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Evaluating the effects of integrated nutrient management and insitu rainwater harvesting on maize production in dry regions of Zimbabwe

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Abstract

Moisture stress and inherent soil fertility caused huge loss in crop production. The use of insitu rainwater harvesting and integrated nutrient management can improve soil health and crop production. The Objective of the study was to evaluate the effects of integrated nutrient management and insitu rainwater harvesting on maize productivity in dry regions of Zimbabwe. Experiment was laid out as a factorial with three main factors which include cattle manure, insitu rainwater harvesting and inorganic manure. Data was collected from harvested net plot to obtain maize grain and stover yields for two growing years. Data was analysed based on analysis of variance using IBM SPSS version 25 and means which were significant different were separated using least significant different. The results show that there was significant different ($p<0.001$) between all treatments combinations. Results recorded higher maize grain yields from100 kg N/ha + 5 t/ha cattle manure treatments for both seasons. High grain yield of 3.41± 0.042 t/ha was recorded from $ZN_{100}C_5$ treatments during the second year and highest maize grain yield of 3.11 t/ha was recorded in first year. There was significant different ($p<0.001$) on the effects of combination of cattle manure and inorganic fertiliser alone on maize grain yields. Control treatments recorded lowest maize (1.17 ± 0.031 t/ha) and stover yields of 4.36 ± 0.046 t/ha. Results indicated significant different ($p<0.001$) on the effects of insitu rainwater harvesting, cattle manure and inorganic manure on maize stover yields. The use of integrated nutrient management and insitu rainwater harvesting has the capacity to increase maize yields and reduce food insecurity in dry regions of most sub-Saharan African countries.

Keywords: Cattle manure, Integrated nutrient management, Maize stover, Insitu rainwater harvesting, Dry regions

Introduction

Increased soil moisture stress and inherent soil fertility has been major causes of poor maize production in dry regions of Zimbabwe (Motsi et al., 2019; Nyagumbo et al., 2019). Erratic and low rainfall in arid and semi-arid regions contributed to poor soil moisture and low crop production in dry regions (Mugwe et al., 2019; Shumba et al; 2020; Muchai et al., 2020). Combination of low rainfall and low nutrient status has significantly affected crop production in most dry regions in African countries (Yazar and Ali, 2016; Mugwe et al., 2019; Shumba et al; 2020). Erratic rainfall and frequent dry spells affected soil moisture which lead to poor maize growth due to reduced nutrient absorption. Climatic variability, long mid-season droughts and dry spell during growing season reduced crop production in dry regions (Nyagumbo et al., 2020).

Maize (*Zea mays* L.) is ranked first in Zimbabwe and is used a one of staple food in African countries. It is widely grown in all regions in Zimbabwe. Integrated nutrient management and insitu rainwater harvesting can be one of the best options to increase maize production in dry regions of Zimba-

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bwe. Integrated nutrient management increases nutrient availability to plant root zone (Vanlauwe *et al*., 2010; Vanlauwe et al., 2014; Shumba et al., 2020). The use of insitu rainwater harvesting techniques increases soil moisture content, reduce soil erosion and improve water availability in the plant root zone (Nyamadzawo *et al*., 2013; Mudatenguha *et al*., 2014). The use of integrated nutrient management and insitu rainwater harvesting techniques has been successfully used by smallholder farmers to improve soil fertility and maize productivity (Mugwe, 2007; Mugwe et al., 2019). Integrated nutrient management option increases nutrient availability in the plant root zone (Mugendi *et al*., 2004; Vanlauwe *et al*., 2010) and this improves both plant growth and nutrient absorption. The use of rainwater harvesting techniques such as tied ridges and *zai* pits harvest and store water for later use by crops (Milkias *et al*., 2018) which if amended with organic and inorganic fertiliser leads to increased crop yield. The use of integrated nutrient management has been used by smallholder farmers for many years (Rusinamodzi et al., 2011; Nyamangara et al., 2013; Shumba et al., 2020) in Zimbabwe to improve crop production. The use of insitu rainwater harvesting and integrated nutrient management has the capacity to improve maize production in dry regions across Africa. The objective of study was to evaluate the effects of integrated nutrient management and insitu rainwater harvesting on maize production in dry regions of Zimbabwe.

Materials and Methods

Study area

The study was carried out in ward 4 of Masvingo district which is located between 20º 2´ 43″ S and 30º 40´ 29″ E. The area is characterised by deep sandy loam soils which are moderately fertile soils associated with *Terminalia-Combretum* species with few Mopane trees on the river banks of Shashe River. Farming in this area has immensely contributed to the siltation and pollution of Shashe River which negatively affect Muzhwi Dam. The area receives 450-500 mm of rainfall per annum on average and temperatures ranges from 18 º C minimum and 32 ºC maximum. This area is made up of small scale commercial farms and few smallholder farmers in the adjacent of the ward.

Experimental Design and Treatments

The experiment was laid out as Randomised Complete Block Design with three main factors namely cattle manure, inorganic fertiliser and water harvesting techniques (tied ridges and zai pits). Each treatments was replicated three times. Cattle manure was applied at a rate of 0 and 5 t/ha, inorganic fertiliser at a rate of 0 kg N/ha, 50 kg N/ ha and 100 kg N /ha and with tied ridges and *zai* pits as rain water harvesting technique. Tied ridges were spaced 2 metres in width and ridges were 35 cm in height. Cross ties were placed at 10 m intervals at a height of 25 cm to prevent damages caused by flowing water. Zai pits were dug to a depth of 20 cm and width of 30 cm in plots. Maize plants were spaced at 0.9 m between rows and 0.3 m within the row to achieve a plant population of 37 037 plants/ ha. Plots used were having measurements of 10 m by 7 m and a net plot of 4.5 m by 4.5 m was marked in each experimental plot.

Land preparation

The trials were established at one site during the short rain season (December 2017 to March 2018 and December 2018 to March 2019) and a short season variety SC 403 was used under supplementary irrigation. Land was ploughed using ox-drawn plough to a depth of 36 cm. Ridges were made using the plough and ties were placed using hand hoe. Seeds were spaced at 0.9 m by 0.3 m. Zai pits were done on lad which was not ploughed to make sure their effectiveness can be evaluated. Cattle manure was applied at before planting in opened farrows and zai pits using two rates of 0 and 5 t/ha. Fertilizers were pre-weighed for each plot before going to the field and applied using dollop cups to ensure uniform distribution within the plot. Weeding was done twice using hand hoe weeding.

Table 1. Experimental treatments used

No.	N kg/ha	Cattle manure (t/ha)	Rainwater harvesting	Treatment combinations
1	0	0	Tied Ridge	TN_0C_0
2	0	5	Tied Ridge	TN_0C_5
3	50	0	Tied Ridge	$TN_{50}C_0$
4	50	5	Tied Ridge	$TN_{50}C_5$
5	100	0	Tied Ridge	$TN_{100}C_0$
6	100	5	Tied Ridge	$TN_{100}C_5$
7	0	0	Zai pit	ZN_0C_0
8	0	5	Zai pit	ZN_0C_5
9	50	0	Zai pit	$ZN_{50}C_0$
10	50	5	Zai pit	$ZN_{50}C_5$
11	100	0	Zai pit	$ZN_{100}C_0$
12	100	5	Zai pit	$ZN_{100}C_5$

Data collection

Harvesting was done using hand hoe to cut maize in the net plot and a sharp knife was used to remove husks. All cobs from each plot/ treatment were collected and separately placed in different sacks which were well labelled.

Grain and stover yield

Grain and stover yields were measured from plants harvested net plots 120 days after planting. Ears and stover were sun dried for 7 days to allow drying. Ears were threshed and weighed at 12 % moisture content. Grain yields was then converted from kilogrammes per net area to tonnes per hectare (t/ha).

Grain yield (kgha^{-1}) = $\dfrac{Yield\ in\ the\ treatment}{Harvest\ area} \times 10000$

Where harvest area = 20.25 m^2 and 10000 is equivalent to area of one hectare.

Stover yields was also measured from the net plot after cutting them into small pieces and weigh using a digital scale and convert the mass to kg ha^{-1}.

Stover yield (kgha^{-1}) = $\dfrac{Yield\ in\ the\ treatment}{Harvest\ area} \times 10000$

Where harvest area = 20.25 m^2 and 10000 m^2 is equivalent to area of one hectare.

Data analysis

Data was processed using Microsoft excel and analysed for analysis of variance (ANOVA) using IBM SPSS version 25. Means were separated using least significant different (LSD) at 0.05 to identify means which were significantly different.

Results and discussion

Effects of integrated nutrient management and tied ridges on grain yields

The results show that there was significant different ($p<0.001$) between all treatments combinations. Results recorded higher maize grain yields from100 kg N/ha + 5 t/ha cattle manure treatments for both seasons. High grain yield of 3.41 t/ha was recorded from $ZN_{100}C_5$ treatments during the second year and highest maize grain yield of 3.11 t/ha was recorded in first year. These results were in agreement with results by Muna-Mucheru et al. (2007) who reported that cattle manure releases nutrients slowly and supply these nutrients throughout the season to crops. Milkias et al. (2018) also reported that the use of insitu rainwater harvesting in combination with mineral fertiliser and cattle manure produces higher maize grain yields. Combining cattle and inorganic manure in combination with insitu rainwater harvesting retains a lot of moisture which boost absorption of nutrients making them available to plants for growth. High soil moisture and nutrient availability in the plant root zone promotes high grain yields.

Table 2. Interactive effects of integrated nutrient management and insitu rainwater harvesting on grain yields

Treatment combinations	Mean Grain yield (t/ha)	
	Farming Seasons	
	Firs year (t/ha)	Second year (t/ha)
TN_0C_0	1.20 ± 0.025	1.24 ± 0.025
TN_0C_5	1.62 ± 0.035	1.72 ± 0.03
$TN_{50}C_0$	1.56 ± 0.045	1.65 ± 0.015
$TN_{50}C_5$	2.11 ± 0.032	2.13 ± 0.026
$TN_{100}C_0$	1.92 ± 0.025	1.9 ± 0.02
$TN_{100}C_5$	3.06 ± 0.067	3.11 ± 0.015
ZN_0C_0	1.17 ± 0.031	1.17 ± 0.031
ZN_0C_5	1.78 ± 0.055	1.75 ± 0.042
$ZN_{50}C_0$	1.69 ± 0.025	1.75 ± 0.025
$ZN_{50}C_5$	2.31 ± 0.036	2.42 ± 0.035
$ZN_{100}C_0$	2.03 ± 0.05	2.02 ± 0.068
$ZN_{100}C_5$	3.18 ± 0.06	3.41 ± 0.042
P-value	<0.001	<0.001

Control treatments (TN_0C_0 and ZN_0C_0) recorded the lowest grain yield for both season which were an average of 1.20 ± 0.025 t/ha and 1.24± 0.025 t/ha for tied ridges and 1.17 ± 0.031 for zai pits the two farming seasons respectively. On average treatments without cattle manure had lower maize grain yields compared to those with cattle manure. All treatments with 5 t/ha cattle manure performed above 2.0 t/ha for both seasons with higher yields of 3.41 1.17 ± 0.042 t/ha obtained from a combination of Zai pits + 100 kg N/ha + 5t/ha cattle manure treatments in the second year. The results were 6.7% higher than same treatment in first year and 8.8 % higher than same treatments with tied ridges in 2019. The results coincides with results by Muchai et al. (2020) who reported that zai pits were amended with soil fertility options to improve maize, sorghum and millet in Kenya. The results were similar from findings by Kilasara et al. (2015) who reported improved sorghum yields from combination of insitu rainwater harvesting and integrated nutrient management options in Tanzania. Higher maize yields from treatment with mineral fertiliser and cattle manure concur with results by Shumba et al. (2020) who reported increased maize grain yields in Zimbabwe after combining cattle manure and mineral fertiliser. Treatments with 5 t/ha cattle manure and 50 kg N/ha recorded 2.31 ± 0.036 t/ha and 2.42 ± 0.035 t/ha from Zai pits treatments and were second highest yields for both farming seasons as indicated in Table 2. The results were in agreement with findings by Muna-Mucheru et al. (2007) who indicated that the use of cattle manure increases nutrient availability which promote plant growth and increase grain yields. These results also coincide with results by Motsi et al. (2019) who reported increased maize grain yields after combining cattle manure and Nitrogen fertiliser. The results show that there was significant different ($p<0.001$) for both two farming years and indicated that the effects of Zai pits and tied ridges in combination with integrated nutrient management were significantly different.

Results also show that the interactive effects of cattle manure and inorganic manure significantly affected maize grain yields. There was significant different ($p<0.001$) on the effects of combination of cattle manure and inorganic fertiliser alone on maize grain yields (Table 2). Higher results (3.21 t/ha and 3.26 t/ha) were obtained from combination of 5 t/ha cattle manure and 100 kg N /ha from both seasons respectively. Results show no significant different between combination of 5 t/ha cattle manure + 50 kg N/ha from treatments with 100kg N/ha only for both years (Table 2). These results coincides with findings by Coulibaly (2015) who reported higher pearl millet yields after combining mineral fertiliser and cattle manure. The findings also concur with results by Shumba et al. (2020) who reported higher yields form a combination of mineral fertiliser and cattle manure on maize grain yields. Nyamangara et al. (2005) reported that cattle manure contains both macro and micro-nutrients which improves grain yields and soil properties. This was also affirmed by Shumba et al. (2020) and Kilasara et al. (2015) who all reported that cattle manure improves water retention and releases nutrients slowly in the plant root zone which later improve plant growth and yields.

Table 3. Interactive effects of cattle manure and inorganic manure on maize grain yields

Cattle manure (t/ha)	Inorganic manure (kg N/ha)	First year Mean grain yield (t/ha)	Second year Mean grain yield (t/ha)
0	0	1.19^{f}	1.21^{e}
	50	1.63^{de}	1.7^{d}
	100	1.98^{bc}	1.96^{bc}
5	0	1.7^{d}	1.73^{d}
	50	2.21^{b}	2.27^{b}
	100	3.12^{a}	3.26^{a}
	P-value	0.001	<0.001

Interactive effects of insitu rainwater harvesting and inorganic manure show significant different ($p=0.043$) between treatments of tied ridges and zai pits in combination with inorganic manure in the first year. During the second year, results show significant different ($p<0.001$) effects between all treatments. Highers yields (2.61 t/ha and 2.71 t/ha) were obtained from combination of zai pits and 100 kg N/ha for both years respectively. These results were 4.6 % and 7.7% higher than results from combination of tied ridges and 100 kg N/ha from same years respectively. All treatments with 0 kg N/ha recorded low yield which were not significantly different as indicated in Table 3. The results concur with findings by Coulibaly (2015) who reported high pearl millet yields from a combination of zai pits with inorganic manure compared with tied ridges with inorganic manures. These results also coincide with results by Milkias et al. (2018) who reported that combining insitu rainwater harvesting with mineral fertiliser increases maize grain yields.

Table 4. Interactive effects of insitu rainwater harvesting and inorganic manure on maize grain yields

Insitu rainwater harvesting	Inorganic manure (kg N/ha)	First year Mean grain yield (t/ha)	Second year Mean grain yield (t/ha)
Tied ridges	0	1.41^{e}	1.48^{e}
	50	1.84^{cd}	1.89^{d}
	100	2.49^{ab}	2.5^{b}
Zai pits	0	1.47^{e}	1.46^{e}
	50	2.0^{c}	2.08^{c}
	100	2.61^{a}	2.71^{a}
	P-value	0.043	<0.001

Results from the study indicates that cattle manure significantly affect grain yields. The use of 5 t/ha cattle manure increased maize grain yields by 31 % under tied ridges for both seasons. Maize grain yield increased with 32.6 % and 34.8% under zai pits (Table 4). This show that combining zai pits and cattle manure produces higher yields. These results were similar to results by Mudatenguha et al. (2014) who reported higher maize yields under zai pits and organic manure. This concurred with results by Coulibaly (2015) who reported increased pearl millet yields under zai pits and 2500 kg/ha cattle manure.

Table 5. Interactive effects of insitu rainwater harvesting and cattle manure on maize grain yields

Insitu rainwater harvesting	Cattle manure (t/ha)	First year Mean grain yield (t/ha)	Second year Mean grain yield (t/ha)
Tied ridges	0	1.56^{cd}	1.6^{c}
	5	2.26^{ab}	2.32^{ab}
Zai pits	0	1.63^{c}	1.65^{c}
	5	2.42^{a}	2.53^{a}
	P-value	0.006	<0.001

Sole effects of inorganic manure, cattle manure and rainwater harvesting show that, use of 100 kg N/ha produces higher maize grain yields compared to all levels of cattle manure and inorganic manure. Zai pits alone produces higher yields than the use of tied ridges (Table 5). This supports the results produced under interaction of organic and inorganic manure in combination with zai pits which produces higher results. This was in support with results by Mudatenguha et al. (2014) who reported high yields from zai pits. The results also concur with results by Kilasara et al (2015) and Milkias et al. (2018) who reported higher yields from using inorganic fertiliser in sorghum production and maize production respectively. These results were in support of findings by Shumba et al. (2020) who indicated that mineral fertiliser produces higher maize grains when used alone. Results show no significant different (p=0.204) between the effects inorganic manure and season on maize grain yields. This show that inorganic manure was not affected by seasonal changes. Results also indicate significant different (p=0.005) on the effect of cattle manure and season on maize grain yields.

Table 6. Sole effects of inorganic manure, cattle manure and rainwater harvesting on maize grain yields

Inorganic manure (kg N/ha)	First year Mean grain yield (t/ha)	Second year Mean grain yield (t/ha)
0	1.44	1.47
50	1.92	1.99
100	2.55	2.61
P-value	<0.001	<0.001
Cattle manure (t/ha)		
0	1.6	1.62
5	2.34	2.42
P-value	<0.001	<0.001
Rainwater harvesting		
Tied ridges	1.91	1.96
Zai pits	2.03	2.09
P-value	<0.001	<0.001

Effects of integrated nutrient management and tied ridges on stover yields

The results show positive correlation between grain and stover yields for all treatments used in the experiment. Higher stover yields were recorded from treatment combinations of 100 kg N/ha and 5t/ha cattle manure ($TN_{100}C_5$) which recorded highest stover yields of 5.78 ± 0.11 t/ha and 5.79 ± 0.075 t/ha for the year 1 and 2 respectively. Integrated nutrient management of cattle and inorganic manure increased stover yields. The results concur with findings by Vanlauwe et al. (2010) and Mugwe et al. (2019) who reported that integrated nutrient management improves plant growth and yields. Combining integrated nutrient management with insitu rainwater harvesting boost crop production and yields. The results were in support of findings by Kanonge *et al.,* (2009) who reported significant increase of maize grain and stover yields after using cattle manure and mineral fertiliser. The results were also supporting findings by Bationo *et al*., (2004); Kokerai and Kugedera (2019) and Shumba et al. (2020) who all reported increased maize yields after using integrated nutrient management options of cattle manure and mineral fertiliser. The results were also in support of reports by Kugedera *et al*., (2018) who indicated high sorghum stover yields after using insitu rainwater harvesting, mineral fertiliser and cattle manure.

The results show significant different ($p<0.001$) on the effect of cattle manure, inorganic manure and rainwater harvesting on maize stover yields. The use of cattle manure, inorganic manure and insitu rainwater harvesting improves soil structure, water retention and nutrient availability which increased plant growth and yields. The results concur with findings by Nyamangara et al. (2005) who reported that cattle manure improves soil structure hence more effective to increase crop productivity. This was also affirmed by Tirol-Padre et al. (2007) who indicated significant increase in stover yields after using cattle manure and mineral fertiliser. Mudatenguha et al. (2014) also reported that the use of insitu rainwater harvesting in combination with organic and inorganic fertiliser increase grain and stover yields. Results from this study were also in agreement with results by Kilasara et al. (2015) who reported increased sorghum stover after combining insitu rainwater harvesting with farm yard manure and mineral fertiliser. Findings from this study also support results by Milkias et al. (2018) who reported increased maize stover yields after using insitu rainwater harvesting and integrated nutrient management.

Table 7. Interactive effects of integrated nutrient management and tied ridges on stover yields

Treatment combinations	Mean Stover yield (t/ha)	
	Farming Seasons	
	Firs year (t/ha)	Second year (t/ha)
TN_0C_0	4.39 ± 0.01^{ef}	4.36 ± 0.046^{ef}
TN_0C_5	4.84 ± 0.055^{de}	4.85 ± 0.038^{de}
$TN_{50}C_0$	4.81 ± 0.051^{de}	4.82 ± 0.025^{de}
$TN_{50}C_5$	5.22 ± 0.051^{bc}	5.29 ± 0.021^{bc}
$TN_{100}C_0$	4.99 ± 0.03^{cd}	4.97 ± 0.03^{cd}
$TN_{100}C_5$	5.78 ± 0.11^{a}	5.79 ± 0.075^{a}
ZN_0C_0	4.48 ± 0.026^{e}	4.47 ± 0.055^{e}
ZN_0C_5	4.83 ± 0.04^{cd}	4.89 ± 0.035^{cd}
$ZN_{50}C_0$	4.93 ± 0.04^{cd}	4.99 ± 0.025^{cd}
$ZN_{50}C_5$	5.39 ± 0.026^{bc}	5.45 ± 0.026^{ab}
$ZN_{100}C_0$	5.03 ± 0.053^{c}	5.05 ± 0.055^{c}
$ZN_{100}C_5$	5.5 ± 0.015^{b}	5.54 ± 0.015^{ab}
P-value	0.001	<0.001

Table 8. Sole effects of inorganic manure, cattle manure and rainwater harvesting on maize grain yields

Inorganic manure (kg N/ha): A	First year Mean stover yield (t/ha)	Second year Mean stover yield (t/ha)
0	4.64	4.64
50	5.09	5.13
100	5.33	5.34
P-value	<0.001	<0.001
Cattle manure (t/ha): B		
0	4.77	4.78
5	5.26	5.3
P-value	<0.001	<0.001
Rainwater harvesting: C		
Tied ridges	5.01	5.01
Zai pits	5.03	5.07
P-value	0.178	0.001
Interaction		
AB	<0.001	<0.001
AC	<0.001	<0.001
BC	0.001	<0.001
ABC	0.001	<0.001

The results indicates that cattle manure can significantly cause a positive effect on stover yields because it supplies both macro and micronutrients. Cattle manure also improves soil structure, water retention and regulate soil pH to improve crop growth and nutrient absorption by plants (Tirol-Padre *et al*., 2007; Motsi *et al*., 2019). Generally, year 2 had higher stover yields compared to year 1 and these results were significantly different (p<0.001). The findings also show that TN_0C_0 treatments recorded lower stover yields to all other treatments except the control treatments only for both seasons and the yields were 24% and 24.7 % less than the highest stover yield for the year 1 and year 2 respectively. The results were significantly different as shown in Table 6.

Results also show significant different (p=0.001) on the effect of rainwater harvesting alone on maize stover yields in year 2 and no significant different (p=0.178) in year 1. Combining rainwater harvesting and cattle manure show significant different (p<0.001) for both years on maize stover yields. Results in Table 7 show that combining rainwater harvesting, cattle and inorganic manure significantly increase maize stover yields irregardless of the season. High stover yields were obtained from the use of 100 kg N/ha. This was supporting indications by Shumba et al. (2020) and Nyamangara et al. (2005) who reported that inorganic fertiliser quickly releases nutrients in the soil which will be immediately absorbed by plants to increase plant growth. These results were also in support of findings by Kanonge et al. (2015) who reported increased legume yields after combining cattle manure and mineral fertiliser in smallholder farming systems in Zimbabwe.

Conclusion

The use of integrated nutrient management and insitu rainwater harvesting has the capacity to increase food security in smallholder farming systems and increase maize productivity. Cattle manure decomposes slowly in the soil releases nutrients throughout the growing season and this facilitate high microbial activity which improves soil structure. Insitu rainwater harvesting harvest water to improve soil moisture content, reduce surface runoff and leaching of nutrients. This increase nutrient availability in the plant root zone and retains a lot of moisture which crops can use during dry spell and drought periods. Use of zai pits in combination with integrated nutrient management recorded higher maize yields and this can be adopted by farmers although the method is labour intensive during first year in preparing the pits. Maize grain yields varied with seasons and this can have been caused by management and amount of rainfall received during these two seasons. Farmers can adopt integrated nutrient management and insitu rainwater harvesting and use it on small plots to maximise yields and reduce labour requirements.

Compliance with Ethical Standards

Conflict of interest

The authors declare that for this article they have no actual, potential or perceived the conflict of interests.

Author contribution

The contribution of the authors 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.

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