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Effect of Plant Density on Growth and Yield of Maize [*Zea mays* (L.)] Hybrids at Luyengo, Middleveld of Eswatini

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Authors' contributions

This work was carried out in collaboration among all authors. Author MM designed the study and performed the statistical analysis. Author TT wrote the first draft of the manuscript and managed the analyses of the study. Author NS managed the literature searches and wrote the protocol. All authors read and approved the final manuscript.

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ABSTRACT

Maize is staple food and the most cultivated crop in Eswatini. However, its yield is very low partly due to use of non-optimum plant density for different maturity group maize varieties. Thus, an experiment was conducted at Luyengo, Middleveld of Eswatini during the 2018/2019 cropping season. The experiment consisted of factorial combinations of two varieties [SC 403 (early maturing) and PAN 53 (medium maturing)] and three plant densities (44444 plants/ha, 50000 plants/ha, 57143 plants/ha) in randomised complete block design in three replications. Results showed that medium maturing maize variety PAN 53 had higher leaf area, leaf area index, plant height, cob height (139.4 cm), days to 90% anthesis (69 days), dry biomass, thousand kernels mass (374.0 g), grain yield (43.1 t/ha), and stover mass (59.8 t/ha) than the early maturing variety SC 403. With respect to the effect of plant density, as the plant density increased from 44444 to 57143 plants/ha, leaf area, dry biomass at V12 and R5 growth stages, number of cobs per plant, grain yield, stover mass, and thousand kernels mass (g) were decreased while the leaf area index was increased. The interaction effects of variety and plant density were not significant on all the parameters recorded. Thus, it can be concluded that medium maturing variety PAN 53 and plant

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density of 44444 plants/ha (90 cm × 25 cm) are best options to maximum productivity of maize in the study area. However, it is recommended that the experiment be repeated with inclusion of more varieties and densities to reach at more conclusive recommendation.

Keywords: Maize hybrids; PAN 53; plant density; SC 403; yield.

1. INTRODUCTION

Maize is the third most important cereal crop after wheat and rice in the world in terms of area and production [1]. In Eswatini, maize is the staple food and the most cultivated crop in the country. It is mainly grown by farmers of rural households in the communal Swazi Nation Land (SNL) and constitutes 95% of the country s cereal production. Yields vary among the four agro- climatic zones in Eswatini, with the highest yields obtained in the Highveld (1.55-4.90 t/ha) and moist Middleveld (1.21- 4.20 t/ha) [2]. However, the maize grain yield obtained in Eswatini is very low as compared to the world average (5.75 t/ha) and southern Africa average (5.786 t/ha) [3]. The major reasons for low yield of maize in Eswatini are: Erratic rainfall associated with climate variability, fall armyworm infestation, soil acidity and associated phosphorus deficiency, and use of non-optimum agronomic practices.

Plant density is one of the most important cultural practices determining grain yield, as well as other important agronomic attributes of maize. Plant density and arrangement of plants in a unit area greatly determine resource utilization (such as light, nutrients and water), the rate and extent of vegetative growth and development of crops, competitive ability of crops with weed, soil surface evaporation, light interception, lodging and development of an optimum number of fruiting sites in a crop canopy [4]. Moreover, grain yield of maize is more affected by variations in plant population density than of other members of the grass family because of its low tailoring ability [5,6]. Hence, optimum plant density of maize will lead to effective utilization of soil moisture, nutrients, and sunlight resulting in high yield [7].

However, the optimum plant population of maize depends on several factors such as fertility status of the soil, soil moisture, varieties, and cultural practices [8]. For instance, Jones [9] recommended higher densities up to 75,000 plants ha^{-1} in humid or irrigated areas when optimum production is required. On the other hand, Chinyere [10] reported that maize plant population for maximum economic grain yield varied from 30,000 to 90,000 plants per ha.

Hybrids developed in recent years are able to withstand higher plant density levels than older hybrids [11]. The ability of newer hybrids to tolerate increased crowding stress can be attributed to lower lodging frequencies, higher N use efficiency [12], higher leaf photosynthesis rates, and more efficient canopy photosynthesis and stomatal conductance during water stress [13]. These variations in recommended density of maize with variations in soil type, climate and varieties, indicate the need to develop location and variety specific recommendation of plant density.

However, in Eswatini, maize spacing recommendation of 44,444 plants ha^{-1} (90 cm×25 cm) has been used since long time [14], without taking into account the numerous morphological and maturity differences that exist among newer maize hybrids as well as the existence of soil and climatic differences.

Thus, the objectives of this study were to determine the effects of plant density on growth, yield components and yield of maize hybrids; and to identify the plant density that maximises the productivity of different maturity group maize hybrids in the Middleveld Agro-ecological zone of Eswatini.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The experiment was carried out at the University of Eswatini, Faculty of Agriculture at Luyengo. Luyengo is located in Middleveld agro-ecology at 26.34° S and 31.12° E at an altitude of 750 m above sea level, and the mean annual temperature is 18°C and annual rainfall is between 800 mm to 1000 mm. The soil type is an *Oxisol* of the Malkerns soil series.

2.2 Treatments and Experimental Design

The experiment consisted of factorial combinations of two varieties [SC 403 (early maturing) and PAN 53 (medium maturing)] and three plant densities [44444 plants/ha (90 cm × 25 cm), 50000 plants/ha (80 cm×25 cm), 57143 plants/ha (70 cm × 25 cm)] in randomised complete block design in three replications. The size of each plot was 4 rows × 0.9 m × 4 m (14.4 m^2) for 90 cm row spacing, 4 rows × 0.8 m × 4 m (12.8 m^2) for 80 cm row spacing, and 4 rows × 0.7 m × 4 m (11.2 m^2) for 70 cm row spacing.

2.3 Experimental Field Management

The experimental field was ploughed and disked to a fine tilth with tractor and the plots were levelled manually. According to the design, a field layout was made and each treatment was assigned randomly to the experimental units within a block. After seed beds were levelled, rows were made and then maize varieties were planted at the rate of one seed per hill on the 22^{nd} November 2018. Compound fertiliser 2:3:2 (22), consisting of 6.3% N, 9.4% P and 6.3% K was applied as basal dressing at the rate 300 kg/ha. Gap filling was done on the 8^{th} of December 2018, a week after first emergence. Limestone ammonium nitrate (LAN) containing 28% nitrogen was side dressed at the rate of 100 kg/ha to all treatments at knee height growth stage of maize. Weeding was carried out manually as required.

2.4 Data Collected

Plant height, leaf area index and aboveground dry biomass were measured at three growth stages, *i.e.* V6 (when the collar of the sixth leaf was visible), V12 (when the collar of the 12^{th} leaf was visible) and R5 (when cobs showed a dark red color) from randomly taken three plants per plot using a 5 m tape and the average of the three plants was recorded. Leaf area was determined by measuring the length and maximum width of all the leaves in three plants per plot. Then the leaf area per plant was calculated using the formula: leaf area = average leaf length × average leaf width × 0.75 × average number of leaves per plant as described by Dwyer and Stewart [15]. Leaf area index was calculated using the ratio of leaf area per plant over ground area occupied by the plant, *i.e*. 2250 cm^2 for 90 cm × 25 cm spacing, 2000 cm^2 for 80 cm × 25 cm spacing, and 1750 cm^2 for 70 cm × 25 cm spacing.

The aboveground dry biomass weight was determined from sample of three plants per plot after oven drying to constant weight and the values were converted to t/ha. Days to 90% anthesis was recorded as number of days from planting to the period when 90% of the plants in each plot produced tassel with visual observation.

Number of cobs per plant was determined by dividing the number of cobs per plot by the number plants per plot. Thousand kernels mass (g) was determined by weighting 1000 randomly taken sun dried kernels from bulk of threshed kernels from each plot area and then the mass was adjusted to 12.5% moisture level. The stover mass was determined by weighing the aboveground biomass per plot area at harvest after sun drying for five days and it was expressed in t/ha. The grain yield (t/ha) was determined by weighed the grain yield using a sensitive balance after shelling the sundried aboveground biomass and the grain yield was adjusted to 12.5% moisture content. Finally, the harvest index was calculated as the ratio of grain yield to the total aboveground dry biomass yield per plot.

2.5 Data Analysis

Data collected were subjected to analysis of variance by using GenStat statistical software 18^{th} edition [16]. The mean separation was made using the Least Significance Difference (LSD) test at 5% level of significance.

3. RESULTS

3.1 Leaf Area and Leaf Area Index

There was no significant difference between the varieties in leaf area and leaf area index. However, medium maturing maize variety PAN 53 had higher leaf area and leaf area index at V6 and V12 growth stages (Table 1). On the other hand, the effect of plant density was significant ($P<0.05$) on the leaf area at V12 and R5 growth stages and on leaf area index at R5 growth stage. At all maize growth stages, the leaf areas were decreased while the leaf area indices were increased with increasing plant density from 44444 to 57143 plants/ha (Table 1). The interaction effects of varieties and plant density were not significant on leaf area and leaf area index of maize.

3.2 Plant Height and Cob Height

Varieties showed significant ($P<0.05$) difference in plant height at V12 growth stage, while the differences in plant height at V12 and R5 growth stages and cob height were not significant. Variety PAN 53 had higher plant height than variety SC 403 at all the growth stages and higher cob height (139.4 cm) (Table 2). The effect of plant density also was not significant on plant height at all the growth stages and on cob height. The plant height at V6 showed increasing trend with increasing plant density (Table 2). The interaction effects of variety and plant density were not significant on plant height and cob height of maize.

3.3 Days to 90% Anthesis and Dry Biomass

Days to 90% anthesis were not significantly different between the varieties, but variety SC 403 was earlier than variety PAN 53 by four days (Table 2). Though the difference was not significant, days to anthesis was decreased with increased plant density. On the other hand, there was significant ($P<0.05$) difference between maize varieties in dry biomass at V12 and R5 growth stages where variety PAN 53 produced higher biomass than variety SC 403 at all the three growth stages (Table 3). The effect of plant density was not significant on dry biomass, but the dry biomass showed decreasing trend as the plant density increased from 44444 to 57143 plants/ha at V12 and R5 growth stages (Table 3). The interaction effects of variety and plant density were not significant on days to anthesis and dry biomass of maize.

3.4 Yield Components and Yield

There was significant ($P <0.05$) difference between the varieties for thousand kernels mass, while there were no significant difference between the varieties on number of cobs per plant, grain yield, Stover mass and harvest index. However, variety PAN 53 had higher grain yield (43.1 t/ha), Stover mass (59.8 t/ha), and thousand kernels weight (374.0 g) while variety SC 403 had higher harvest index (0.464) (Table 4). The effect of plant density was not significant on yield components and yield of maize, but number of cobs per plant, grain yield, Stover mass, and thousand kernels mass (g) showed

Table 1. Main effects of variety and plant density on leaf area per plant and leaf area index (LAI) of maize at different growth stages

Treatment	Leaf area at V6 (cm^2)	Leaf area at V12 (cm^2)	Leaf area at R5 (cm^2)	LAI at V6	LAI at V12	LAI at R5
Variety						
PAN 53	6924	7317	8195	3.49	3.67	4.11
SC 403	6656	6631	8382	3.33	3.32	4.22
LSD (0.05)	ns	ns	ns	ns	ns	ns
Plant density (ha^{-1})						
44444	7200	7593a	8898a	3.20	3.37	3.95b
50000	6818	7036ab	829ab	3.41	3.52	4.15a
57143	6353	6294b	7670b	3.63	3.60	4.38a
LSD (0.05)	ns	1087.6	668.1	ns	ns	0.35

ns = non-significant at P = 0.05; Means in columns followed by different letters are significantly different to each other at P = 0.05 according to Least Significance Difference (LSD) test

Table 2. Main effects of variety and plant density on plant height and cob height of maize

Treatment	Plant height at V6 (cm)	Plant height at V12 (cm)	Plant height at R5 (cm)	Cob height (cm)
Variety				
PAN 53	52.44	238.1a	240.0	139.4
SC 403	50.33	227.1b	233.4	133.5
LSD (0.05)	ns	8.83	ns	ns
Plant density (ha^{-1})				
44444	50.00	231.1	238.3	140.3
50000	51.50	233.5	237.4	134.3
57143	52.67	233.2	234.5	134.8
LSD (0.05)	ns	ns	ns	ns

ns = non-significant at P = 0.05; Means in columns followed by different letters are significantly different to each other at P = 0.05 according to Least Significance Difference (LSD) test

Table 3. Main effects of variety and plant density on days to 90% anthesis and dry biomass of maize

Treatment	Days to 90% anthesis	Dry biomass at V6 (t/ha)	Dry biomass at V12 (t/ha)	Dry biomass at R5 (t/ha)
Variety				
PAN 53	69.0	6.14	18.13a	37.0a
SC 403	65.0	5.92	15.86b	30.4b
LSD (0.05)	Ns	ns	2.07	4.80
Plant density (ha^{-1})				
44444	69.2	6.10	18.43	34.6
50000	67.5	6.72	17.14	33.4
57143	64.3	5.28	15.42	33.1
LSD (0.05)	ns	ns	ns	ns

ns = non-significant at P = 0.05; Means in columns followed by different letters are significantly different to each other at P = 0.05 according to Least Significance Difference (LSD) test

Table 4. Main effects of variety and plant density on yield components and yield of maize

Treatment	No. of cobs per plant	1000 kernels mass (g)	Grain yield (t/ha)	Stover mass (t/ha)	Harvest index
Varieties					
PAN 53	1.040	374.0a	43.1	59.8	0.436
SC 403	1.040	335.7b	33.5	45.9	0.464
LSD (0.05)	ns	34.71	ns	ns	ns
Plant density (ha^{-1})					
44444	1.06	381.2	43.8	70.6	0.398
50000	1.03	347.8	39.1	52.1	0.471
57143	1.03	335.6	32.1	35.8	0.481
LSD (0.05)	ns	ns	ns	ns	ns

ns = non-significant at P = 0.05; Means in columns followed by different letters are significantly different to each other at P = 0.05 according to Least Significance Difference (LSD) test

decreasing trend as the plant density increased from 44444 to 57143 plants per ha (Table 4). The interaction effects of variety and plant density were not significant on the yield components and yield of maize.

4. DISCUSSION

4.1 Leaf Area and Leaf Area Index

Variety PAN 53 had higher leaf area and leaf area index at V6 and V12 growth stages (Table 1) owing to genetic differences in number, length and width of leaves it produced. In line with this result, Ahmad et al. [17] reported the highest leaf area index (5.82) from variety Pioneer-30D55, while the lowest leaf area index (5.55) was obtained from variety pioneer-3012 and attributed this to less number of leaves per plant and less leaf width.

At all maize growth stages, the leaf area were decreased while the leaf area indices were increased with increasing plant density from 44444 to 57143 plants/ha (Table 1). The reduction in leaf area with higher plant density might be due to high competition for assimilates at higher plant density, hence less average leaf area per plant. Increasing plant density could reduce leaf area due to the accelerated leaf senescence, increased shading of leaves, and reduced net assimilation of individual plants. In agreement with this result, Sangakkara et al. [18] reported that the leaf area per plant tended to decline with increasing plant density in maize. Similarly, Imran et al. [19] reported that increasing plant density from 65000 to 95000 plants ha^{-1} decreased the leaf area per plant from 2585 cm^2 to 2316 cm^2 in maize linearly and significantly. On the other hand, the increased LAI at higher plant density could be on account of more area occupied by green canopy of plants per unit area. The general trend is that increasing plant density increases leaf area index on account of more number of plants per unit area. Williams [20] also reported that one of the ways of increasing leaf area index is to increase plant density. In line with this result, Abuzar et al. [6]

obtained LAI of 2.77 at plant population of 120,000 plants ha^{-1} while the lowest LAI (1.21) was obtained with lower plant population density of 40,000 plants ha^{-1}. Dinh et al. [21] also reported that increasing plant density from 57000 to 84000 plants ha^{-1} increased the leaf area index from 3.52 to 4.67 in maize.

4.2 Plant Height and Cob Height

Variety PAN 53 had higher plant height and higher cob height (Table 2). The differences in plant height and cob height observed between the varieties might be attributed to differences in genetic characteristics of the individual varieties, including height of the varieties. In conformity with this result, many authors [e,g, 22,23,24] reported significant plant height differences among maize cultivars. For instance, Azam et al. [22] reported the tallest height (145 cm) for variety Cargill 707 and the shortest height (134 cm) for variety Baber. Karasu [24] also reported significant difference in ear height of maize cultivars where the highest ear height (144.1 cm) was recorded from variety LG 2687 and the lowest ear height (131.5 cm) was obtained for variety GH2547.

The plant height at V6 showed increasing trend with increasing plant density (Table 2). The increase in plant height with the increase in plant density might be due to the increase in the inter-plant competition for light and the disruption of the balance of growth regulators. The decrease in light penetration into middle and lower layers of canopy decreases auxin decomposition and thus, plant height increases. In consistence with this result, Zamir et al. [25] reported that plant height was increased significantly from 209 cm to 221 cm as the plant population increased from 55556 plants ha^{-1} to 111111 plants ha^{-1}. Adeniyan [26] also reported that when the plant density was increased from 53000 plant ha^{-1} to 106 000 plant ha^{-1}, the plant height was increased significantly from 137.6 cm to 210.8 cm, respectively.

4.3 Days to 90% Anthesis and Dry Biomass

Variety SC 403 was earlier than variety PAN 53 (Table 2). This might be due to the genetic variation among the varieties where early maturing varieties require less heat units to reach anthesis while late maturing varieties exhibit extended vegetative period [27].

Days to anthesis was decreased with increased plant density. The earliest anthesis observed in the highest plant density might be due to intra-specific competition for soil nutrients, water and sunlight among the plants which ultimately triggers the plants to early reproductive phase. In agreement with this result, Nwokwu [28] reported that the lowest plant density of 20,000 plants ha^{-1} took more days to tasseling (69.89) while the earliest tasseling (67.35 days) was observed in the highest plant densities of 80,000 plant ha^{-1}. In contrast to this result, Tokatlis and Koutroubas [29] reported that the time from planting to silking increased from 84 to 95 days as density of maize increased from five to 20 plants m^{-2}. Similarly, Mohammad et al. [30] reported that with increasing plant density from 57000 plant ha^{-1} to 99000 plant ha^{-1}, the number of days to 50% silking was delayed in four days.

Variety PAN 53 produced higher biomass than variety SC 403 at all the three growth stages (Table 3). This result was expected as medium maturing variety PAN 53 had more leaf area and height than early maturing variety SC 403 resulting in more photosynthesis to accumulate more dry matter. In line with this result, Aziz et al. [31] obtained the highest aboveground dry biomass yield (21.54 t ha^{-1}) for late maturing maize cultivar Ehsan, while the lowest aboveground dry biomass yield (16.83 t ha^{-1}) was obtained from early maturing cultivar Pahari.

The dry biomass showed decreasing trend with increased plant density at V12 and R5 growth stages (Table 3) possibly due to increased inter-plant competition for growth resources like light, soil moisture and nutrients. Similarly, Asea et al. [32] revealed that plant populations that are higher than the optimum will lead to competition among the maize plants resulting into thin plants that will give low yield. In contrast to this result, Ayman and Samier [33] reported the highest dry biomass of 28914 kg ha^{-1} at the highest plant density of 57124 plants of ha^{-1}.

4.4 Yield Components and Yield

Variety PAN 53 had higher thousand kernels mass (374.0 g), higher grain yield (43.1 t/ha), and higher stover mass (59.8 t/ha), while variety SC 403 had higher harvest index (0.464) (Table 4). Thousand kernels weight is a major yield component that has an essential role in determining the potential yield of variety [25]. Significantly higher thousand kernels mass for medium maturing variety PAN 53 might indicate the more efficient conversion of solar radiation and other growth resources into economic yield due to its long grain filling period. In line with this result, Moraditochaee et al. [34] reported that thousand kernels weight is a trait, which is more dependent on the genetic characteristics of varieties, and it is less affected by environmental factors. Similarly, Belay [35] obtained significantly higher thousand kernels weight (410.15 g) for the late maturing maize variety BH-661 as compared to the medium maturing variety BH-QPY-545 (288.6 g).

The higher stover yield and grain yield for variety PAN 53 could be due to its higher height and leaf area as well as its late maturity which created a better chance to utilize more nutrients and more photosynthetic activity, which ultimately resulted in higher biomass production and partitioning to the grain yield. In conformity with this result, Belay [35] also reported the maximum grain yield (11.09 $t{\cdot}ha^{-1}$) for late maturing maize variety BH-661 than medium maturing maize variety BH-QPY-545 (9.57 $t{\cdot}ha^{-1}$).

Harvest index indicates the physiological efficiency of a plant for changing the total dry matter into economic yield [36]. Higher harvest index (0.46) was recorded for early maturing maize variety SC 403 than the medium maturing variety PAN 53 (0.43) (Table 4). The higher harvest index for the early maturing maize variety could be due to lower leaf area index and plant height that might have reduced the above-ground dry biomass yield. In agreement with this result, Iptas and Acar [37] obtained higher harvest index (41.3%) for early maturating hybrid maize than the mid (40.3%) and late (30.1%) maturities of maize hybrids. Belay [35] also reported the highest harvest index (47%) for medium maturing variety BH-QPY-545 than for the late maturing maize variety BH-661 (36%).

The number of cobs per plant, thousand kernels weight (g), grain yield and stover mass showed decreasing trend as the plant density increased from 44444 to 57143 plants per ha (Table 4). The use of high plant densities might have reduced the supply of photosynthates to the growing ear thereby reducing the number of ears per plant. Similarly, Abuzar et al. [6] reported that the number of ears per plant increased with decreased plant population density where the maximum number of ears $plant^{-1}$ (1.33) was produced in plant density of 60,000 plants per whereas the lowest number of ears per plant (1.0) was produced from plant density of 140,000 plants per hectare. Zamir et al. [25] also reported that as the plant population increased from 55556 plants ha^{-1} to 111111 plants ha^{-1}, the number of ears per plant was significantly reduced from 1.42 to 1.21 possibly due to more competition for light, aeration and nutrients and consequently enabling the plants in closer spacing undergo less reproductive growth.

Lower grain weight in high plant density was possibly due to availability of less photosynthates for grain development on account of high intra-specific competition which resulted in low rate of photosynthesis and high rate of respiration as a result of enhanced mutual shading. In conformity with this result, Ijaz et al. [38]; and Amin and Meyasam [39] reported that as the plant density increased, 1000 grain weight was decreased linearly and significantly. Abuzar et al. [6] also reported maximum 1000 kernels weight (350.0 g) at minimum plant density (80000 plants/ha) and the minimum 1000 kernels weight (166.7 g) at the highest plant population (140,000 plants/ha). Similarly, Mohammad et al. [30] reported that increasing plant population from 45000 plants ha^{-1} to 65000 plants ha^{-1} decreased thousand kernels weight and maximum thousand grain weight (315 g) was produced at planting density of 45000 plants ha^{-1}.

The reduction in stover and grain yields with increased plant density might be that plant populations that are higher than the optimum will lead to competition among the maize plants. This result was in agreement with the study by Abuzar et al. [6] who reported the maximum grain yield (2.6 t ha^{-1}) from 60000 plants ha^{-1} and the lowest grain yield (0.8 t ha^{-1}) from 140000 plants ha^{-1} of maize. In contrast to this result, Raouf et al. [23] reported that grain yield of maize was increased with increasing density from 80,000-120,000 plants per hectare from 3910 to 4650 kg ha^{-1}. Norwood [40] also reported that hybrid maize with higher population density of 60,000 plants ha^{-1} gave higher yield (4.02 t ha^{-1}) than lower population density of 30,000 plants ha^{-1} (2.69 t ha^{-1}). These differences in response suggest that the optimum plant density depends upon environmental conditions and the cultivars used.

5. CONCLUSION

Medium maturing maize variety PAN 53 had higher leaf area, leaf area index, plant height, cob height, thousand kernels mass and grain yield than the early maturing variety SC 403. As the plant density increased from 44444 to 57143 plants/ha, leaf area, number of cobs per plant, thousand kernels mass and grain yield were decreased. Thus, it can be concluded that medium maturing variety PAN 53 be adopted while plant density of 44444 plants/ha is still the best option for maize farmers. It is therefore, recommended that PAN 53 at a density of 44444 plants/ha be adopted by farmers of the Middleveld Agro-ecological zone of Eswatini. However, the experiment has to be repeated over years with the inclusion of more varieties and densities to make a more reliable recommendation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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