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Growth and Yield of Rice as Influenced by Nitrogen and Water Management Approaches

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Achieving sustainability of the rice production in the irrigated areas in eastern India in general and Odisha in particular, under progressive climate change and variability, necessitates adoption of practices and technologies that increase food production, adaptation and mitigation in a feasible way. A field experiment was carried out for two consecutive years during 2020-21 and 2021-22 with *kharif* rice in the research farm of OUAT, Bhubaneswar. The experiment was conducted in a strip plot design having four each of water and nitrogen management approaches replicated four times. All the growth attributes like plant height, tillers/hill, LAI and dry matter production were superior under 3DADPW and INM treatments in water and nitrogen management approaches, respectively.

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Rotational irrigation 3 DADPW in rice resulted in higher grain yield (5.28 t/ha) followed by soil saturation. Similarly, INM practices comprising of Green manuring + 75% STBNR produced higher grain yield (5.45 t/ha) as compared to other N-management options and was closely followed by STBNR.

Keywords: 3DADPW; AWD; RTNM; STBNR; INM; LAI.

1. INTRODUCTION

Rice has been cultivated in four major ecosystems in India *viz*., irrigated, rainfed lowland, rainfed upland and deep water system. More than half of rice growing area (55 %) is under rainfed ecosystem. Rice is the staple food for over two thirds of the population and is cultivated over an area of 45.1 Mha with a production of 110.15 Mt in India, while in the state of Odisha, area is 4.31 Mha with production is 8.04 Mt [1]. Good yield of rice crop cannot be achieved without having better growth of the plants at critical stages like tillering and panicle initiation. Better growth of plants under optimal input supply is directly related to the uptake of the nutrients, which in turn helps more dry matter accumulation resulting in higher yield. But indiscriminate use of external inputs in the input intensive cereal production system has gradually led to the deterioration of agri-environment and natural resources [2]. Chemical fertilizers, because of their high nutrient concentration, easy availability, and convenient transportation as well as application, are very attractive and commonly used to enhance crop yields [3]. But despite the continued increase in application of chemical fertilizers in recent years, crop yields have remained almost stagnant, and environmental costs have continued to rise [4]. The excessive and injudicious application of N causes a series of detrimental ecological and environmental impacts [5]. In rice only 30 to 40% of the applied N is recovered by the crop resulting in large losses of reactive N, which not only negatively affects yield but also, pollute the environment. Site-specific, demand-driven, balanced and efficient use of fertilizer N in conjunction with organic manures, bio-fertilizers, *etc.* on the principle of integrated nutrient supply system is a right prescription to increase the nitrogen use efficiency, minimize the use of synthetic fertilizers, facilitate carbon sequestration, minimize the pool of excessive N in soil and thus reduces nitrous oxide emissions and increases yield. Rice being a high duty crop with the least water use efficiency requires alternate methods of irrigation to curtail water requirement without yield penalty. The AWD practice is able to increase grain yield in the range of 6-15%, water productivity by 27-51% and reduce irrigation water applied by 23-43% as compared to conventional irrigation practices [6].

Under progressive climate change scenario, it is the need of the hour for the adoption of such practices and technologies that increase food production, adaptation and mitigation in a feasible way.

2. MATERIALS AND METHODS

2.1 Location of Experimental Site

A field experiment was carried out for two consecutive years during 2020-21 and 2021-22 starting with *kharif* rice in the research farm of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar ($20^0$15’ N latitude, $85^0$52’ E longitude with an elevation of 25.9 m above MSL). The station falls under the East and South Eastern Coastal Plains Agro-climatic Zone (AZ 63) of Odisha as per NARP classification and Agro Ecological Sub Region (AESR) 18.4 of NBSS & LUP classification with moisture deficit index (MDI) value of -0 to -20 and length of growing period (LGP) of 180 to 210 days. The climate of Bhubaneswar is characterized by hot, moist and sub-humid with hot summer and mild winter. The rainfall is monsoonal with unimodal distribution. The soil of the experimental site was sandy loam in texture (Table 1).

2.2 Details of Experiment

The experiment was carried out in a strip plot design having four each of water and nitrogen management approaches in a system mode replicated four times in rice-sweet corn-cowpea system. The present paper deals with data on rice crop only. The nitrogen management approaches comprised of organics (N_1), integrated nutrient management-INM (N_2), soil test based nitrogen recommendations-STBNR (N_3) and real time nitrogen management-RTNM (N_4). The organic treatment (N_1) for rice crop comprised of Green manure (GM) + 1/3rd N each by FYM and NOC (Neem oil cake), while the INM practice has Green manure + 75% STBNR. Organic manures such as farmyard manure and neem oil cake were analysed for NPK contents to calculate equivalent recommended dose of nitrogen based on their N contents. All the organic manures were applied in line at sowing. *Dhaincha* was sown @ 25 kg seeds/ha as per the treatment specifications and was incorporated in the field at 42 DAS. In STBNR approach, 100 kg N/ha was applied for rice as soil N content was low. In STBNR and INM approach nitrogen was applied in 3 splits *i.e*., 25% at transplanting, 50% at active tillering and 25% at panicle initiation (PI) stage in the form of neem coated urea (NCU). Again in RTNM approach, nitrogen was applied based on the SPAD readings *i.e.,* 20 kg/ha as basal and @ 20 kg N/ha each, when the SPAD reading falls to 35.

The water management approaches for rice crop were, W_1: Continuous shallow submergence, W_2: 3 days after disappearance of ponded water-DADPW, W_3: Soil saturation throughout and W_4: Alternate Wetting and Drying (AWD). In shallow submergence, water level was maintained at 5 cm depth up to dough stage and thereafter excess water was drained out of experimental plot automatically by maintaining the height of the sluice. Water was drained out 10 days before harvesting to facilitate easy harvesting. Under 3 DADPW treatment, irrigation was applied three days after disappearance of ponded water to a shallow depth of 5 cm each time. In soil saturation throughout, the soil was kept as close to saturation as possible, thereby reducing the hydraulic head of the ponded water. In practice, a shallow irrigation was given to attain about 2 cm depth of ponded water. Whenever, water falls below 2 cm marked peg, once again irrigation was given, so that the soil was brought back always to above the saturation level. Irrigations were applied at 5-7 days interval depending on rainfall received. For AWD, a field water tube called `*pani* pipe' was used which is typically 30 cm long with an inner diameter of 15 cm, inserted into the soil to a depth of 15-20 cm and soil was removed from inside the tube. The section of the *pani* pipe below the soil surface is perforated to allow water to enter the pipe. It is helpful to assess the water level in the soil by simply measuring the depth of water in the pipe. Irrigation was applied to a shallow depth of 5 cm above the soil surface when water level inside the pipe falls to 15 cm below the soil surface.

Seedlings of 'Prativa' rice (125 days duration) were raised in wet bed method on a well puddled and levelled seed bed. The seeds were treated with Vitavax power (carboxin 37.5% + thiram 37.5%) @ 2.5 g/kg seed against seed borne diseases. Optimum soil moisture was maintained in the nursery for healthy growth of seedlings. Seedlings of 25-30 days were planted in the main field @ 2/hill at a spacing of 20 cm x 10 cm.

2.3 Details Observations on Plant Height, Tillers/Plant, Leaf Area Index (LAI), Dry Matter Production and Yield

Plant height: Plant height of 10 randomly selected plants in each plot was measured from the base of the plant to the tip of the topmost fully opened leaf or panicle at 30, 60, 90 DAT and at harvest and was expressed in centimeter (cm).

Tillers per hill: Number of tillers per hill was counted from 10 randomly selected hills in each plot at 30, 60, 90 DAT and at harvest and averaged to compute tillers/hill.

Leaf area index (LAI): Leaves of the hills uprooted for recording dry weight at different stages were detached for sun drying, oven drying and recording dry weight. The Specific Leaf Area *i.e.,* leaf area to leaf weight (cm^2/g) was worked out at each stage and the same was multiplied by the leaf dry weight at each stage to obtain the leaf area/hill. Ground area occupied by each hill was taken as 20 cm x 10 cm. The LAI was worked out as the ratio of leaf area to ground area proposed by Watson [7].

$$LAI = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

Dry matter accumulation: Dry weight of plant was recorded at 30, 60, 90 DAT and at harvest. The above ground plant parts of three sample hills from the destructive sampling area were cut close to the ground. Their dry weight was taken separately with help of electronic balance after sun drying followed by oven drying at 70^0C till a constant weight was obtained and was expressed in g/hill.

Grain and straw yield: The crop was harvested plot wise leaving border and sampling areas. Threshing was done by a power operated thresher after sun drying for 3-4 days and grain and straw yields were separately recorded in kg/plot and converted to t/ha.

Harvest index: Harvest index was computed by using the following expression [8].

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (t/ha)}}{\text{Biological yield (t/ha)}} \times 100$$

2.4 Statistical Analysis

Data collected on various characters of rice were analyzed statistically following standard analysis of variance technique (ANOVA) for strip-plot design [9]. The treatment variations were tested for significance by 'F' test. The standard error of mean SE (m)± and critical difference (CD) at 5% probability level were calculated to interpret the results.

3. RESULTS AND DISCUSSION

3.1 Plant Height

Plant height increased progressively till harvest, although the increase was at a diminishing rate after 90 DAT (Table 2). In general, the plants were taller during 2020-21 than 2021-22. The average plant height at 30, 60, 90 DAT and at harvest were 36.4, 90.4, 111.8 and 113.3 cm, respectively. Water management approaches failed to express significant variation in plant height in both the years of experimentation, except at 60 DAT and harvest, where 3DADPW recorded higher plant height as compared to other treatments. Three days drainage period might not have hampered the growth of rice plants during the *kharif* season with high relative humidity and low evaporative demand of the atmosphere rather facilitated root growth due to better aeration resulting in more nutrient uptake and growth. Among different nitrogen management approaches, application of nitrogen based on soil test value along with green manuring (INM) recorded significantly higher plant height at all the stages (38.4, 94.8, 115.1, 115.4 cm at 30, 60, 90 DAT and at harvest, respectively) followed by STBNR and RTNM treatments. The plants were the shortest in organic treatments (*i.e.* GM + 1/3rd N each through FYM and NOC). Rapid growth rate under INM practice could be attributed to adequate nutrient supply to the crops due to rapid mineralisation of N from green manure and absorption by the crop that enhances various metabolic processes increasing net photosynthesis and better mobilisation of synthesized carbohydrate to amino acids and proteins. This in turn stimulated rapid cell division and cell elongation allowing the plants to grow faster [14].

3.2 Tillers per Hill

The tillers/ hill increased up to 60 DAT in both the years and declined thereafter (Table. 3). On an average, the crop produced 10.7, 15.9, and 15.1 tillers/hill at 30, 60 and 90 DAT, respectively. Among the water management approaches, 3 DADPW (W_2) resulted in significantly higher number of tillers/hill (11.2, 16.7 and 15.6 at 30, 60 and 90 DAT, respectively) and it was on a par with soil saturation (W_3). The INM treatment recorded the highest number of tillers/hill *i.e*., 12.1, 17.8 and 16.8 at 30, 60 and 90 DAT, respectively, followed by inorganic practice (STBNR) for the reasons stated earlier. The organic sources of nitrogen (GM + 1/3rd N each by FYM and NOC) produced the minimum number of tillers at all the stages.

Table 1. Initial soil physico-chemical characteristics of the experimental site

Particular	Value	Method employed
I. Mechanical composition of the soil (%)		
Sand	75.2	Bouyoucos Hydrometer Method [10]
Silt	11.5	
Clay	13.3	
Textural class	Sandy loam	
II. Physical characteristic		
Bulk density (Mg/m^3)	1.31	Core method [11]
III. Chemical properties		
pH ((1:2.5:: soil:water))	6.1	Glass electrode pH meter [12]
EC (dS/m) at 25^{o}C	0.51	Digital Electrical Conductivity meter [12]
Organic carbon (%)	0.39	Modified Walkley and Black [12]
Available N (kg/ha)	183.1 (Low)	Alkaline potassium permanganate [13]
Available P (kg/ha)	11.8 (Medium)	Bray's method [12]
Available K (kg/ha)	181.0 (Medium)	Ammonium acetate extraction method [12]

3.3 Leaf Area Index (LAI)

Leaf area index increased progressively up to 60 DAT in both the years and decreased towards maturity (Table 4). The average LAI at 30, 60 and 90 DAT were 1.28, 4.41 and 2.60, respectively. The LAI followed the same trend as that of tillers/hill under both water and nitrogen management approaches. Among the four nitrogen management options, the LAI was the highest in INM treated plots at all the stages in both the years followed by STBNR, RTNM and organic treatment in sequence.

3.4 Dry Matter Accumulation

Dry matter production increased throughout the crop growth period with the average of 5.1, 14.1 and 34.8 g/hill at 30, 60 and 90 DAT, respectively (Table 5). Although the water management approaches did not have any significant impact on dry matter production at 30 DAT, but higher dry matter production was recorded under 3DADPW at 60 and 90 DAT (15.2 and 35.6 g/hill) followed by soil saturation. Nitrogen management approaches significantly influenced the dry matter production at all the stages in both the years. The INM treatment resulted in the highest dry matter accumulation at all the stages, with an average of 5.7, 16.1 and 37.7 g/hill at 30, 60 and 90 DAT, respectively, closely followed by STBNR, which were 21.2, 25.7 and 14.9 per cent higher than RTNM as well as 32.5, 36.4 and 18.5 per cent higher than organic treated plots at respective stages.

More number of tillers, higher LAI and dry matter production were recorded under 3DADPW followed by soil saturation, might be due adequate availability of nutrients which enhanced the root activity. This finding is in conformity with Harishankar *et al*. [15]. The INM practice enhanced the availability and use of nitrogen due to slow release of N from organic source supplemented with readily availability from inorganic fraction, closely matching the N supply with rice N demand that increased the rate of leaf expansion leading to better interception of solar radiation by the canopy, enhanced photosynthesis, nitrogen metabolism, transformation of carbohydrates and oxidation reduction process in plants thereby producing more tillers, LAI and other growth attributes. Singh [16] also reported higher chlorophyll content, tiller number, LAI as well as dry matter production of hybrid rice with 75% RDF + green manuring.

3.5 Yield and Harvest Index

Among the water management approaches, 3 DADPW resulted in significantly higher grain yield (5.28 t/ha) being at par with soil saturation throughout (5.15 t/ha) (Table 6). Both the treatments also produced at par straw yield. Amongst the nitrogen management approaches, INM practice produced the maximum grain yield (5.45 t/ha), which was, on an average, 9.2, 11.9 and 13.5 per cent more than the STBNR, RTNM and organic practice, respectively. Straw yield followed the same trend as that of grain yield under nitrogen management approaches. Different nitrogen and water management approaches did not have any significant impact on harvest index of rice.

Higher grain yield under 3DADPW might be due to rotational irrigation practices, which might have reduced nutrient loss resulting in better uptake of nutrients leading to better yield attributing characters. The findings are in conformity with Sandhu and Mahal [17] and Nayak *et al*. [18]. Green manure crop *dhaincha* was a succulent herbage with high above and underground biomass having low C:N (18:1). On decomposition, N is released to the soil synchronizing with the demand that resulted in better yield attributes and yield. Due to deep root system, green manuring crops also increase P and K availability in plough layer of paddy soil, which is favourable to promote N absorption. In addition to the macro-nutrients (N, P and K), green manuring plants also contain micro-and secondary nutrients (Ca, Mg, Si, Zn, etc.), which promote and maintain the sustainable nutrients supply to the soil. Combining green manuring with N, enhanced the photosynthetic rate, stomatal conductance of rice, effective translocation of assimilates to sink leading to increase in the dry matter accumulation as well as yield attributes. Mankotia [19], Mohanty *et al*. [20] and Wang *et al*. [21] reported better performance of rice crop in INM comprising of green manuring resulting in higher grain and straw yields and harvest index.

Table 2. Effect of nitrogen and water management approaches on plant height (cm) of rice at different stages

Particular	30 DAT			60 DAT			90 DAT			Harvest		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Water management												
W_1	38.2	34.6	36.4	93.2	86.7	89.9	114.8	110.1	112.5	115.8	112.2	114.0
W_2	38.2	34.5	36.3	96.1	88.5	92.3	113.8	110.6	112.2	115.9	112.7	114.3
W_3	38.1	35.6	36.8	93.0	88.1	90.6	114.0	110.1	112.0	114.0	112.1	113.0
W_4	37.8	34.4	36.1	91.2	86.3	88.7	112.8	108.6	110.7	113.2	110.5	111.8
SEm (±)	0.65	0.30	0.36	1.18	0.88	0.74	1.63	0.76	0.90	0.93	0.80	0.61
CD (0.05)	NS	NS	NS	3.8	NS	2.2	NS	NS	NS	NS	NS	1.8
Nitrogen management												
Organic	36.7	33.6	35.2	90.4	84.8	87.6	110.2	106.0	108.1	111.3	107.9	109.6
INM	40.3	36.6	38.4	98.3	91.4	94.8	117.5	112.7	115.1	115.9	114.8	115.4
STBNR	38.2	34.9	36.5	94.1	87.4	90.7	115.6	111.7	113.7	117.7	113.8	115.7
RTNM	37.1	34.1	35.6	90.7	85.9	88.3	112.1	108.9	110.5	113.9	110.9	112.4
SEm (±)	0.72	0.49	0.44	1.83	1.13	1.08	1.65	0.85	0.93	1.30	0.89	0.79
CD (0.05)	2.3	1.6	1.3	5.9	3.6	3.2	5.3	2.7	2.8	4.2	2.8	2.3

Table 3. Effect of nitrogen and water management approaches on tillers/hill of rice at different stages

Particular	30 DAT			60 DAT			90 DAT		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Water management									
W_1	10.8	10.2	10.5	16.0	15.7	15.9	15.5	14.9	15.2
W_2	11.5	10.9	11.2	16.8	16.5	16.7	16.0	15.3	15.6
W_3	11.5	10.8	11.1	16.6	16.3	16.4	15.6	14.9	15.3
W_4	10.4	9.7	10.1	14.6	14.3	14.4	14.4	13.8	14.1
SEm (±)	0.35	0.33	0.24	0.54	0.53	0.38	0.39	0.38	0.27
CD (0.05)	NS	NS	0.7	1.7	NS	1.1	1.3	1.2	0.8
Nitrogen management									
Organic	9.7	9.2	9.4	13.4	13.1	13.3	13.5	13.0	13.2
INM	12.5	11.8	12.1	18.0	17.6	17.8	17.1	16.4	16.8
STBNR	11.8	11.1	11.4	17.2	16.8	17.0	16.3	15.6	15.9
RTNM	10.2	9.6	9.9	15.5	15.2	15.4	14.6	14.0	14.3
SEm (±)	0.34	0.32	0.24	0.45	0.44	0.32	0.30	0.29	0.21
CD (0.05)	1.1	1.0	0.7	1.4	1.4	0.9	1.0	0.9	0.6

Table 4. Effect of nitrogen and water management approaches on leaf area index of rice at different stages

Particular	30 DAT			60 DAT			90 DAT		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Water management									
W_1	1.34	1.24	1.29	4.40	4.23	4.31	2.69	2.53	2.61
W_2	1.37	1.27	1.32	4.73	4.53	4.65	2.76	2.58	2.66
W_3	1.32	1.23	1.28	4.58	4.39	4.48	2.71	2.54	2.62
W_4	1.26	1.21	1.23	4.30	4.12	4.21	2.58	2.45	2.52
SEm (±)	0.036	0.021	0.021	0.206	0.198	0.143	0.061	0.057	0.042
CD (0.05)	NS	NS	NS	NS	NS	0.42	0.20	NS	0.13
Nitrogen management									
Organic	1.13	1.05	1.09	3.86	3.58	3.72	2.58	2.42	2.50
INM	1.47	1.37	1.42	5.05	5.00	5.03	2.80	2.63	2.71
STBNR	1.35	1.28	1.32	5.02	4.67	4.84	2.73	2.56	2.65
RTNM	1.33	1.24	1.28	4.09	4.05	4.07	2.64	2.48	2.56
SEm (±)	0.044	0.030	0.027	0.240	0.181	0.150	0.041	0.039	0.028
CD (0.05)	0.14	0.10	0.08	0.77	0.58	0.45	0.13	0.12	0.08

Table 5. Effect of nitrogen and water management approaches on dry matter production (g/hill) of rice at different stages

Particular	30 DAT			60 DAT			90 DAT		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Water management									
W_1	5.1	4.8	4.9	14.1	13.6	13.9	35.4	34.2	34.8
W_2	5.6	5.4	5.5	15.6	14.8	15.2	36.0	35.3	35.6
W_3	5.4	5.1	5.2	14.6	14.1	14.4	36.4	34.4	35.4
W_4	4.9	4.5	4.7	13.3	12.9	13.1	34.2	32.8	33.5
SEm (±)	0.19	0.21	0.14	0.55	0.75	0.47	1.01	0.97	0.70
CD (0.05)	NS	NS	NS	1.8	NS	1.4	NS	NS	2.0
Nitrogen management									
Organic	4.4	4.1	4.3	12.3	11.4	11.8	32.6	31.0	31.8
INM	5.9	5.6	5.7	16.3	15.9	16.1	38.4	36.9	37.7
STBNR	5.8	5.4	5.6	16.2	15.4	15.8	37.3	36.7	37.0
RTNM	4.9	4.6	4.7	12.8	12.8	12.8	33.6	32.0	32.8
SEm (±)	0.34	0.32	0.23	1.07	1.06	0.75	0.84	1.18	0.72
CD (0.05)	1.1	1.0	0.7	3.4	3.4	2.2	2.7	3.8	2.1

Table 6. Effect of nitrogen and water management approaches on grain yield, straw yield and harvest index of rice

Particular	Grain yield (t/ha)			Straw yield (t/ha)			HI (%)		
	2020-21	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**
Water management									
W_1	5.02	4.76	4.89	7.10	7.24	7.17	41.38	39.85	40.62
W_2	5.42	5.15	5.28	7.53	6.74	7.13	41.92	43.46	42.69
W_3	5.42	4.88	5.15	7.93	6.69	7.31	40.68	42.32	41.50
W_4	4.91	4.67	4.79	7.38	6.61	7.00	39.97	41.60	40.79
SEm (±)	0.155	0.135	0.103	0.183	0.378	0.210	0.700	0.839	0.546
CD (0.05)	0.50	0.43	0.31	0.58	1.22	0.62	NS	NS	NS
Nitrogen management									
Organic	4.94	4.67	4.80	6.94	6.58	6.76	41.68	41.72	41.70
INM	5.73	5.17	5.45	8.09	7.52	7.80	41.54	41.11	41.32
STBNR	5.09	4.88	4.99	7.48	6.63	7.05	40.45	42.44	41.44
RTNM	5.01	4.74	4.87	7.43	6.56	6.99	40.29	41.97	41.13
SEm (±)	0.108	0.097	0.072	0.204	0.236	0.156	0.857	0.735	0.565
CD (0.05)	0.35	0.31	0.22	0.65	0.76	0.46	NS	NS	NS

4. CONCLUSION

Rotational irrigation to rice at 3DADPW resulted in higher grain yield (5.28 t/ha) followed by soil saturation. The INM practice produced higher rice grain yield (5.45 t/ha) as compared to other N-management options, but was at par with STBNR. Integrated nutrient management approach comprising of 75% STBNR (inorganic) *i.e*., 75 kg N/ha + green manuring with *dhaincha along* with irrigation at 3DADPW is the optimal combination for better growth and yield of *kharif* rice.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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