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Effect of Groundnut Shell Amendment and Tillage Implements on Soil Properties, Growth and Yield of Rainfed Sorghum

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Authors' contributions

This work was carried out in collaboration between both authors. Author AHS prepared and wrote the manuscript. Author MAH revised the manuscript. Both authors read and approved the final manuscript.

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Abstract

In most rainfed areas, crop productivity is strongly affected by lack of soil fertility and unreliable rainfall. Therefore, enhancing soil organic carbon as well as selecting the right tillage methods that improves soil condition is highly needed. A field experiment was conducted at the training and research farm in the Centre for Dryland Agriculture, Bayero University, Kano, Nigeria, to investigate the effect of groundnut shells as soil amendment using different tillage implements on growth and yield of rain-fed sorghum. The treatments consisted of three groundnut shell rates (0 t/ha, 5 t/ha and 10 t/ha) and three types of tillage implements viz. cultivator, rotavator and offset disc harrow. The results showed the application of groundnut shells significantly decreased the values of soil bulk density and increased soil water storage compared to non-application (0 t/ha). Water holding capacity and soil water storage were significantly affected by different tillage implements. Both cultivator and the offset disc harrow had higher values of water holding capacity and soil water storage in comparison with the rotavator. However, the effect of different groundnut shell rates and

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tillage implements on soil organic carbon was not significant. Moreover, the application of groundnut shell compared to non-application had a positive influence on sorghum plant height, stem girth, leaf area index and days to 50% heading; as well as it is increased both sorghum grain and stover yield by 20.9% and 17.3%, respectively, at 10 t/ha rate and by 13.5% and 10.9%, respectively, at the rate of 5 t/ha. On the other hand, the tillage implements did not show a significant effect on the sorghum growth and yield attributes except on 1000 seed weight, where it was higher under rotavator followed by cultivator.

Keywords: Groundnut shell; soil amendments; tillage implements; rainfed sorghum; soil properties.

1. Introduction

Sorghum [*Sorghum bicolour* (L.) Moench] is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic staple food for many rural communities. Sorghum plays an important role in the diets and economies of people in Kano state and Nigeria at large, Kano is one of the highest Sorghum producing state in Nigeria, yet, majority of domestic production are used for household consumption in many rural communities in the state. Also *Sorghum* is a very important crop serving as a primary source of food, beverage, and total livelihood for millions of people in the country as well as a fodder for animals.

In arid and semi-arid regions, crop productivity is strongly influenced by soil fertility and moisture retention capacity. Restoring soil health and enhancing soil organic carbon are essential for improving and sustaining agronomic productivity. A high soil organic carbon can be achieved through the adoption of appropriate crop rotations, integrated nutrient management systems and conservation agriculture practices. Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2008). Conservation agriculture is characterized by three sets of practices namely minimal mechanical soil disturbance, maintaining organic matter soil cover, especially by crop residues and cover crops and diversified crop rotations in the case of annual crops or plant associations in case of perennial crops, including legumes. In Nigeria, the soils of the Guinea savanna zone are inherently low in soil fertility, especially of nitrogen and organic matter with resultant low crop yields (Nottfige et al., 2005).

Groundnut shells are an agricultural by-product from an oilseed leguminous crop groundnut. The addition of groundnut shells as organic amendments increases nutrient levels such as carbon, nitrogen, phosphorus and calcium structure and reduces soil salinity (Mojiri et al., 2011). Bako et al., (2022) found that growth and yield of maize were significantly influenced by different levels of groundnut shells incorporation and improved soil physical and chemical properties as well. Dioumacor et al., (2018) also stated that, peanut shells application improved soil chemical properties and reduced soil salinity.

Rain-fed farming is the most widely practiced and most vulnerable to crop failure due to insufficient or unequal rainfall distribution. According to previous studies, the productivity of the main crops in the traditional rain-fed sub-sector is very low compared to their productivity in other sectors. The major constraints contributing to low yield of sorghum in rain-fed sub-sector are low soil fertility and unreliable rainfall. Low productivity in the traditional rain-fed sub sector is the main reason of low income, and has resulted in substantial migration to urban areas. Cultivation of groundnut is widely spread in Sudan and West African countries namely Nigeria, Gambia, Senegal, Chad, Ghana and Niger (Vara Prasad et al., 2010). It is used mainly for oil extraction, roasted nuts and peanut butter. A huge amount of groundnut shells is produced as waste each year. There is a necessity to investigate new opportunities for the usage of groundnut shell as organic materials. Application of groundnut shell as soil amendments for improving soil condition is rarely used. Moreover, the availability of fertilizer as agricultural input is usually inadequate and at prices substantially higher. On the other hand, an excessive input of chemical fertilizers, especially nitrogen fertilizers, led to a variety of environmental problems, such as the decrease of nutrient utilization efficiency, the acceleration of soil organic carbon loss, and the destruction of soil structure (Corato, 2020; Zhao et al., 2021). According to Nirmala & Vasavi, (2018) the use of peanut waste in agriculture can reduce the need for chemical fertilizers and it restores organic carbon deficiency in soils. Therefore, continuous application of organic matter as farm compost, farmyard manure and plant residues such as groundnut shells is needed to maintain soil organic matter and increase crop productivity. Similarly, selecting of appropriate tillage implements that conserve more soil moisture in rainfed areas, improve soil physical properties and increase crop yields it is needful. Hence, the general objective of this study was to investigate the effect of groundnut shells as soil amendment using different tillage implements on growth and yield of rain-fed sorghum.

2. Materials and Methods

The study was conducted during the rainy season of 2024 at the training and research farm (Latitude 11° 58' N and Longitude 8° 26' E) in the Centre for Dryland Agriculture, Bayero University, Kano, Nigeria. The farm is situated at an altitude of 475 meters above sea level.

Prior to experimentation, soil samples were collected and analyzed for physical and chemical properties using standard methods and procedures (Table 1). The experiment treatments consisted of three tillage implements (the cultivator, the offset disc harrow and the rotavator) and three different rates of groundnut shell (10 t/ha, 5 t/ha and 0 t/ha). The experiment was laid out in strip plot design with three replications. The tillage implements assigned as vertical treatments and three groundnut shell rates as horizontal treatments, each plot was 22 m long and 4 m wide (each subplot was 7 m long). Crushed groundnut shells were applied manually on the specific area before tillage operation and planting. A tractor of Landini 80 hp used in the trail and the tillage implements made only one pass during the tillage operation. The tillage implement width and average working depth are as shown in Table 2. A sorghum cultivar SAMSORG 49 was used, sown at 75 cm inter-row and 25 cm intra-row spacing, with the seed rate of 3 seeds per hole and later thinned to one per hole. The fertilizer of NPK 15:15:15 was applied at ten days after sowing (DAS), while the balance of urea was side placed at four weeks after sowing (WAS). Weed control was done manually 3 times at intervals of 2 – 4 weeks. Sorghum harvesting was done manually; the panicles were cut, dried, threshed and cleaned.

The plant growth data collected were plant height, number of leaves per plant, stem diameter, chlorophyll content, leaf area index, plant dry matter and days to 50% heading. Five plants per plot were selected at random and tagged. Plant height of tagged plants was measured from the ground level to the tip of the plant using measuring tape at 4, 6 and 8 WAS then the average was taken and recorded. The number of leaves per plant was counted at 4, 6 and 8 WAS. The stem diameter of tagged plants was measured at 8 and 10 WAS using digital caliper. Leaf chlorophyll content of tagged plants was measured using chlorophyll meter SPAD-502 plus from the fully matured leaves counted from the top of the plants at 6 and 8 WAS. The leaf area index was measured using ceptometer at 8 and 10 WAS. Plant dry matter was obtained by choosing randomly five plants then cut aboveground, packed in an envelope and oven dried at 6 and 8 weeks after sowing, the dried plants were weighed and their means were recorded. The days to 50% heading was done by counting the number of days from planting to when half (50%) of the plants on each plot produced head. While the yield characteristics were as follows: Panicle length which was determined using meter rule on six randomly selected panicles. Panicle weight was determined by weighing the selected panicles using 10 kg top loader weighing balance. For 1000 grain weight the samples of grains were taken from the produce of each treatment plot and then 1000 grains were separated by counting from each sample and weighed using an electronic balance. Grain yield per hectare which was obtained by weighing the threshed grains from each net plot then converted to kilogram per hectare using the following formula:

$$\text{Grain yield (kg/ha)} = \frac{yield\ per\ net\ plot\ (kg)}{net\ plot\ area\ (m^2)} \times 10000\ \text{m}^2$$

Stover weight (kg/ha) was obtained by cutting all the stover of the rows on net plot area (m^2), sun dried and weighed then converted to hectare. Harvest index was calculated using the following equation:

$$\text{Harvest index} = \frac{grain\ yield\ per\ plot\ \ kg/ha}{biolgical\ yield\ per\ plot\ \ \ kg/ha}$$

Soil samples at depths 0 – 15 and 15 – 30 cm were taken in each plot to determine soil bulk density, soil water storage, organic carbon and water holding capacity, the total nitrogen, the phosphorus and potassium. The soil bulk density was measured using the core method during the sorghum growth stage. Soil water storage (SWS) is defined as the total amount of water that is stored in the soil within the plant's root zone. Soil water storage at specific depth was calculated by multiplying the mean soil volumetric water content by the soil profile depth (Zhang et al., 2018b). Soil organic carbon was determined as suggested by Walkley & Black (1934). Water holding capacity refers to the amount of water held between field capacity and wilting point. It was determined using the pressure plate apparatus (PPA) method by applying various soil suctions and measuring the changes in soil water content.

Data collected were analyzed using Statistix 8 software computer program for analysis of variance and least significant difference (LSD) used to compare treatment means at the 5% significance.

Table 1. Soil physical and chemical properties of the experimental site

Property	Depth	
	0 - 15 cm	15 - 30 cm
Clay %	14.56	19.23
Silt %	30.54	20.67
Sand %	54.90	60.10
Textural class	Sandy loam	Sandy loam
pH (1:1)	5.91	5.72
Organic carbon (%)	0.45	0.62
Nitrogen (%)	0.05	0.05
Phosphorus (mg/kg)	8.86	6.39
Potassium (cmol(+)/kg)	0.20	0.33
Calcium (cmol(+)/kg)	2.25	1.84
Sodium (cmol(+)/kg)	0.10	0.09
Magnesium (cmol(+)/kg)	0.69	0.55
Effective cation exchange capacity (cmol(+)/kg)	3.38	2.81

Table 2. Tillage implements width and average working depth

Tillage Implements	Number of units	Working width (m)	Tillage depth (cm)
Offset disc harrow	12 discs	2.28	22
Cultivator	No. of shovels 13	3.28	29
Rotavator	No. of working components 42 (7 flanges and 6 blades)	2.45	15

3. Results and Discussion

3.1 Effect of Tillage Treatments and Groundnut Shell Rates on the Soil Bulk Density:

The application of groundnut shell had a significant effect ($P<0.05$) on soil bulk density (Table 3). It was observed that the application of groundnut shell compared to control (0 t/ha) led to significant decrease in soil bulk density. This implies the soil bulk density could be altered by adding groundnut shell to the soil and this in turn might help in protection the soil surface (structure) from the harmful effect of raindrops as well as increasing the amount of organic matter. This result is in accord with Bako et al., (2022) they reported soil bulk density was decreased with increase in groundnut shell application rate. On the other hand, tillage methods did not significantly affect ($P>0.05$) soil bulk density (Table 3). The rotavator compared to the cultivator and offset disc harrow showed slight reduction in bulk density. The results are similar to the findings of Bhattacharyya et al., (2006) and Jabro et al., (2024). The interaction between tillage methods and groundnut shell did not show significant difference.

3.2 Effect of Tillage Treatments and Groundnut Shell Rates on the Water Holding Capacity and Soil Water Storage

Tillage practices had a significant effect ($P< 0.05$) on water holding capacity and water storage (Table 3).The highest values of water holding capacity and water storage were obtained under the cultivator and offset disc harrow while the rotavator recorded the minimum values. An increase in water holding capacity and soil water storage under the cultivator and the offset disc harrow could be due to creation of a rough soil surface that conducive to conserve more moisture and prevent the process of soil capping and thus more water infiltrated into the soil. These results are similar to those obtained by Yu et al. (2023) and Bama et al., (2017).

Soil water storage increased significantly with the application of groundnut shells as shown in Table 3. It was higher at the rate of 5 t/ha followed by the rate of 10 t/ha, while the lowest value was at the control (0 t/ha). An improvement in soil water storage with the application of groundnut could be attributed to the favorable effect of groundnut shell on soil physical properties such as soil structure in terms of pore and aggregate distribution particularly in the soil with high sand content, which directly affect the water stored in the soil. Similar findings observed by Nie et al., (2024), who reported the application of organic fertilizer increased the soil water content.

Table 3 shows water holding capacity was not significantly affected by the application of different rates of groundnut shell. However, the application rate of 10 t/ha showed a tendency to increase in water holding capacity by 6.7% and 18.6% when compared with the rates of 5 t/ha and 0 t/ha, respectively. The result is in consistent with Panagea et al., (2021). They observed that adding exogenous organic materials led to increase in soil water retention and water holding capacity. The interaction effect of different tillage methods and groundnut shell rates on water holding capacity and water storage was not significant.

3.3 Effect of Tillage Treatments and Groundnut Shell Rates on the Organic Carbon

Effect of the different tillage methods and groundnut shell rates was not significant (*P>0.05*) (Table 3). However, the application of groundnut shell rate 10 t/ha in comparison with the rates of 5 t/ha and 0 t/ha showed increase in the value of organic carbon by 11.9% and 20.9%, respectively. So, frequent application of groundnut shell could be one of the practices leading to increase and conserve organic carbon of the soil. The result agreed with Bako et al., (2022), they observed the soil organic matter was increased by the application of groundnut shells. On the other hand, the cultivator also recorded the highest value of organic carbon was 0.63% followed by the offset disc harrow was 0.60%, while the lowest value of 0.56% obtained by the rotavator. An increase of organic carbon value under the cultivator may be due to the mode of operation as loosening, crumbling and mixing; this in turn help in preserving soil structure and subsequently reducing the loss of carbon. A similar finding was observed by Khan et al., (2017) and Mishra et al., (2019).The interaction between tillage practices and groundnut shell did not significantly affect soil organic carbon.

3.4 Effect of Tillage Treatments and Groundnut Shell Rates on Soil N, P and K

The effect of tillage implements and groundnut shell rates on the total N, P and K is presented in Table 3. Application of groundnut shell did not show a significant influence on the N, P and K. However, groundnut shells rates 5 and 10 t/ha both increased the N by 20% compared to no application. Also there was increase in P by 17.1% and 16.4% at rates 5 t/ha and 10 t/ha, respectively. Nevertheless, it observed the application of groundnut shell reduced the K.

On the other hand, the total percentage of N was significantly higher under the cultivator as compared to the rotavator and offset disc harrow. While the P and K was not significantly affected by the tillage implements. An improvement in total percentage of N under the cultivator could be due to benefits as enhancing soil aeration and mixing materials into the soil, and this in turn boosts the soil biological activity as well as speedup the decomposition of the organic material mixed into the soil. The interaction effect of different tillage methods and groundnut shell rates on soil N, P and K was not significant.

Table 3. Effect of different tillage implements and groundnut shells rates on soil bulk density, organic carbon, water holding capacity and water storage

Treatments	BD (g/cm^3)	W H C (cm^3/cm^3)	S W S (mm)	O C (%)	N (%)	P mg/kg	K (cmol(+)/kg)
Cultivator	1.48	32.44 ^{a}	30.08 $^{a\,b}$	0.63	0.06	4.54	0.23
Disc harrow	1.43	21.71 ^{b}	36.04 ^{a}	0.60	0.04	6.93	0.26
Rotavator	1.38	12.71 ^{c}	24.11^{b}	0.56	0.05	5.85	0.22
LSD $_{0.05}$	NS	4.03	8.51	NS	0.00	NS	NS
Shell rate 0 t/ha	1.61 ^{a}	19.81	27.94^{c}	0.53	0.04	5.09	0.27
Shell rate 5 t/ha	1.33 ^{b}	22.70	32.57 ^{a}	0.59	0.05	6.14	0.20
Shell rate 10 t/ha	1.35 ^{b}	24.34	29.69 ^{b}	0.67	0.05	6.09	0.24
LSD $_{0.05}$	0.15	NS	1.15	NS	NS	NS	NS

Means having the different superscript letter (s) are significantly different at (P<0.05) NS: not significant (P>0.05), BD: bulk density, WHC: water holding capacity, SWS: soil water storage, OC: organic carbon

3.5 Effect of Tillage Treatments and Groundnut Shell Rates on Sorghum Growth Attributes

Effect of tillage treatments and groundnut shell rates on the studied growth attributes is shown in Tables 4 and 5. The application of groundnut shells as compared to the control (no application 0 t/ha) led to a significant effect (*P< 0.05*) on the sorghum plant height, stem diameter, leaf area index, dry matter and days to 50% heading. The highest values of plant height in all readings were obtained at the rate of 10 t/ha followed by the rate 5 t/ha. The same trend was observed with regard to the leaf area index and dry matter. However, the stem diameter was higher at the rate of 5 t/ha followed by the rate of 10 t/ha. Furthermore, the rates 10 t/ha and 5 t/ha both recorded the shortest days to 50% heading compared to the control. The positive impact on the growth characteristics could be attributed to beneficial effects of groundnut shell on soil water relation. The results are in agreement with Bako et al., (2022). They found the application of groundnut shell had a positive effect on maize growth characteristics.

No significant differences were observed among tillage practices in all sorghum growth attributes. However, there was slight increase among the growth attributes under the rotavator compared to the cultivator and the offset disc harrow. Similar findings reported by Khalil et al., (2021). The interaction effect of tillage treatments and groundnut shell was not significant.

Table 4. Effect of different tillage implements and groundnut shells rates on sorghum plant height, number of leaves and stem girth

Treatments	Plant height (cm)			Number of leaves per plant			Stem girth (mm)	
	4 WAS	6 WAS	8WAS	4WAS	6WAS	8WAS	8WAS	10WAS
Shell rate 0	33.96 [b]	74.53 [b]	103.67 [b]	7.11	9.22	11.67	20.10	23.71 [b]
Shell rate 5	39.56 [a]	83.89 [a]	116.11 [ab]	7.44	10	12.44	22.40	26.64[a]
Shell rate 10	41.40 [a]	86.41[a]	120.11 [a]	7.67	10.33	12.22	22.93	26.50 [a]
$LSD_{0.05}$	4.39	8.96	12.93	NS	NS	NS	NS	2.40
Cultivator	34.82	76.10	107.33	7.22	9.67	11.67	23.62	26.80
Disc harrow	37.60	80.83	110.33	7.22	9.56	11.78	19.34	24.09
Rotavator	42.49	87.91	122.22	7.78	10.33	12.89	22.46	25.98
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS

Means having the different superscript letter (s) are significantly different at (P<0.05) WAS: weeks after sowing, NS: not significant (P>0.05)

Table 5. Effect of different tillage implements and groundnut shells rates on sorghum chlorophyll content, leaf area index, Dry matter and Days to 50% heading

Treatments	chlorophyll content		leaf area index		Dry matter		Days to 50%
	6 WAS	8WAS	8WAS	10WAS	8WAS	10WAS	heading
Shell rate 0	46.13	48.16	2.17	1.87 [b]	39.76 [b]	41.57	79 [a]
Shell rate 5	46.18	53.56	2.21	2.27 [a]	46.64 [ab]	42.63	76.22 [ab]
Shell rate 10	46.97	53.60	2.30	2.65 [a]	51.76 [a]	46.63	75.22 [b]
$LSD_{0.05}$	NS	NS	NS	0.72	9.57	NS	3.47
Cultivator	47	50.37	2.13	1.77	45.74	43.79	78.78
Disc harrow	48.91	51.76	2.22	2.49	46.85	40.34	77.11
Rotavator	43.37	53.19	2.33	2.52	45.57	46.70	74.56
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS

Means having the different superscript letter (s) are significantly different at (P<0.05). WAS: weeks after sowing, NS: not significant (P>0.05)

3.6 Effect of Tillage Treatments and Groundnut Shell Rates on Sorghum Yield Attributes

The application of groundnut shell showed a significant increase in sorghum stover and grains yield while the effect was not significant (*P>0.05*) on panicle weight, panicle length, 1000 grains weight and harvest index (Table 6). Sorghum grains and stover yield were both increased by 20.9% and 17.3%, respectively, when compared the rate of 10 t/ha with the control (0/t/ha). Similarly, at 5 t/ha groundnut shell rate the sorghum grains and stover yield increased by 13.5% and 10.9%, respectively compared to the control. In general, application the groundnut shell to the soil had proved to be effective. It improved the sorghum growth and yield performance due to the favorable effects on soil conditions. Organic fertilizer can comprehensively improve the soil environment in terms of soil physical properties, total nutrients, available nutrients, and enzyme activities, and promote the improvement of sorghum yield and quality (Nie et al., 2024). Similar findings were observed by Bako et al., (2022). They found the yield and yield components of maize were significantly increased with the application of groundnut shell.

On the other hand, the results revealed that yield components were not affected by the different tillage methods (Bashir, et al., 2015; Suliman et al., 2025). Except 1000 seed weight was significantly higher under rotavator of 23.86 g followed by the cultivator of 23.19 g.

It was observed that there was an increase in sorghum grain yield by 15.5% and 12.8% when compared the rotavator with the cultivator and offset disc harrow, respectively. The positive effect in both sorghum growth and yield traits under the rotavator compared to other two methods could be due to the way of working by creating a good seedbed, mixing and pulverizing the tilled soil which was conducive to a good crop emergence and establishment. Similar findings were observed by Matani & Bhishnurkar (2017), they found the seedbed prepared by the rotavator led to increase on the crop production.

Table 6. Effect of different tillage implements and groundnut shells rates on sorghum yield characteristics

Treatments	Panicle weight (g)	Panicle length (cm)	Stover yield (kg/ha)	Grain yield (kg/ha)	1000 grains weight (g)	Harvest index (%)
Shell rate 0	98.61	21.41	3961.1^{c}	2078.6^{b}	22.81	33.41
Shell rate 5	103.14	21.41	4444.4^{b}	2403.1^{ab}	22.98	34.80
Shell rate 10	105.77	21.81	4788.9^{a}	2630.6^{a}	23.63	34.83
LSD $_{0.05}$	NS	NS	282.18	348.12	NS	NS
Cultivator	102.06	21.81	4405.6	2211.1	23.19^{ab}	32.44
Disc harrow	102.76	21.71	3994.4	2282.8	22.35^{b}	35.47
Rotavator	102.71	21.11	4794.4	2618.4	23.86^{a}	35.12
LSD $_{0.05}$	NS	NS	NS	NS	1.09	NS

Means having the different superscript letter (s) are significantly different at (P<0.05). NS not significant (P>0.05)

4. Conclusion

It could be concluded from this study that the application of groundnut shell compared to without application significantly increased soil water storage, sorghum plant height, stem girth, leaf area index, dry matter, stover yield and sorghum grains yield, while reduced the soil bulk density and Days to 50% heading. When it comes to the tillage implements, the water holding capacity and soil water storage were significantly higher under the cultivator and offset disc harrow. Also there was a significant increase in the percentage of total nitrogen under the cultivator. However, sorghum growth and yield components were not significantly affected by the different tillage implements except 1000 grains weight, which was higher under the rotavator. So, adding groundnut shell into the soil as amendments is one of the practices to be promoted to improve soil conditions and crop productivity. This in turn helps in sustainability of crops production particularly in rainfed areas. Further studies should be carried out to determine the performance of the groundnut shell on different types of crops and other soil properties. As well as studies on a combination use of water conserving tillage practices and soil amendments is highly needed to ensure higher sorghum grain yield in rain-fed areas.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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