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Use of Organic Inputs in Management of Alfisols and Ultisols for Sustainable Maize Production in Western Kenya

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Authors' contributions

This work was part of a PhD thesis. Author JA was the student and he designed the study, managed the experiment, collected all the data and conducted statistical analysis. He also wrote the protocol and the first draft of the manuscript. Author GO was the principal supervisor while author GO was the second supervisor. Besides supervision, they managed the literature searches. All the authors read and approved the final manuscript.

Research Article

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ABSTRACT

Maize (*Zea mays* L.) is an important food crop in western Kenya, mostly grown by smallholder farmers in complex and risky cropping systems. Trends in population growth in the country indicate that the demand for maize is projected to increase 3-4% annually. Production is however hampered by the predominance of fragile ecosystems (acidic soils), low soil fertility and low use of chemical inputs. The average grain yield is less than 1.0 t ha^{-1} instead of a reachable 5.0 t ha^{-1}, leading to vicious cycle of food insecurity. An on-farm experiment was conducted in two soil types (Alfisols and Ultisols) in Kakamega, western Kenya, between February and September 2007 to test effects of various organic inputs (Farmyard manure, Tithonia biomass and Desmodium cover crop) in combination with inorganic fertilizers (N, P, K, Mg, B and Zn) on yield of maize. The design was Randomized Complete Block Design, replicated 5 times and the data was subjected to ANOVA and DMRT tests. Soil analysis before planting indicated that pH was 5.0 and 5.4 in Alfisols and Ultisols, respectively. Both soils were deficient in N and P but adequate in exchangeable bases (K, Ca and Mg). Maize grain yield was higher in Ultisols compared to Alfisols. In Alfisols, organic inputs in combination with 30 kg N ha^{-1} gave maize grain yield

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improvement of nearly 100% over farmer's practice (non improved maize variety, wider plant spacing, inorganic fertilizer applied at the rate of 20 N + 20 P ha^{-1}, one weeding). When inorganic fertilizer (60 kg N + 60 kg P ha^{-1}) was applied to maize/banana intercrop, maize yield increased by about 40%. In contrast, in Ultisols, organic inputs increased maize grain yield by between 85% and 115%, while maize/banana intercrop (plus 60 kg N + 60 kg P ha^{-1}) increased maize grain yield by only 4% over the farmer's practice. Banana intercrop reduced maize population resulting in low maize grain and stover yield. Use of either farmyard manure, tithonia biomass or desmonium cover crop in combination with 30 kg of N ha^{-1} (from inorganic source) can enhance maize production among smallholder farmers in acidic soils who ordinarily cannot afford to purchase adequate quantities of inorganic fertilizers.

Keywords: Alfisols; Ultisols; maize; organic inputs; sustainable production; Western Kenya.

1. INTRODUCTION

Maize (*Zea mays* L.) is the most important staple food crop in Kenya. It is estimated that about 1.6 million hectares of land are under the crop annually with 80% being grown by smallholder farmers [1,2], majority of whom are in western part of the country. However, the production does not match the population and industrial demand that increases at about 4.7% annually. Low soil fertility has been identified as one of the major constraints to maize production among smallholder farmers. Exacerbating the low soil fertility in the region is the high rate of acidity in many soils due to high rainfall, depletion of soil carbon and continuous cultivation. Predominant soils in western Kenya include Alfisols and Ultisols [3]. Alfisols are known to have undergone moderate leaching, are susceptible to surface compaction, erosion and acidify rapidly under continuous cultivation [4]. They have low water retention capacity [4] and are deficient in N and P [5,6]. On the other hand, Ultisols are strongly leached, highly acidic, have multiple nutrient deficiencies of N, P, K, Ca and Zn and P-fixation tendencies; they are susceptible to erosion and compaction [7].

In Kenya, acid soils cover about 13% of prime agricultural land, mostly concentrated in western part of the country [8]. Acid soils significantly limit crop production through toxic levels of aluminum (Al) and manganese (Mn), as well as sub-optimal levels of P [9]. For optimum growth and grain yield, maize requires soils with ≥2.0% N [10], ≥13 mg P kg^{-1} [11] and pH range of 5.5-6.5. Studies have shown that crop yields in acidic, un-limed soils have declined even with application of adequate amounts of inorganic fertilizers [12]. Use of organic inputs, especially Tithonia *diversifolia* and *Desmodium* sp., can raise the pH [13] and improve fertility of the acidic soils [14]. Soils fallowed to Tithonia improved soil's physical properties and had higher mineral values like N, P, K Ca and Mg [15]. Tithonia has a faster rate of decomposition because of it's low lignin (6.5%) and polyphenol (1.6%) content [15], but has high nitrogen (3.5%), phosphorus (0.4%) and potassium (4.1%) [16]. Tithonia is an invasive annual weed growing abundantly in western Kenya mainly along roads, hedges and on uncultivated fields. Desmodium is a nitrogen-fixing shrub legume characterized by the following attributes: fast growing, easily degradable biomass, compatibility with maize crop and has no allelopathic effect on cereals [16, 17]. Several desmodium sp. are used as cover crops in maize and sorghum fields to repel *Chillo partellus* (stem borer) as well as suppression of witch-weed. They are also used as living mulch, green manure, besides being good animal fodder. Although organic inputs cannot meet crop P requirements, they can increase P availability by reducing its adsorption capacity in the soil [18]. Nutrient content of some commonly used organic materials is presented in Table 1.

The objective of this experiment was to study the effect of organic inputs and their combinations with inorganic fertilizers on growth and yield of maize intercropped with banana in Alfisols and Ultisols in Kakamega, western Kenya.

Table 1. Nutrient content of some organic materials

Material	N (%)	P (%)	K (%)
Cow manure	0.4-0.6	0.2	0.2-0.5
Goat manure	1.4	0.2	0.3-1.0
Sheep manure	0.7	0.3	0.4
Poultry manure	1.1-1.5	0.8-1.3	0.5-2.7
Tithonia biomass	3.97	0.3	4.6
Desmodium biomass	3.44	0.15	-
Mucuna biomass	3.56	0.17	-
Leucaena leucocephala	3.74	0.26	3.37

Source: [19].

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was carried out in Kakamega within four administrative divisions of Ikolomani, Ileho, Shinyalu and Lurambi, western Kenya. The region has one of the most densely populated rural areas in the world with 500 to 1200 people km^{-2} [20,21] with average household farm size of 0.7 ha of which about one half is planted to maize in combination with beans and sometimes, banana. The remaining portion is usually either under tea or sugarcane. The whole area is characterized by low input-low output and low incomes. Maize grain deficit lasts for at least four months every year, resulting in high levels of hunger and extreme poverty [22]. The experiment was carried out during the long rains season of 2007, beginning February to September.

The soils in the study site are mainly Ultisols or Alfisols. Although there are pockets of fertile soils in the County, about 85% of the land is poor as a result of leaching from high rainfall and intensive cultivation with inadequate measures to maintain soil fertility. Annual rainfall ranges from 1200 to 1800 mm with a bimodal distribution allowing two cropping seasons. Long rains are experienced from March to June, peaking in April/May while the short rains begin in July, peaking in September. The mean maximum and minimum temperatures range from 28ºC to 32ºC and 11ºC to 13ºC, respectively. Mean altitude of the area is 1200 m.

2.2 Field Experiment

Soil sampling was done in representative locations within the study site covering Alfisols and Ultisols prior to planting. Air-dried 2 mm sieved samples were subjected to chemical analysis at National Agricultural Research Laboratories, Nairobi, as described by Okallebo [23]. Total N and available P were determined by micro Kjeldahl and molybdenum blue colorimetry methods, respectively. Exchangeable K, Ca and Mg were extracted using ammonium acetate. Soil pH was measured using a soil water ratio of 1:2.5 (w/v).
On-farm experiment was established on selected ten farms (five each in Alfisols and Ultisols). Land preparation was done by hand-hoeing to a fine tilth and planting was done at the on-set of rain. Each experimental plot was planted with maize variety H614 at a spacing

of 75 cm between the rows and 30 cm along the rows; two seeds per hole but later thinned to one plant per hill after emergence. The treatments of the experiment were: control/farmer's practice (non-improved maize variety, wider plant spacing, fertilizer rate of 20 N/P ha^{-1}, one weeding); no weeding + no fertilizer, weeded-no fertilizer, 60 kg N ha^{-1}, 60/60 kg N/P ha^{-1}, 60/60/40 kg N/P/K ha^{-1}, 5 tons FYM + 30 kg N ha^{-1}, 5 tons tithonia + 30 kg N ha^{-1}, desmodium + 30/30 kg N/P ha^{-1}, banana + 60/60 kg N/P ha^{-1}, optimal fertilizer, and modified farmers' practice (one weeding + 20/20 kg N/P ha^{-1}). The treatments were arranged in a randomized complete block design with five replications in each soil type. Each experimental unit measured 19.5 m^2. Data was subjected to ANOVA using SAS [24] Version 8 and Duncan's Multiple Range Test (DMRT) at 5% level was used to separate the means.

Tissue-culture banana (cv. Kanyinjia) was planted as an intercrop at the same time with maize at a spacing of 3m x 3m. *Desmodium intortum* (green leaf) seed, also planted at the same time with maize, was drilled midway between maize rows at the rate of 1kg per ha. Desmodium cover crop was pruned two times during the season and leaves left on the soil surface to decompose and generate organic matter. Tithonia twigs were cut from the nearby roadsides, carried to the Research Station, sun dried and stored in a dry place in gunny bags. Tithonia and farmyard manure were incorporated on the plots 7 days before planting at the rate of 5 t ha^{-1} dry weight of each. Basal fertilizer was applied at the time of planting followed by side-dressing five weeks after emergence of maize. Inorganic N fertilizer was sourced from Urea, P was from Di-Ammonium Phosphate, K was from Potassium Chloride, Mg was from Magnessium Chloride, Zn was from Zinc Chloride while B was from Borate Chloride. Hand weeding was done two times except on farmers' practice treatment that received one weeding.

Maize was harvested at physiological maturity as indicated by the formation of black layer at the pedicel of 50% of the sampled kernels. At this stage, mean plant height was obtained by randomly selecting 5 plants from each plot, which were then cut at the soil surface level and their length measured with a tape measure from the cut surface to the tip of the longest tassel branch. Maize was harvested from four inner rows from a net plot of 13.5 m^2. Number of plants and ears from the net plot were counted. An ear was described as any biological structure on a maize plant having a cob (with or without grains). All clean ears were hand shelled, weighed and recorded at the farm. Grain yield, adjusted to 13% moisture content was calculated by the formula:

$$Grain\ yield\ (t\ ha^{-1})\ = FW * (100 - MC)/87 * (10{,}000/NP) * SP)/1{,}000$$

Where: FW = Grain field weight from the net plot (kg),
MC = Grain moisture content at harvesting,
NP = Net plot (m^2),
SP = Shelling percentage of the ear (estimated at 0.85)

Another set of five plants was randomly selected and cut at the soil surface for purposes of estimating plant biomass. The plants were de-husked, cobs were removed and the remaining parts tied together, labeled and taken to KARI-Kakamega Laboratories. They were then chopped into small pieces, put in paper bags and dried in an oven at 70ºC until a constant weight was reached. The final weight represented the final biomass for each plot.

3. RESULTS

3.1 Soil Chemical Properties before Planting Maize

Soil analysis before planting indicated significant differences between Alfisols and Ultisols (Table 2). Alfisols was more acidic compared to Ultisols. Other than available P that was higher in Alfisols, all other nutrients (carbon, nitrogen, potassium, calcium and magnesium) were higher in Ultisols.

Table 2. Soil characteristics of maize fields in Alfisols and Ultisols in the administrative divisions of the study site

Division	∗Soil Type	Soil pH (H_2O)	Total C (%)	Total N (%)	Extr. P (mg kg^{-1})	Exch. K (cmol kg^{-1})	Exch. Ca (g kg^{-1})	Exch. Mg (g kg^{-1})
Ileho	Alf.	5.0	1.09	0.12	4.78	0.35	0.75	0.07
Lurambi	Alf.	4.9	1.08	0.11	7.85	0.42	1.07	0.10
Shinyalu	Ult.	5.4	2.39	0.22	5.00	0.55	1.65	0.18
Ikolomani	Ult.	5.3	1.45	0.15	5.23	0.41	1.14	0.14
Mean (Alfisols)		5.0	1.07	0.12	6.18	0.38	0.81	0.08
Mean (Ultisols)		5.4	1.92	0.18	5.14	0.48	1.39	0.16

∗Soil type: Alf. = Alfisols, Ult. = Ultisols

3.2 Effect of Organic Inputs on Growth Parameters of Maize

3.2.1 Maize population at physiological maturity

In Alfisols, highest plant population (37,778 per hectare) was recorded in optimal fertilizer treatment (Table 3). This was about 85% of the potential population. Farmer's practice (control) had 62% of the potential plant population. All other treatments gave populations higher than farmer's practice but significantly less than that in optimal fertilizer. In Ultisols, N (60 kg) treatment gave the highest plant population (39,556); which was 89% of maximum expected while farmer's practice gave 62% of maximum expected (Table 4). Organic inputs: FYM, tithonia and desmodium gave populations that were significantly similar to that of NP treatment. Banana intercrop gave 68% of potential population.

Table 3. Effects of organic inputs and inorganic fertilizer combinations on attributes and maize grain yield in Alfisols of Kakamega, Kenya

Treatment	Plants (ha^{-1})	Ears (ha^{-1})	Plant Height (m)	Maize Yield (t ha^{-1})	Stover Yield (t ha^{-1})
Farmer's practice (Control)	27,704 b	17,778 de	2.3 c	1.9 e	6.0 f
Unweeded, no fertilizer	28,593 ab	15,407 e	2.3 c	2.0 e	7.6 ef
Weeded, no fertilizer	31,407 ab	22,222 bcde	2.3 c	2.9 cde	10.2 cdef
N (60 kg)	31,407 ab	21,037 cde	2.4 bc	4.1 bcd	13.9 bc
NP (60 kg N + 60 kg P)	30,815 ab	26,222 bc	2.5 abc	4.2 bc	13.7 bc
NPK (60 kg N + 60 kg P + 40 kg K)	36,000 ab	29,481 ab	2.6 abc	4.7 b	16.5 b
FYM + 30 kg N	30,815 ab	22,815 bcde	2.6 abc	3.9 bcd	12.2 bcde
Tithonia + 30 kg N	34,815 ab	25,630 bcd	2.4 bc	3.8 bcd	13.1 bcd
Desmodium + 30 kg N + 30 kg P	33,926 ab	26,963 bc	2.5 abc	3.4 bcd	11.9 bcde
[1]Optimal fertilizer	37,778 a	35,407 a	2.8 ab	6.6 a	24.3 a
Modified farmer's practice	31,852 ab	22,518 bcde	2.5 bc	2.7 de	8.6 def
Banana intercrop + 60 kg N + 60 kg P	29,630 ab	19,259 cde	2.9 a	2.7 de	11.6 bcde
Mean	**32,235**	**24,047**	**2.5**	**3.7**	**12.5**
CV (%)	**17.1**	**19.5**	**9.4**	**24.1**	**24.0**

Means followed by the same letter within the same column are not significantly different at $P \leq 0.05$, using DMRT.

[1]Optimal fertilizer = Optimal fertilizer: (N, P, K, Mg, Zn and B ((NPK was broadcast at planting at the rate of 200, 60 and 120 kg ha^{-1} of each)), respectively; Mg 20 kg ha^{-1}, Zn 20 kg ha^{-1} and B 5 kg ha^{-1})

3.2.2 Number of ears

In Alfisols, optimal fertilizer treatment gave the highest number of ears (35,407) (Table 3). In relation to optimal fertilizer treatment, unweeded- no fertilizer and control gave 43% and 50% ears, respectively. Among the organic inputs, desmodium gave number of ears significantly similar to that of NP (60 kg N + 60 kg P). FYM gave number of ears similar to that recorded in weeded, no fertilizer treatment. Banana intercrop treatment gave nearly half of the ears in relation to optimum fertilizer treatment.

Table 4. Effects of organic inputs and inorganic fertilizer combinations on attributes and maize grain yield in Ultisols of Kakamega, Kenya

Treatment	Plants (ha^{-1})	Ears (ha^{-1})	Plant Height (m)	Maize Yield (t ha^{-1})	Stover Yield (t ha^{-1})
Farmer's practice (control)	27,654 de	20,741 c	2.4 b	2.5 c	14.1 c
Unweeded, no fertilizer	32,444 bcd	25,333 bc	2.5 b	3.9 bc	13.9 c
Weeded, no fertilizer	33,111 abcd	26,222 bc	2.6 b	4.6 bc	16.1 bc
N (60 kg)	39,556 a	29,926 ab	2.6 b	5.4 b	22.5 b
NP (60 kg N + 60 kg P)	36,296 abc	29,037 ab	2.8 ab	5.4 b	20.5 bc
NPK (60 kg N + 60 kg P + 40 kg K)	33,556 abcd	27,704 abc	2.6 b	5.6 b	21.8 b
FYM + 30 kg N	35,111 abc	27,259 bc	2.6 b	5.3 b	20.1 bc
Tithonia + 30 kg N	35,185 abc	27,852 abc	2.7 ab	5.0 bc	22.4 b
Desmodium + 30 kg N + 30 kg P	36,593 abc	25,778 bc	2.6 b	4.7 bc	21.6 b
[1]Optimal fertilizer	37,111 ab	34,518 a	3.2 a	9.1 a	30.8 a
Modified farmer's practice	26,111 e	24,259 bc	2.9 ab	4.0 bc	20.3 bc
Banana intercrop + 60 kg N + 60 kg P	30,371 cde	20,741 c	2.8 ab	2.6 c	19.3 bc
Mean	**34,060**	**27,084**	**2.7**	**4.8**	**20.5**
CV (%)	**12.4**	**17.4**	**11.9**	**14.1**	**22.4**

Means followed by the same letter within the same column are not significantly different at $P \leq 0.05$, using DMRT.

[1]Optimal fertilizer = Optimal fertilizer: (N, P, K, Mg, Zn and B ((NPK was broadcast at planting at the rate of 200, 60 and 120 kg ha^{-1} of each)), respectively; Mg 20 kg ha^{-1}, Zn 20 kg ha^{-1} and B 5 kg ha^{-1})

In Ultisols, optimal fertilizer treatment gave the highest number of ears (34,518) (Table 4). In relation to optimal fertilizer, control and banana intercrop treatments reduced ear number by nearly 40% while modified farmer's practice + fertilizer reduced it (ears) by about 30%. Whereas in relation to optimum fertilizer, desmodium and FYM reduced ear yield by nearly 25%, tithonia and NPK reduced the ears by about 20%. N and NP in relation to optimum fertilizer reduced ear yield by nearly 15%.

3.2.3 Maize plant height

In Alfisols, banana intercrop gave tallest maize plants (2.9 m) (Table 3). Control, unweeded-no fertilizer and weeded-no fertilizer treatments gave plants shorter by nearly 30% compared to banana intercrop treatment. NP, NPK, FYM and desmodium treatments were equal in height though nearly 10% shorter than the banana intercrop treatment. N, tithonia and modified farmer's practice + fertilizer gave plants nearly 22% shorter compared to banana intercrop. In Ultisols, optimal fertilizer gave tallest plants (3.2 m) followed by NP, tithonia, farmer's practice + fertilizer and banana intercrop which were nearly 13% shorter (Table 4). All the other treatments were not significantly different in height though they were about 21% shorter than banana intercrop treatment.

3.2.4 Maize grain yield

In Alfisols, farmer's practice (control) gave lowest maize yield of 1.9 t ha^{-1} (Table 3). Optimal fertilizer gave maize yield of 6.6 t ha^{-1}, an increment of nearly 250% over the control. NPK and NP had a grain yield increment of 150% and 120% over control. Organic inputs (FYM, tithonia and desmodium) and N gave significantly similar yield with about 100% increment over control. Banana intercrop and modified farmer's practice + fertilizer gave 42% yield improvement over control. In Ultisols, control gave the lowest grain yield of 2.5 t ha^{-1} (Table 4). Optimal fertilizer gave 9.1 t ha^{-1}, an increment of nearly 260% over control. Treatments N, NP, NPK and FYM gave grain yield increment of about 115% over control. Tithonia, desmodium, unweeded-no fertilizer and weeded-no fertilizer all gave grain yield improvement of nearly 84% while banana intercrop had a 4% increment.

3.2.5 Maize stover yield

In Alfisols, control treatment recorded the lowest stover yield (6.0 t ha^{-1}) (Table 3.) while optimal fertilizer gave 24.3 t ha^{-1}, an increment of about 300%. NPK treatment increased stover yield by nearly 175% over control while N and NP gave an increment of about 130%. Organic inputs (tithonia, FYM and desmodium) and banana treatment doubled stover yield over control. In Ultisols, control treatment gave stover yield of 14.1 t ha^{-1} compared to optimal fertilizer that gave 30.8 t ha^{-1}, an increment of about 118% over the control (Table 4). Treatments N, NPK, tithonia and desmodium yielded about 56% above the control while NP, FYM, weeded-no fertilizer and banana treatments had an improvement of only 38% above control.

4. DISCUSSION

In our study, both Alfisols and Ultisols had low levels of N that may not be adequate for proper growth of maize (Table 2). Maize requires high levels of N (2%) to perform well [9]. Both soils were also low in P as they both fell below the critical level of 13.0 mg P kg^{-1} required by maize for normal growth [10]. However, both soils had enough K with values ranging over the critical limit of 0.2 cmol K [25]. Abundance of rainfall in the area is partly responsible for leaching away of nitrates resulting in deficiencies of N. However, P is less prone to leaching. Its deficiency results rather from retrogression process in clay soils. Despite high rainfall in the area, the soils are moderate in Ca and Mg but generally higher in Ultisols compared to Alfisols. These exchangeable bases (K, Ca and Mg) are less prone to leaching because they are normally attached to the negatively charged surfaces of the soil colloids and not in soil solution as nitrates and phosphates. The soil analysis indicated that Ultisols are more productive (Table 2) and hence favour maize production compared to Alfisols. This probably explains why in the study, plant population, plant height, grain and stover yield was higher in Ultisols.

Plant population was higher in Ultisols compared to Alfisols. However in both soils, cover crop (desmodium) and tithonia mulch significantly increased plant population. A similar observation was reported in a wheat crop [26]. Besides increasing soil fertility, mulches and cover crops help in retaining soil moisture, reduce soil temperatures and conserve soil. They also provide a more stable environment for seedling establishment and growth than un-mulched soil [27,28].

Organic inputs with added minimal doses of inorganic fertilizer increased plant height in both soil types compared to non-fertilized treatments. This confirms a similar report by [14,29].

Tithonia biomass is rich in N and P [15,30]. Organic fertilizers exert strong influence on plant growth and development. Luxuriant growth resulting from fertilizer application leads to larger dry matter production, owing to better utilization of solar radiation and more nutrients. The significant increase in plant height reflects the effect of organic fertilizer nutrients. An optimum plant height is positively correlated with productivity of the plant [31].

Even though maize grain and stover yield showed higher improvement in Ultisols due to organic inputs, both soils recorded substantial increase in yield compared to non-fertilized treatments. A similar observation was reported by [32] in Ultisols of Cameroon. Desmodium cover crop, with minimal addition of N had a dramatic effect on maize plant height and grain yields in both soils. [33] reported a similar observation.

5. CONCLUSION

Integrated use of desmodium, tithonia biomass and farmyard manure with minimal addition of inorganic N fertilizer increased maize grain and yield components. The implication is that organic inputs could play significant role in enhancing and replenishing the depleted nutrients and sustain maize production in fragile soils. Combining organic and inorganic fertilizers appear to be advantageous because they both support the plant at early growth stage as well as late in the development stage. Moreover, nutrients from organic sources are not susceptible to leaching. Tithonia biomass that is cheaply and abundantly available is rich in N and P. Several desmodium spp are useful as living mulch and as green manure, as they are able to replenish fertility due to their ability to fix atmospheric N besides being good animal fodder as well as stem borer repellant. Intercropping maize and banana reduced maize grain yield. However, it is not likely that farmers will stop the cropping practice. There is need to study socio-economic benefits of the system before a recommendation can be made. Adoption of integrated soil improvement approaches remains the only feasible option for smallholder farmers to improve maize production in fragile environments as long as the prices of imported inorganic fertilizers remain un-affordable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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