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Production and profitability of maize and soybean grown in rotation in the North-Western Free State, South Africa

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The production and profitability of maize in the North-Western Free State is important for the livelihood of South Africa's population. Most of the country's maize is produced in the area despite its sandy soils and semi-arid climate. Crop rotation has been identified as a management practice which has potential to maintain and improve crop production and profitability. This study's objective was to determine the effect of different rotational systems on the production and profitability of maize and soybean in this area. A field trial was set up where maize, soybean and cover crops were used to compare rotational systems with monoculture maize. Trials were monitored for three consecutive years with yield and enterprise data collected and analysed accordingly. Analysis of variance (ANOVA) showed that although climate played a role, maize in rotational systems with soybean and cover crop performed 14% better than monoculture maize. In addition, soybean production and profitability increased up to 40% over time when incorporated with maize. These results emphasise the importance of crop rotation as a means of ensuring economic viability and agricultural sustainability. It is recommended that maize in the North-Western Free State be grown in rotation with soybean and cover crop to ensure sustainability.

Key words: Crop rotation, maize, North-Western Free State, production, profitability, soybean.

INTRODUCTION

Sustainable agriculture, which aims at improving livelihoods, is the focus of many recent studies (Fehér and Beke, 2013). One of the overarching agricultural sustainability goals with regards to economic viability is enhancing crop production in a profitable way. Crop production and profitability is important as agricultural outputs affect a significant part of any population, either directly or indirectly (Machek and Špička, 2014). The two concepts typically go hand in hand. Productivity is a measurement of physical units and generally defined as the aggregate output versus the aggregate input (Machek and Špička, 2014; O'Donnell, 2010). Increased productivity improves agricultural and non-agricultural resources ultimately maintaining the environment and

improving the standard of living, which is key to economic development (O'Donnell, 2010; Xaba and Masuku, 2013). Maximum profitability (a monetary value calculated by deducted costs from revenue) is achieved by maximising the output from a given resource, or minimising the resources required for a given output (Machek and Špička, 2014; O'Donnell, 2010; Olujenyo, 2008). The more financial stable a farmer becomes, the more likely they are to invest in new technology, equipment and resources which in return again sustains production levels (Atube et al., 2021).

Crop production and profitability is highly dependent on crop management (Feng et al., 2021). Crop rotation is an on-farm strategy that has potential to decrease production risks and increase profitability by optimising nutrient availability, managing pests and diseases, suppressing weeds, enhancing soil structure and buffering the effects of extreme climate conditions (Acevedo-Siaca and Goldsmith, 2020; Meena et al., 2018). Maize-soybean rotations are ideal in that they require simple management, similar equipment, sufficient seed availability, and they have relatively high market prices (Feng et al., 2021). However, the challenge is to find sustainable systems that are suitable for a specific environment (Strauss et al., 2021). Rotational effects are known to be site-specific (Acevedo-Siarca and Goldsmith, 2020) and little is known about their effects on sandy soils. Therefore, this study looks at the production and profitability of different rotation systems in the North-Western Free State, which is known for its extremely sandy soils. The authors hypothesise that maize and soybean production and profitability will be improved by rotational systems.

MATERIALS AND METHODS

Site description

The study was conducted in the North-Western Free State, South Africa. Almost half of the country's maize is produced in the Free State (Hensley et al., 2006), with the North-Western section forming part of what is known as South Africa's 'maize quadrangle' (Figure 1). Typical weather conditions include hot summers, mild winters and an annual rainfall of approximately 500 mm per year (Hensley et al., 2006; Nortjè and Laker, 2021). Despite its sandy soils with little to no organic material a layer of clay about 1.5 to 2 m deep, prevents water drainage, forming temporary water tables contributing to the area's maize success (Beukes et al., 2019).

Trial layout and conditions

A trial comparing different crop rotation systems (maize-cover crop-soybean (MCS), maize-soybean-maize (MS) and maize-maize-soybean (MMS)) with monoculture maize (MM) as a control was established on the farm Christinasrus. The MMS system was further identified as MMS1 and MMS2 to distinguish between the first (MMS1) and second (MMS2) season of maize. The cover crop mixture was made up of 60% grasses (sorghum and pearl millet) and 40% legumes (dolichos and cowpeas).

A randomised complete block design with three replicates was used for the trial layout. Plots were 80 × 24.4 m in size. Rotational systems were assigned to plots and each crop within each system, representing a different stage, was assigned to a plot in each season to be able to distinguish between seasonal and rotational effects. The trial was monitored for three consecutive seasons (2020/2021, 2021/2022 and 2022/2023).

At the start of each season, prior to planting, the soil was cultivated with a tandem ripper at a depth of 750 mm. Pre-plant fertiliser was applied to all plots. Maize, soybean and cover crop were planted in each December, respectively. Maize was additional fertilised at planting and top-dressed while soybean and the cover crop received no additional fertiliser. Maize and soybean plots were sprayed with round-up (glyphosate) for the control of weeds.

The first season (2020/2021) experienced favourable rainfall conditions, with a seasonal rainfall of 689 mm. The second season (2021/2022) was very wet, with a seasonal total of 922 mm (309 mm was measured in December 2021 alone). A more wide-spread rainfall was experienced in the third season (2022/2023), with a seasonal total of 700 mm.

Sample collection

Maize and soybean were combine-harvested using commercial farm equipment in September of each season, respectively. Their weights were determined electronically. Yield results and industry data were used for further enterprise analysis. The cover crop yield was measured by cutting aboveground plant material over a randomly selected two rows 2 m length. Plant material was placed in a plastic bag and weighed. Sub samples were taken and the moisture content determined to calculate dry biomass.

Analysis

Enterprise analysis was conducted for maize and soybean production. The seasonal commodity price for maize and soybean together with the yield data were used to determine the gross production value for each crop in each rotational system. Input costs were calculated from total specified costs and deducted from gross production values to obtain a gross margin for each crop in each rotational system.

Yield data were cleaned and prepared for SPSS version 29 where it was further analysed using descriptive and inferential statistics. Descriptive statistics included means as measures of central tendency while inferential statistics included one-way and two-way analysis of variance (ANOVA), which were run to determine if there was a statistically significant interaction effect of rotational system and season on yield. The data met the requirements for ANOVA and assumptions including testing for outliers, normal distribution, and homogeneity of variances were met. Post hoc Least Significant Difference (LSD) tests were run for statistically significant ANOVA results. Statistical significance was accepted at $p \leq 0.05$.

RESULTS

Maize yields

Maize yield is as shown in Figure 2 and varies from 1.69 to 8.49 ton ha^{-1}. The two-way ANOVA results showed that the maize yield was affected by rotational system ($F(4) = 4.17$, $p = 0.01$) and season ($F(2) = 61.78$, $p < 0.001$). There was also a statistically significant interaction between these variables, $F(8) = 2.61$ $p = 0.03$.
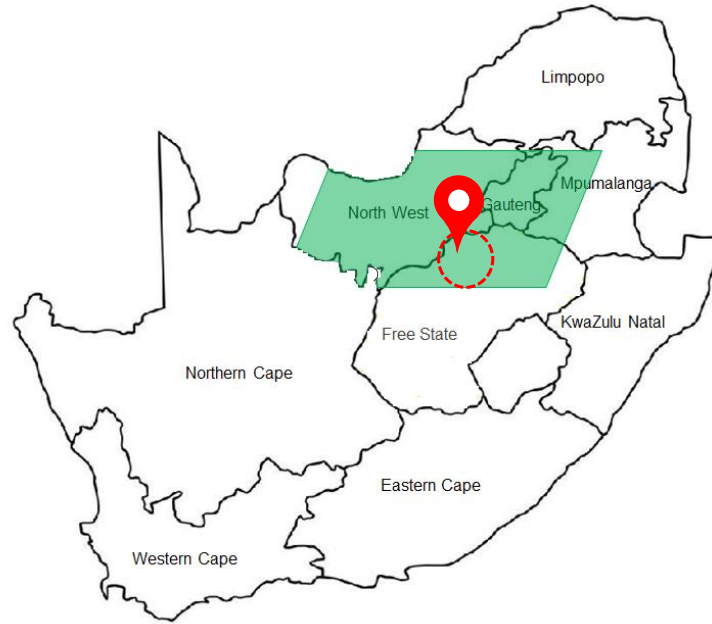
Figure 1. Map of South Africa showing the location of the trial and sample collection.
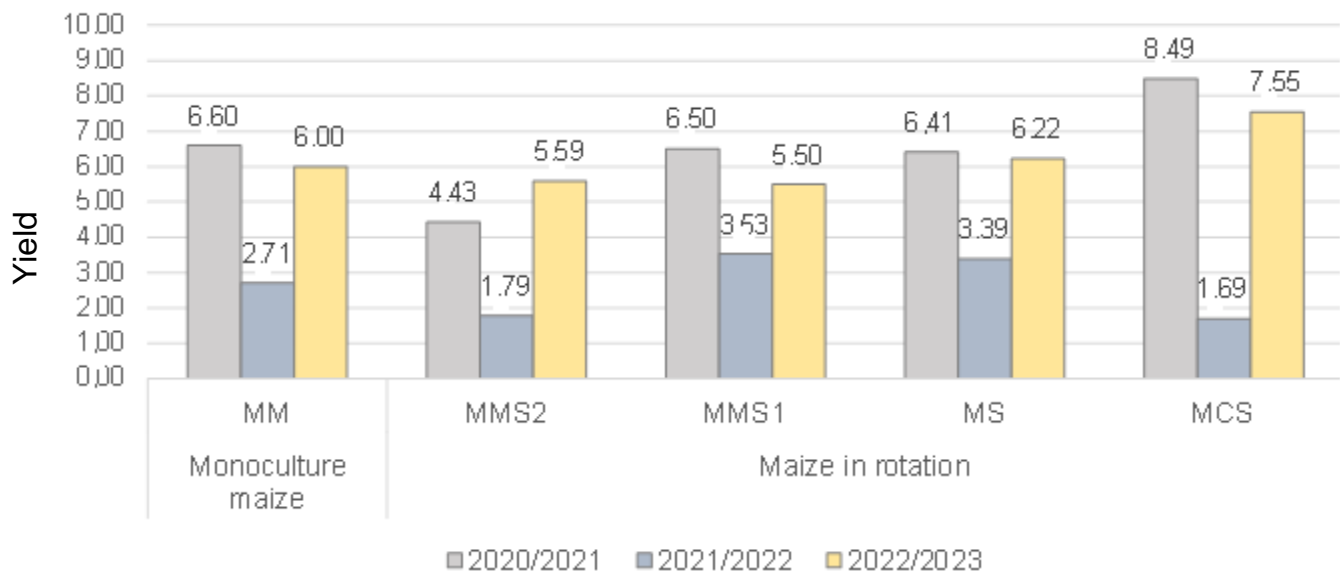Source: Compiled and designed by authors.

Figure 2. Mean maize yield in different rotational systems for three seasons (2020/2021 - 2022/2023).
Source: Author's computation.

Maize in the MCS rotational system had the highest mean yield (5.91 ton ha^{-1}), 14% higher than the mean yield for monoculture maize. Maize in the MMS2 system had the lowest mean yield and was statistically significantly lower than all other systems ($p < 0.05$). Additional analysis showed that maize yields after soybean were 18% higher than maize yields after maize, this difference was statistically significant ($F(1) = 6.08$, $p = 0.02$). LSD results showed that the mean maize yield was statistically significantly different from the second season (2021/2022), with maize yield from this season being 58 to 60% lower than season one (2020/2021) and
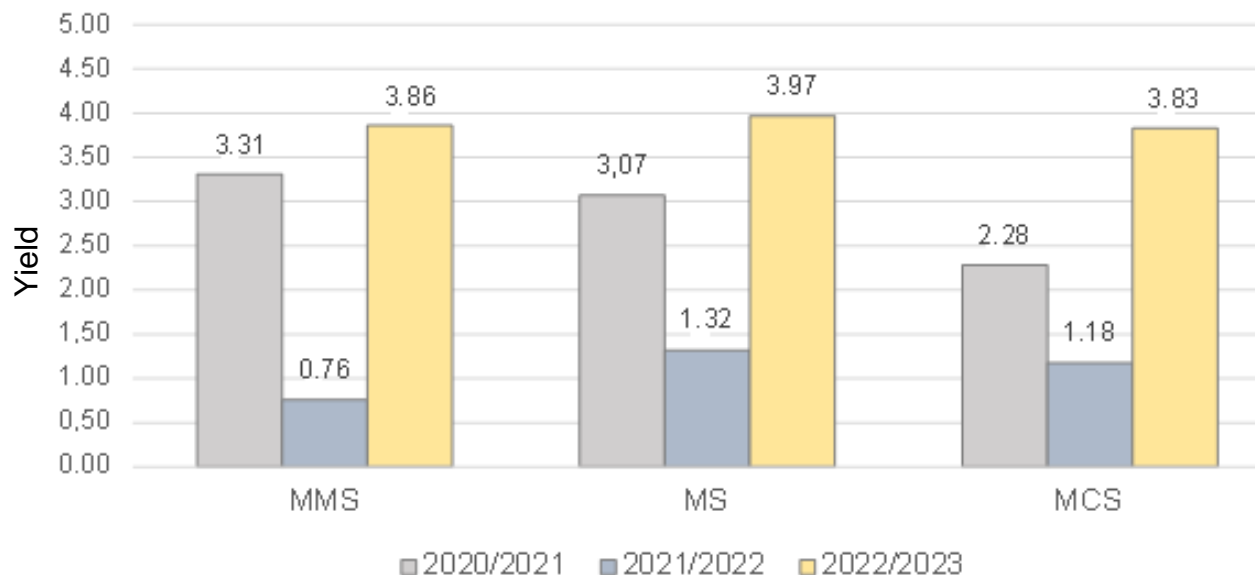
Figure 3. Mean soybean yield in different rotational systems for three seasons (2020/2021 - 2022/2023).
Source: Author's computation.

season three (2022/2023).

Soybean yields

The soybean yield ranged from 0.76 to 3.97 ton ha^{-1} and showed an overall improvement from the first season (2020/2021) to the third season (2022/2023) (Figure 3). The MCS rotational system had the greatest improvement of 40%. The two-way ANOVA results showed that soybean yield was not affected by rotational system but was affected by season ($F(2) = 140.60$, $p = 0.03$). LSD results showed that all season's soybean yield differed significantly ($p < 0.05$). There was also a statistically significant interaction that affects between rotational system and season, $F(4) = 3.32$, $p = 0.03$. The MMS rotational system was the rotational system with the highest soybean yield in the first season (2020/2021), 9% more than MS and 33% more than MCS. In the wetter second (2021/2022) and following third season (2022/2023) soybean in the MS rotational system performed up to 42% better than the MMS rotational system.

Cover crop yields

The mean cover crop biomass ranged from 2.64 to 11.37 ton ha^{-1} (Figure 4). ANOVA and LSD results showed that the cover crop biomass was statistically significantly different between seasons ($p \leq 0.05$). The highest cover crop biomass was in season one (2020/2021), 35% higher than season two (2021/2022) and 78% higher than

season three (2022/2023). The third season's cover crop biomass was well below the expectation of at least 7 ton ha^{-1}, and was therefore regarded as a failure.

Enterprise analysis

The results for the enterprise analysis for maize and soybean production are shown in Table 1. The highest gross margin for maize production was seen in the MCS rotational system in 2020/2021 (R16 604.50 ha^{-1}) and 2022/2023 (R15 949.96 ha^{-1}), 32 to 33% more than the gross margin for maize production of monoculture maize in the respective seasons. In the unfavourable second season (2021/2022), the MMS1 rotational system had the highest gross margin (R2960.65 ha^{-1}), 95% more than the gross margin for maize production of monoculture maize (R136.66 ha^{-1}). Soybean production in the MMS rotational system had the highest gross margin in the first season (2020/2021), while soybean production in the MS rotational system did better in the second and third season (2021/2022 and 2022/2023), resulting in an overall 14% higher gross margin for soybean production in the MS rotational system compared to the MCS and MMS rotational systems. Estimating the gross margin of the cover crop, the mean gross margin of the rotational systems were: MS (R11 153.87) > MCS (R9 755.00) > MMS (R8 064.92) > MM (R7 349.66).

DISCUSSION

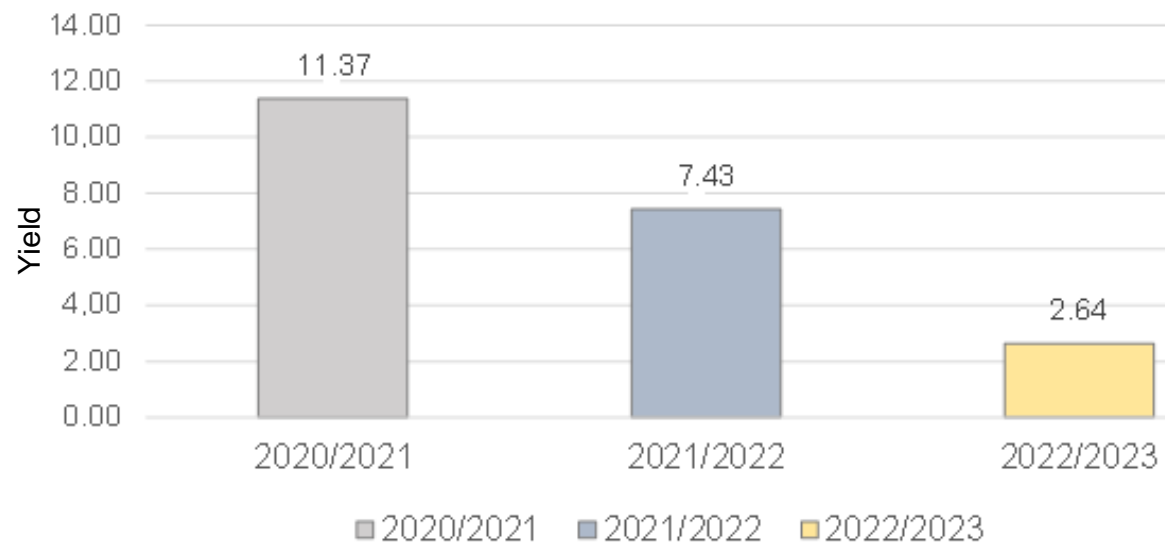The production of maize and soybean were in line with

Figure 4. Mean cover crop biomass in different rotational systems for three seasons (2020/2021 - 2022/2023). Source: Author's computation.

Table 1. Enterprise analysis for the study period.

Season	Crop	Commodity price (ton⁻¹)	Rotational system	Average yield (ton ha⁻¹)	Gross production value	Input costs (ha⁻¹)	Gross margin (ha⁻¹)	Break-even yield (ton ha⁻¹)
			MM	6.60	R18 810.00	R7 520.00	R11 290.00	2.64
			MMS2	4.43	R12 625.50	R7 457.00	R5 168.50	2.62
	Maize	R2850,00	MMS1	6.50	R18 525.00	R7 417.00	R11 108.00	2.60
			MS	6.41	R18 268.50	R7 513.00	R10 755.50	2.64
2020/2021			MCS	8.49	R24 196.50	R7 592.00	R16 604.50	2.66
			MMS	3.31	R24 163.00	R6 441.00	R17 722.00	0.88
	Soybean	R7300,00	MS	3.07	R22 411.00	R6 432.00	R15 979.00	0.88
			MCS	2.28	R16 640.00	R6 411.00	R10 229.00	0.88
			MM	2.71	R9 495.66	R9 358.00	R137.66	2.67
2021/2022	Maize	R3500,00	MMS2	1.79	R6 268.73	R9 310.00	-R3 041.27	2.66
			MMS1	3.53	R12 361.65	R9 401.00	R2 960.65	2.69

Table 1. Cont.

			MS	3.39	R11 875.36	R9 394.00	R2 481.36	2.68
			MCS	1.69	R5 912.14	R9 305.00	-R3 392.86	2.66
			MMS	0.76	R6 411.45	R7 281.00	-R869.55	0.86
	Soybean	R8490,00	MS	1.32	R10 016.42	R7 311.00	R3 916.06	0.86
			MCS	1.18	R11 227.06	R7 303.00	R2 713.41	0.86
			MM	6.00	R21 003.62	R10 383.00	R10 620.61	2.97
			MMS2	5.59	R19 578.23	R10 362.00	R9 216.23	2.96
	Maize	R3500,00	MMS1	5.50	R19 250.69	R10 357.00	R8 893.68	2.96
			MS	6.22	R21 784.04	R10 390.33	R11 393.70	2.97
2022/2023			MCS	7.55	R26 413.96	R10 464.00	R15 949.96	2.99
			MMS	3.89	R31 643.01	R10 098.00	R21 545.01	1.23
	Soybean	R8200,00	MS	3.97	R32 516.72	R10 103.00	R22 413.72	1.23
			MCS	3.83	R31 385.94	R10 096.00	R21 289.94	1.23

Source: Author's computation.

that produced nationally in South Africa. The average maize production of 5.10 ton ha^{-1} was above the average national maize production of 3.60 ton ha^{-1} during the study period (Boakye, 2023). Similarly, the average soybean production was 2.62 and 0.32 ton ha^{-1} above the national soybean production over the study period (Van der Linde, 2023). The production results were proportional to profitability results with similar trends being identified between the two for both maize and soybean. Maize production was affected by rotational systems with maize yields after soybean generally higher than maize yield after maize. This was expected as a number of studies have shown that maize grown after soybean gives higher yield than maize after maize (Crookston et al., 1991; Meese et al., 1991; Porter et al., 1997; Stanger et al., 2008). This supports

the notion that crops grown in rotational systems promote better yield, possibly due to optimised nutrient availability, management of pests and diseases, suppressed weeds and enhanced soil structure (Acevedo-Siaca and Goldsmith, 2020). Acevedo-Siaca and Goldsmith (2020) further mentioned that the incorporation of soybean in maize-rotation not only has a benefit for the maize crop but also improves soybean yield. This was the case for soybean production in this study, with an overall improvement from season one (2020/2021) to season three (2022/2023). It appears that soybean tolerated waterlogging conditions better than maize in the sandy soil. This could be due to the ability of soybean to form secondary aerenchyma (which is different to primary aerenchyma formed by maize), a type of tissue that enhances aeration and transports

oxygen to roots (Boru et al., 2003; Takahashi et al., 2014). Furthermore, soybean also has the ability to form a barrier that prevents oxygen leakage and enhances O_2 diffusion to root tips (Langan et al., 2022).

The MCS rotational system performed the best over the study period, confirming that including a cover crop as a third crop in rotational systems with maize and soybean improve the system's productivity (Magdoff and Van Es, 2021; Smit et al., 2021). Benefits associated with cover crop include minimising runoff and soil erosion, preventing runoff and increasing organic matter, which is a principal source of energy for soil microorganisms (Lal, 2016; Magdoff and Van Es, 2021). Although the MCS rotational system performed best overall, the rotational systems were dependent on the season with the MMS1

system outperforming MCS in the wetter second season (2021/2022). The anaerobic conditions formed in waterlogged MCS plots suppressed growth and caused excessive damage, negatively affecting its maize yield (Horneck et al., 2011). In addition, the cover crop consisted of sorghums, which are known to produce sorgoleone (Sarr et al., 2020). Sorgoleone has allelopathic properties which can suppress the growth and yield of the proceeding crops in certain seasons, especially on sandy soil (Bansal, 2020; Sarr et al., 2020). *Trichoderma viride* and *Aspergillus* species are some organisms that are responsible for the loss of sorgoleone (Bansal, 2020) and could have been inhibited during the second season (2021/2022), resulting in a poorer performance of maize and soybean in the MCS rotational system.

Although no single rotational system dominated over seasons, it can be noted that monoculture maize never had the top-ranking position, while maize after soybean (MCS and MMS1) always performed better, with MS having the highest mean gross margin over the study period. Soybean, and the legumes in the cover crops, are able to fix atmospheric nitrogen in symbiosis with *Rhizobium* bacteria resulting in natural fertilisation which allows for a slower release of nutrients over a longer period of time ultimately enhancing production (Coskan and Dogan, 2011; Hernandez et al., 2021).

CONCLUSION AND RECOMMENDATIONS

Maize in rotation with soybean has potential to increase the production and profitability of each crop, respectively. Based on the results, farmers in the North-Western Free State are encouraged to introduce soybean and cover crops in rotation with maize to improve production and profitability, resulting in agricultural sustainability. However, policy makers, farmers and other stakeholders should keep in mind that season plays a major role in the success of these rotational systems. The prediction of more extreme weather conditions in the future (Chemura et al., 2022) should be taken into consideration with systems excluding cover crops having the potential to perform better in wetter conditions. Unfortunately, the effect of these site-specific rotational systems in dry seasons is not known and should be prioritised in future research.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

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