with other nutrients in potato production has been noted to increase growth, yield and quality tubers (Winch, 2006; Kumar *et al*., 2012).

Lack of knowledge about earthing up of potatoes (Sakadzo *et al*., 2020) and inadequate use of mineral and organic fertiliser has contributed to low potato yields in smallholder farming systems (Masvodza, 2015). There is need for proper dissemination information about these technologies to smallholder farmers as means of improving potato tuber yields. Zimbabwe has the capacity to produce higher yields of potatoes if smallholder farmers are equipped with knowledge and resources (Vita, 2015). The major objective of the study was to assess the effects of earthing up and nutrient management on potato growth and yield.

Methodology

Description of the Study Area

The study was carried out in ward 18 of Masvingo district which lies between 6°35'18" to 6°56'37"N and 38°35'60" to 38°53'36"E. The experimental site is 64 km south east of Masvingo town at geographic coordinate of 06041' N and 38043' E with elevation of 2521 masl. On average the areas receives 420 mm rainfall per annum with high rates of evapotranspiration due to high temperatures which ranges from 18 ºC (minimum) to 32 ºC (maximum). The study area is characterised by sandy loam soils which are infertile (FAO, 2016). Soil characterisation indicated that the soil had 80 % sand, 9 % clay and 11 % silt with a pH of 5.3. The soil also had 1.4 % organic carbon, 0.15 % total N and 3.87 mg kg^{-1} available phosphorous. Major crops grown include sorghum, groundnuts, maize, Bambara nuts, cowpeas, sweet potatoes, and finger millet. Nutrition gardens are also common with farmers growing crops such as cabbage, tomatoes, onion, covo, rape, sugar beans and potatoes.

Experimental design

The experiment was arranged as a 2*3*3 factorial design with two main factors which were type of tillage and nutrient management. Tillage method was divided into earthing-up and flat bed. Nutrient management was subdivided into cattle manure (0, 2.5 and 5 t/ha) and potassium fertiliser (0, 25 and 50 kg/ha). A total of 18 treatments were used, which were each replicated three times. Treatment combinations are shown in Table 1. Cattle manure used had the following properties; 1.09% total N, 0.23 % P, 0.38% K and 18.2% organic carbon as well as 18.6 % moisture content.

Table 1. Treatment combinations

Treatment No.	Treatments	Combinations
1.	earthing up	E
2.	flat bed	F
3.	2.t ha^{-1} cattle manure +earthing up	$CM_{2.5}E$
4.	5 t ha^{-1} cattle manure +earthing up	CM_5E
5.	25 kg ha^{-1} potassium +earthing up	$25KO_2E$
6.	50 kg ha^{-1} potassium +earthing up	$50KO_2E$
7.	2.5 t ha^{-1} cattle manure +25 kg ha^{-1} potassium + earthing up	$CM_{2.5}25KO_2E$
8.	2.5 t ha^{-1} cattle manure+ 50 kg ha^{-1} potassium +earthing up	$CM_{2.5}50KO_2E$
9.	5 t ha^{-1} cattle manure +25 kg ha^{-1} potassium + earthing up	CM_525KO_2E
10.	5 t ha^{-1} cattle manure + 50 kg ha^{-1} potassium + earthing	CM_550KO_2E
11.	2.5 t ha^{-1} cattle manure + flat bed	$CM_{2.5}F$
12.	5 t ha^{-1} cattle manure + flat bed	CM_5F
13.	25 kg ha^{-1} potassium + flat bed	$25KO_2F$
14.	50 kg ha^{-1} potassium +flat	$50KO_2F$
15.	2.5 t ha^{-1} cattle manure + 25 kg ha^{-1} potassium + flat bed	$CM_{2.5}25KO_2F$
16.	2.5 t ha^{-1} cattle manure +50 kg ha^{-1} potassium + flat bed	$CM_{2.5}50KO_2F$
17.	5 t ha^{-1} cattle manure + 25 kg ha^{-1} potassium + flat bed	CM_525KO_2F
18.	5 t ha^{-1} cattle manure + 50 kg ha^{-1} potassium + flat bed	CM_550KO_2F

Experimental plot layout

Each plot was measuring 3 m by 4 m and planting spacing of 0.3m x 0.9 m was used and the distance between two plots was 1.5m. In each plot, 44 tubers were sown. A total of 54 plots were used. Experimental site was ploughed using oxen drawn plough to a depth of 30 cm and seed tuber were placed to a depth of 5 cm in the soil in each plot at a spacing of 0.3 m between each seed tuber and 0.9 m between rows in same plot. Mineral fertiliser, potassium (KO_2) was applied using banding methods at full dose and variations according to treatments at plant and covered with soil before seed tuber was placed. Cattle manure was applied at full dose and variations according to treatments were used

two weeks before planting. Cattle manure was incorporated and mixed well with soil to give it time to decompose. Furrow irrigation was done from planting to harvesting and all other agronomic activities were observed during the growing season.

Data Collection

Data collected was based on objectives of the study. Growth parameters collected was plant height which was measured in cm 30 days after sowing (DAS), 60 DA, 90 DAS and at harvesting using ruler and tape measure. Plant height was measured from ground level to the tip of a plant. Twelve plants were randomly selected and marked from a net plot measured 2 m by 3 m. These plants were measured in each plot and mean calculated and used for analysis. Days to maturity were observed when potato plant leaves turned yellow and 85% of the tubers were for harvest at physiological maturity. Yield parameters were measured after harvesting each plot. Total yield was recorded for each plot and tubers were sorted into marketable and unmarketable tubers. Total yield was converted from kilogrammes to tonnes per hectare using the formula below:

$$Tuber\ yield\ (t\ ha^{-1} = \frac{yield\ (kg)}{6m^2}\ x\ 10000m^2$$

Where $6m^2$, the area of net is plot and $10000m^2$ is the area of 1 ha.

Data analysis

Collected data was recorded and processed using Ms Excel and data was statistically analysed for Analysis of variance (ANOVA) using IBM Statistical Package for Social Sciences (SPSS) version 25. Significant means were separated using least significant different (LSD) at 0.05 level of significance.

Results

Effects of nutrient management and earthing up on potato height

Results show that plant height was not significantly ($p>0.05$) influenced by earthing up. Plant height during 30 days after sowing (DAS) was significantly influenced ($p<0.05$) by earthing up and nutrient management (Figure 1). Plant height increased with increase in application rates of cattle manure and potassium fertiliser irregardless of tillage system. All treatments with cattle manure and earthing up recorded higher plant heights which were significantly different ($p <0.05$) from treatments with flat beds and cattle manure (Figure 1). Results show no significant effects ($p>0.05$) on plant height from all treatments at 90 DAS and harvesting stage (Figure 1). Plant height did not increase statistically ($p>0.05$) from 90 DAS to harvesting stage.

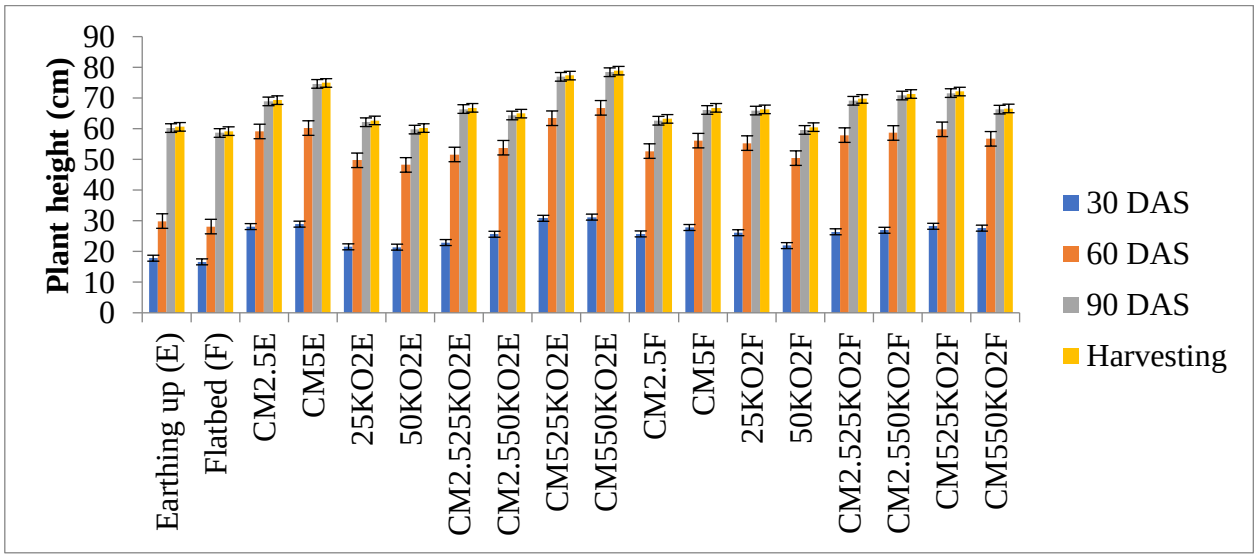

Figure 1. Effects of tillage systems and nutrient management and its interaction on plant height

Effects of earthing up and integrated nutrient management on days to maturity of potatoes

Results show that days to maturity were significantly affected ($p<0.05$) by main treatment factors. Earthing up had longer days tom maturity which was significantly different ($p<0.05$) from potatoes grown in flat beds (Table 2). Days to maturity increased with increase in application rates of nutrient management sources. Potatoes grown under cattle manure treatments had considerably ($p<0.05$) higher days to maturity compared to those grown under potassium fertiliser (Table 2).

Interactive effects of cattle manure and earthing up significantly affected ($p<0.05$) days to maturity but did not show significant difference ($p>0.05$) with interaction of flat beds and cattle manure at any application rate. Interaction of potassium fertiliser with earthing up and flat beds did not show any significant difference ($p>0.05$) but show significant effects ($p<0.05$) among treatment levels. Treatments without any nutrient amendments had the lowest days to maturity which was significantly different ($p<0.05$) between tillage systems (Figure 2). Results also show that application rate of 2.5 t ha^{-1} and 5 t ha^{-1} cattle manure did not show any significant effects ($p>0.05$) on days to maturity for both tillage systems (Figure 2). Combining cattle manure with potassium fertiliser show significant effects ($p<0.05$) on days to maturity even when combined with earthing up and flat beds.

Table 2. Effects of earthing up and integrated nutrient management on days to maturity of potatoes

Treatments	Mean ± SE days to maturity
Tillage practice	
Earthing up	115.53 ± 0.449[a]
Flat	115.27 ± 0.611[b]
P-value	<0.05
Cattle manure (t ha^{-1})	
0	112.19 ± 0.601[a]
2.5	116.74 ± 0.13[b]
5	117.27 ± 0.162[c]
P-value	<0.05
Potassium Fertiliser (KO_2) (kg ha^{-1})	
0	113.78 ± 0.864[a]
25	116.16 ± 0.412[b]
50	116.26 ± 0.417[c]
P-value	<0.05

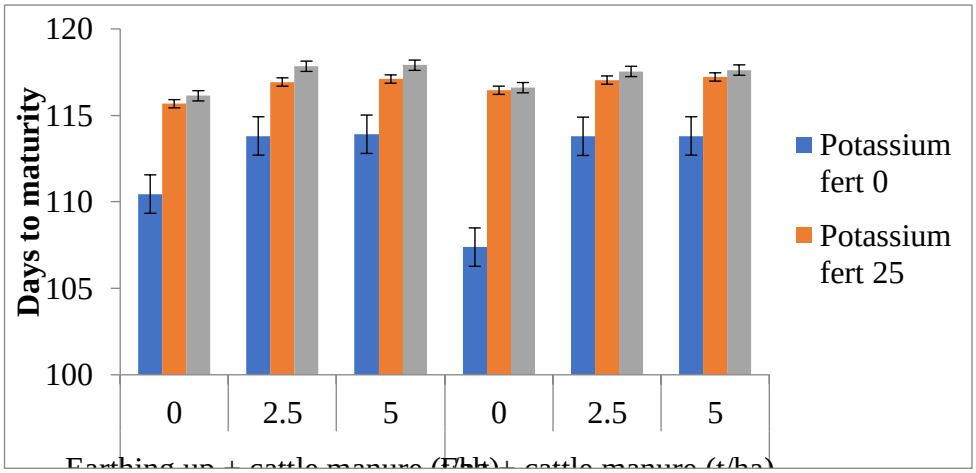

Figure 2. Interactive effects of tillage systems and nutrient management on days to maturity of potatoes.

Effects of earthing up and integrated nutrient management on days to tuber yield

Main treatment factors significantly influenced ($p<0.05$) potato tuber yields. Tuber yield was considerably different between earthing up and flat beds together with cattle manure and potassium fertiliser (Table 3). Tuber yield was highest from treatments applied 5 t ha^{-1} cattle manure which was significantly different ($p<0.05$) from all other treatments (Table 3). Increasing application rate of cattle manure and potassium fertiliser statistically increased tuber yield by 12.5 % and 6.3 % respectively. Tuber yield difference between earthing up and flat beds was 1.79 t ha^{-1} (8.6 %) higher from earthing up treatments.

Table 3. Effects of earthing up, flatbed, cattle manure and KO_2 on potato tuber yields

Treatments	Mean ± SE tuber yield
Tillage practice	
Earthing up	20.91 ± 0.953[a]
Flat	19.12 ± 1.02[b]
P-value	<0.05
Cattle manure (t/ha)	
0	14.73 ± 0.774[a]
2.5	21 ± 0.683[b]
5	24.83 ± 0.87[c]
P-value	<0.05
Potassium Fertiliser (KO_2) (kg/ha)	
0	15.8 ± 0.973[a]
25	21.41 ± 1.02[b]
50	22.84 ± 0.996[c]
P-value	<0.05

Results show that earthing up statistically influenced ($p<0.05$) tuber yield when integrated with cattle manure and potassium fertiliser compared to flat beds (Figure 3). Yield increased significantly with increase in cattle manure + potassium fertiliser. Higher yields were observed from all treatments with cattle

manure + potassium fertiliser and earthing up compared to same treatments under flat beds. Tuber yield at 5 t ha^{-1} cattle manure combined with 50 kg ha^{-1} did not show significant differences ($p>0.05$) between tillage systems (Figure 3). Application of 2.5 t ha $^{-1}$ cattle manure + 25 kg ha^{-1} potassium fertiliser significantly influenced ($p<0.05$) tuber yield (Figure 3).

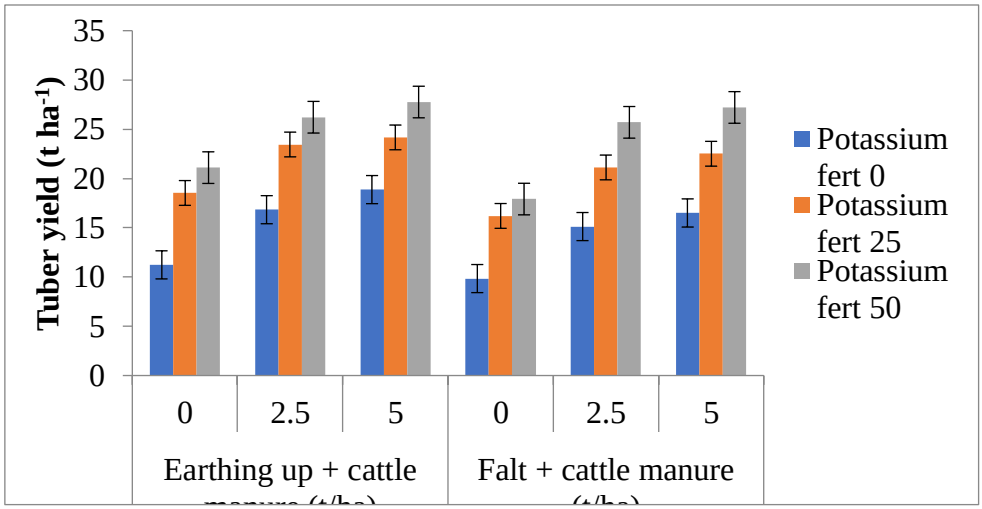

Figure 3. Interactive effects of tillage systems and nutrient management on potato tuber yields

Discussion

Effects of nutrient management and earthing up on potato height

Plant heights were low from control treatments because potato is one of the most sensitive crop to nutrient stress (Joergensen, 2012). Higher plant heights were recorded from treatments which were added cattle manure and potassium fertiliser and grown on earthing up lands. These results coincides with results by Geremew *et al.* (2007) who reported that addition of organic and mineral fertiliser stimulates vegetative growth of potatoes. Cattle manure also improves soil structure that reducing leaching of nutrients allowing potato plant to absorb maximum nutrient for growth and other processes (Israel *et al.*, 2012; Israel *et al.*, 2018; Kugedera, 2019). The results also coincides with results by Suh *et al.* (2015) who reported that potato growth rate and plant height is significantly influenced by application of high quantities of cow dung and mineral fertiliser. The results also concurs with results by Najm *et al.* (2013) who reported that combining cattle manure and mineral fertiliser increases concentration of both major and trace elements which are required for metabolic and physiological processes which increases plant growth rates. Combining cattle manure and inorganic fertiliser increases nutrient availability which promotes plant growth rates leading to increased plant height (Kumar *et al.*, 2012). Earthing up also increased soil depth which allows plants to spread their roots freely and go deep absorbing more nutrients and take up more water as earthing up conserves moisture and reduces leaching of nutrients especially where cattle manure is applied (Sakadzo *et al.*, 2020).

Effects of earthing up and nutrient management options on days to maturity and potato yield

Day to maturity were significantly influences by nutrient management options and earthing up. Potatoes grown on earthing up beds amended with cattle manure in combination with potassium fertiliser mature late. Early maturity was recorded from control treatments on flat beds and earthing up but flatbed recorded the lowest days to maturity. These results overlaps with results by Zelalem *et al.* (2009) who reported that N and P nutrients delay maturity as this promotes growth and increase in number of main stems. The results also matches with results by Nebret (2012) who reported that organic and mineral fertilisers delay physiological maturity. Cattle manure also delays physiological maturity as it improves soil structure leading to improved nutrient availability, stimulates nutrient uptake and promotes plant growth. This accords with results by Kugedera (2019) who reported increased days to maturity after using cattle manure and reduced rates of mineral fertiliser. The results also agree with work done by Amin (2018) who reported increased days to maturity with the use of cattle manure and mineral fertiliser on potatoes.

Effects of earthing up and nutrient management options on potato yield

Treatments with cattle manure, potassium fertiliser and earthing up recorded tuber yield larger than those without cattle manure. These results corresponds with results by Taheri *et al.* (2010) who reported highest tuber yield of 20 t/ha of cattle manure was applied in combination with mineral fertiliser same as the results from this study were highest tuber yield was recorded from treatments with 5 t/ha cattle manure amended with 50 kg potassium fertiliser. The results also coincides with results by Mohammad *et al.* (2013) who reported that cattle manure application balances nutrients in the soil which promotes growth rate, metabolic reactions and other processes which leads higher tuber yields produced. The use of cattle manure increases soil water retention, nutrient availability and regulates soil pH as well as temperature which delays maturity hence more days were observed. This concurs with findings by Kugedera (2019) in Zimbabwe who reported increased tuber yields after using cattle manure and reduced rates of mineral fertiliser. The results also agree with work by Amin (2018) in

Ethiopia who reported increased tuber yields with the use of cattle manure and mineral fertiliser on potatoes. Results from this project were in support of results by Sakadzo *et al*. (2020) who reported increased tuber yields with the use of earthing up potatoes in Zimbabwe (Zaka district). Results from this experiment corroborate with report by Masvodza (2015) who indicated that earthing up increased tuber yields if done on right time.

Conclusion

The results from the study indicated that plant heights were higher from treatments with a combination of cattle manure and potassium fertiliser applied to potatoes grown on earthing up. Higher rates of cattle manure and potassium fertilisers had significant effect on potato plant heights. Earthing up also significantly influenced plant growth rates and plant heights. Potatoes grown on flatbed recorded lower plant heights compared to those grown on earthing up. Days to maturity were also influenced by combination of cattle manure, potassium fertiliser and earthing up. Potatoes grown on earthing up mature late compared to potatoes grown on flatbed. The results also show that days to maturity were influenced by nutrient management and earthing up which also had a significant effect on tuber yields. Potato plants which mature late had the highest tuber yield compared to those which mature earlier. Application of cattle manure in combination with potassium fertiliser also significantly increased tuber yields irregardless of being grown on earthing up or flat beds.

Recommendations

Farmers are recommended to grow potatoes on earthing up beds and use a combination of cattle manure and potassium fertilisers to maximise yields but the use of larger quantities of mineral fertiliser are not recommended as they cause soil acidity. Farmers are recommended to use 5 t/ha cattle manure or more as cattle manure controls land degradation and improves soil biophysio-chemical properties.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal.

All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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