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Growth Potential of Hydroponic Maize and Horse Gram with customized Nutrient Supplements for Climate Resilient Fodder Production

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ABSTRACT: Inadequate availability of green fodder is commonly noticed in livestock feeding. Land and water are the essential resources for fodder production. Limited allocation of land for fodder cultivation and climatic variability reduces green fodder production for livestock. Hydroponic fodder production is an alternative technology to increase green fodder production by vertical farming. The study established that if nutrient supplementation for hydroponic fodder production is to be done, a pH of 7.5 is ideal for nutrient solution. However, ground water without addition of any nutrients supported significantly ($P<0.05$) highest fresh biomass yield (kg / kg of seed) for both hydroponic fodder maize (3.89 ± 0.09) and hydroponic fodder horse gram (5.50 ± 0.14). On comparing different water sources for hydroponic fodder production, water from Chennai district supported maximum fresh biomass yield. A hydroponic fodder production unit with a capacity to produce 18.18 kg of hydroponic fodder maize and 6.73 kg of hydroponic fodder horse gram per day was designed. Hence, hydroponic fodder maize and horse gram can be produced by utilizing ground water in a fabricated unit for feeding ruminants in climate change scenario.

Keywords: Hydroponic fodder, Nutrients, Ground water, Hydroponic unit.

INTRODUCTION

India's livestock sector as per 20th Livestock census, 2019 holds 535.78 million livestock in the country showing an increase of 4.6% over Livestock Census 2012. Land and water are the primary resources for fodder production. Land allocation to cultivation of fodder crops is limited and availability of water for fodder cultivation is also limited as groundwater and freshwater resources are declining unremittingly (Rodell *et al.,* 2009). Hence, it is very much essential to evolve an alternate system for fodder production. Hydroponic green fodder can be produced without soil, utilizing less water. Hydroponically growing fodder is the transformation of grains into high quality, very lush, highly nutritious, disease free grass and root combination animal feed produced in a versatile and intensive hydroponic unit (Kide, 2015). This hydroponic technology has been proved successful using different crops such as maize, sorghum, barley, and oats and resulted in high-quality, nutritious and palatable green fodder for dairy animals (Swain *et al.,* 2020). Reviews indicated that around 600 kg of hydroponic maize fodder per day is produced in 50 square meter area (Kumar, 2019). Growing plants in nutrient supplemented liquid media under controlled conditions of moisture and temperature contains significant amount of supplements like nitrogen, potassium, magnesium, calcium, phosphorus, sulfur etc. that are required for the growth of the plant (El Morsy *et al*., 2013). Keeping this in mind, the following studies was conducted to optimize the nutrient supplements for hydroponic fodder maize and horse gram, to check different sources of ground water for producing hydroponic fodder maize and horse gram and fabrication of hydroponic fodder production unit for producing hydroponic fodder ɇ maize and horse gram.

MATERIALS AND METHODS

The first experiment was conducted to quantify nutrient supplements for the growth of hydroponic fodder maize and horse gram. The second experiment was conducted by utilizing different sources of ground water to produce hydroponic fodder maize and horse gram. The third experiment was conducted to design and fabricate dismountable hydroponic fodder production unit for cultivating hydroponic fodder maize and horse gram.

A. Quantification of nutrient supplements for both hydroponic fodder maize and hydroponic fodder horse gram.

The objective of this experiment was to quantify nutrient supplements required for production of both hydroponic fodder maize and hydroponic fodder horse gram. The nutrients that were considered for supplementation for hydroponic fodder maize and hydroponic fodder horse gram were nitrogen, phosphorus, potassium, calcium, magnesium and sulphur.

The ideal pH of nutrient solution for the development of crops lies between 5.5 and 6.5 (Trejo-Téllez *et al*., 2007). However in this experiment, nutrient solutions with pH 6.5 and pH 7.5 were tested to elicit response of nutrient solution to pH. The pH of ground water is around 7.5, hence this pH was included for this study. The respective nutrient solutions were prepared and adjusted to pH 6.5 or 7.5 and were used to quantify the optimum nutrient requirement for production of hydroponic fodder maize and hydroponic fodder horse gram.

The experiment had seven treatments each for hydroponic fodder maize and hydroponic fodder horse gram. Each treatment had six replications

T_1 - Distilled water with no added nutrient

T_2 - Ground water (Kancheepuram district) with no added nutrient

T_3 - Distilled water with basal dose

T_4 - Distilled water with 25 per cent less than basal dose

T_5 - Distilled water with 50 per cent less than basal dose

T_6 - Distilled water with 25 per cent more than basal dose

T_7 - Distilled water with 50 per cent more than basal dose

The optimized conditions required for the growth of hydroponic fodder maize and fodder horse gram was adopted (Gunasekaran *et al.,* 2018; Gunasekaran *et al.,* 2020; Gunasekaran *et al.,* 2022). The fodder biomass yield was documented on fresh matter basis by weighing the trays on 9th and 6th day respectively for hydroponic fodder maize and hydroponic fodder horse gram and subtracting the respective weights from respective empty tray weights. Fodder biomass was expressed on fresh matter basis as kg / kg seed.

B. Utilizing different sources of ground water to produce hydroponic fodders

Ground water from different sources vary in their dissolved salt content, hence different sources of ground water if used for irrigation without nutrient supplementation is postulated to impact biomass yield of hydroponic fodder. Hence this trial was conducted to study the impact of different ground water sources on biomass yield of hydroponic fodder maize and hydroponic fodder horse gram.

Ground water samples and bulk quantity of ground water were collected from Chennai, Thiruvallur and Kancheepuram districts of Tamil Nadu. The water samples were tested for pH (IS 3025 part II - 1983) and presence of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur (APHA, 1998).

The water collected from the three districts was used to irrigate hydroponic fodder maize and hydroponic fodder horse gram. The optimized conditions required for the growth of hydroponic fodder maize and fodder horse gram was adopted (Gunasekaran *et al.,* 2018; Gunasekaran *et al.,* 2020; Gunasekaran *et al.,* 2022). The seeds after soaking and germination were spread in cleaned and disinfected trays at their respective seed rate and allowed to grow in open type hydroponic fodder production unit shrouded in 70 per cent shade net. The fodder biomass yield was documented on fresh matter basis by weighing the trays on 9th and 6th day respectively for hydroponic fodder maize and hydroponic fodder horse gram and subtracting the respective weights from respective empty tray weights. Fodder biomass was expressed on fresh matter basis as kg / kg seed.

C. Designing, fabricating and testing hydroponic fodder production unit

Hydroponic unit capable of functioning under semi controlled environmental conditions was fabricated. This fabricated unit was with dismountable frame with provision for racks to support the fodder growing trays. The unit was planned to have an irrigation system with timer.

D. Statistical analysis

Data collected were analyzed using analysis of variance (ANOVA) using IBM SPSS statistics 20.

RESULTS AND DISCUSSION

Quantification of nutrient supplements for both hydroponic fodder maize and hydroponic fodder horse gram.

The objective of this experiment was to quantify nutrient supplements required for production of both hydroponic fodder maize and hydroponic fodder horse gram. The nutrients at their respective levels with pH of nutrient solution adjusted to 6.5 or 7.5 were tested. The average germination percentage of maize seeds and horse gram seeds used for this experiment was 83.00 ± 1.52 per cent and 91.33 ± 1.33 per cent respectively.

The fresh biomass yield of hydroponic fodder maize at optimized conditions supplemented with different levels of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur through distilled water at pH 6.5 or 7.5 is presented.

Biomass yield (kg / kg seed) of hydroponic fodder maize was significantly lower ($P<0.05$) when the distilled water or ground water or nutrient solutions *viz.,* distilled water with basal dose / 25 per cent less basal dose / 50 per cent less basal dose, 25 per cent more basal dose and 50 per cent more basal dose) were delivered at pH of 6.5 compared to when the same were delivered at pH 7.5. This indicated that ideal pH for nutrient delivery was 7.5 with regard to hydroponic fodder maize.

At pH 7.5 significantly highest (P<0.05) biomass yield of hydroponic fodder maize was documented in T_2 - ground water with no added nutrient. Next highest biomass yield was documented in T_3 - distilled water with basal dose, followed by yield documented in T_4 - distilled water with 25 % less basal dose, followed by yield documented in T_6 - distilled water with 25 % more basal dose which was comparable to the yield documented in T_5 - distilled water with 50 % less basal dose and T_7 - distilled water with 50 % more basal dose. Significantly lowest (P<0.05) biomass yield of hydroponic fodder maize was documented in T_1 - distilled water with no added nutrient presented in Table 1.

Biomass yield of hydroponic fodder horse gram was significantly (P<0.05) lower where the distilled water or ground water or nutrient solutions at different levels were delivered at pH 6.5 compared to the same when they are delivered at pH 7.5.

At pH of 6.5 for hydroponic horse gram, ground water with no added nutrient documented significantly lowest (P<0.05) biomass yield. At this pH significantly highest (P<0.05) biomass yield was documented when nutrients were added at 25 per cent less basal dose. Hence with regard to hydroponic horse gram nutrient solution containing N, P, K, Ca, Mg and S at 7.91, 15.82, 7.91, 90.00, 34.50 and 16.58 per cent respectively is recommended when pH is around 6.5 presented in Table 2.

Table 1: Biomass yield (kg / kg seed) on fresh matter basis of hydroponic fodder maize at optimized conditions* supplemented with different levels of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur through distilled water at pH 6.5 or 7.5 (Mean* ± SE)**

Treatment	Fresh biomass yield (kg / kg seed)	
	pH 6.5	pH 7.5
T_1 - Distilled water with no added nutrient	$1.63^{Aa} \pm 0.04$	$3.35^{Ba} \pm 0.07$
T_2 - Ground water with no added nutrient	$3.29^{Ae} \pm 0.05$	$3.89^{Bd} \pm 0.09$
T_3 - Distilled water with basal dose**	$2.06^{Ac} \pm 0.01$	$3.68^{Bc} \pm 0.04$
T_4 - Distilled water with 25% less basal dose	$2.17^{Ad} \pm 0.02$	$3.55^{Bbc} \pm 0.06$
T_5 - Distilled water with 50 % less basal dose	$2.12^{Acd} \pm 0.03$	$3.46^{Bab} \pm 0.04$
T_6 - Distilled water with 25% more basal dose	$1.83^{Ab} \pm 0.01$	$3.47^{Bab} \pm 0.05$
T_7 - Distilled water with 50% more basal dose	$1.83^{Ab} \pm 0.01$	$3.44^{Bab} \pm 0.06$

**Basal dose (N - 46.00 ppm, P - 31.00 ppm, K - 15.40 ppm, Ca - 32.00 ppm, Mg - 10.00 ppm and S - 44.20 ppm)

***Optimized conditions - Pre treatment - 2% Sodium hypochlorite for 30 minutes, Soaking time -12 hrs, Germination time - 24 hrs, Seed rate - 250g / foot^2, Water requirement - 250 ml/tray, Day of harvest - 9th day

* Mean of six replications,

a,b,c,d Means bearing different superscripts within column differ significantly (P<0.05)

A, B Means bearing different superscripts between columns differ significantly (P<0.05)

Table 2: Biomass yield (kg / kg seed) on fresh matter basis of hydroponic fodder horse gram at optimized conditions* supplemented with different levels of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur through distilled water at pH 6.5 or 7.5 (Mean* ± SE).**

Treatment	Biomass yield (kg / kg seed)	
	pH 6.5	pH 7.5
T_1 - Distilled water with no added nutrient	$3.26^{Aab} \pm 0.07$	$4.02^{Ba} \pm 0.24$
T_2 - Ground water with no added nutrient	$2.64^{Aa} \pm 0.23$	$5.50^{Bc} \pm 0.14$
T_3 - Distilled water with basal dose**	$3.82^{Aabc} \pm 0.06$	$4.96^{Bb} \pm 0.31$
T_4 - Distilled water with 25% less basal dose	$4.22^{Ac} \pm 0.18$	$4.54^{Bab} \pm 0.42$
T_5 - Distilled water with 50 % less basal dose	$4.02^{Abc} \pm 0.27$	$5.01^{Bb} \pm 0.15$
T_6 - Distilled water with 25% more basal dose	$4.13^{Abc} \pm 0.23$	$4.30^{Bab} \pm 0.30$
T_7 - Distilled water with 50% more basal dose	$3.58^{Aab} \pm 0.19$	$4.28^{Bab} \pm 0.07$

**Basal dose (N - 46.00 ppm, P - 31.00 ppm, K - 15.40 ppm, Ca - 32.00 ppm, Mg - 10.00 ppm and S - 44.20 ppm)

***Optimized conditions - Hydroponic fodder horse gram-Soaking time -12 hrs, Germination time - 4 hrs, Seed rate - 50g / foot^2, Water requirement - 100 ml/tray, Day of harvest - 6th day

* Mean of six replications

a,b,c Means bearing different superscripts within column differ significantly (P<0.05)

A, B Means bearing different superscripts between columns differ significantly (P<0.05)

At pH of 7.5 significantly (P<0.05) highest biomass yield of hydroponic fodder horse gram was documented in T_2 - ground water with no added nutrient. Next highest biomass yield of hydroponic fodder horse gram was documented in T_5 - distilled water with 50 % less basal dose, next highest biomass yield of hydroponic fodder maize was documented in T_3 - distilled water with basal dose, followed by yield documented in T_4 - distilled water with 25 % less basal dose, followed by yield documented in T_6 - distilled water with 25 %

more basal dose and T_7 - distilled water with 50 % more basal dose. Significantly (P<0.05) lowest biomass yield of hydroponic fodder maize was documented in T_1 - distilled water with no added nutrient presented in table 3. The results of this study concurred with earlier reports that use of nutrient solution for production of hydroponic forage is not mandatory as it can also be produced by tap water (Naik *et al.,* 2015).

Among factors affecting hydroponic crop/fodder production systems, the nutrient solution is considered to be one of the most important determining factors of crop yield and quality.

The results of the present study indicated that ideal pH for nutrient delivery for hydroponic fodder maize and hydroponic fodder horse gram was 7.5. Ground water with no added nutrients gave the highest biomass yield irrespective of pH (6.5 or 7.5) for hydroponic fodder maize. For hydroponic fodder horse gram at pH of 6.5, significantly highest (P<0.05) biomass yield was documented when nutrients were added at 25 per cent less basal dose, however at pH 7.5 significantly highest (P<0.05) biomass yield was documented when ground water with no added nutrient was used.

Further with regard to hydroponic fodder maize at both pH (6.5 or 7.5) and hydroponic fodder horse gram at pH 7.5, maximum bioavailability of nutrients occurred when nutrients were present as such in ground water. Distilled water with no added nutrients gave the lowest yield for both hydroponic fodder maize and hydroponic fodder horse gram. Adding nutrients to distilled water to create a synthetic nutrient solution gave yield higher than distilled water, but did not give best result in all dosages, as interaction between the added nutrients would have lowered their bioavailability. Moreover, micro / trace nutrient addition (iron, copper, zinc, boron and manganese etc.) to distilled water was not considered in this study. Ground water documented best results because all the nutrients including micro / trace nutrients would have been present in the right proportion and each nutrient did not interfere with the bioavailability of the others.

The reason why hydroponic fodder horse gram at pH 6.5 responded well with nutrients added at 25 per cent below basal dose could be because that changing the pH of a nutrient solution affects its composition, elemental speciation and bioavailability. Speciation indicates the distribution of elements among their various chemical and physical forms like: free ions, soluble complexes, chelates, ion pairs, solid and gaseous phases and different oxidation states (De Rijck and Schrevens 1998).

In nutritive content view, nutrient solutions improve the crude protein level of the hydroponic fodder than using tap water (Girma and Gebremarian 2018). The studies published by Sneath and McIntosh (2003); Dung *et al.* (2010) also indicated that there was non significant (P>0.05) improvement in nutrient content of sprouts which does not justify the added expense of using nutrient solution rather than fresh water. Moreover the short growth cycle of hydroponic fodder (7 to 9 days) does not seem adequate to bring about the desired changes that would encourage the use of a nutrient solution (Dung *et al.,* 2010).

Utilizing different sources of ground water to produce hydroponic fodder

The result of the pH and nutrients present in ground water collected from the three districts of Tamil Nadu that was utilized to grow hydroponic fodder is presented in Table 3.

Table 3: pH and nutrients present in ground water collected from three districts of Tamil Nadu utilized to grow hydroponic fodder (Mean* ± SE).

Parameters	Districts		
	Chennai	Thiruvallur	Kancheepuram
pH	$7.50^c \pm 0.10$	$6.85^a \pm 0.05$	$7.15^b \pm 0.10$
Nitrogen (ppm)	$34.00^a \pm 2.00$	$49.50^b \pm 1.50$	$36.00^a \pm 4.01$
Phosphorus (ppm)	$0.20^a \pm 0.02$	$0.18^a \pm 0.01$	$0.71^b \pm 0.03$
Potassium (ppm)	$23.99^c \pm 0.00$	$8.97^b \pm 0.06$	$1.03^a \pm 0.01$
Calcium (ppm)	$71.56^c \pm 0.28$	$35.94^a \pm 0.45$	$54.83^b \pm 0.43$
Magnesium (ppm)	$7.41^a \pm 0.10$	$7.42^a \pm 0.08$	$45.50^b \pm 0.50$
Sulphur (ppm)	$69.46^b \pm 1.04$	$12.25^a \pm 0.25$	$13.25^a \pm 0.25$

* Mean of six replications

a,b,c Means bearing different superscripts between column differ significantly (P<0.05)

The pH of the water from Chennai was similar to the pH found favorable in the growing of hydroponic fodder in this study. The water from Chennai also had nitrogen content that simulated 25 per cent lower than basal dose of nitrogen, and potassium content was higher than the basal dose of potassium. This water also had calcium content that was in between 25 and 50 per cent lower than basal dose of calcium. Hence this water could be ideal for growing hydroponic fodder maize and hydroponic fodder horse gram. For water from the other two districts pH was lower, and had lower levels of calcium, potassium and sulphur.

The biomass yield (kg / kg seed) on fresh matter basis of hydroponic fodder maize and horse gram grown utilizing different ground water sources at optimized conditions is presented in Table 4.

Table 4: Biomass yield (Mean* ± SE) of hydroponic fodder maize and hydroponic fodder horse gram grown utilizing different ground water sources at optimized conditions**

Ground water source	Biomass yield (kg / kg seed)	
	Hydroponic fodder maize	Hydroponic fodder horse gram NS
Chennai	$3.48^{c} \pm 0.01$	4.10 ± 0.12
Thiruvallur	$3.28^{a} \pm 0.00$	4.21 ± 0.19
Kancheepuram	$3.44^{bc} \pm 0.02$	4.39 ± 0.12

** Optimized conditions - Hydroponic fodder maize - Pre treatment - 2% Sodium hypochlorite, Soaking time -12 hrs, Germination time - 24 hrs, Seed rate - 250g / sq.ft., Water requirement - 250 ml/tray, Day of harvest - 9th day. Hydroponic fodder horse gram- Soaking time -12 hrs, Germination time - 4 hrs, Seed rate - 50g / sq.ft., Water requirement - 100 ml / tray, Day of harvest - 6th day *Mean of six replications, NS - No significant variation ($P<0.05$)

a,b,c Means bearing different superscripts within column for respective hydroponic fodder differ significantly ($P<0.05$)

Significantly ($P<0.05$) highest biomass yield was documented when water collected from Chennai was used to grow hydroponic fodder maize, this yield was comparable to that obtained when water collected from Kancheepuram was used to grow hydroponic fodder maize. In case of hydroponic fodder horse gram no significant variation ($P>0.05$) was observed in biomass yield irrespective of water source.

Karaki (2011) had used waste water in irrigation of green forages in hydroponic system, obtained hydroponic fodder of 224 to 320 T/ha.

The study focused to determine whether variation in nutrient profile of ground water from different sources impacted fresh biomass yield of hydroponic fodder, and found positive results. Thus, an insight that rather than adding nutrients to water for hydroponic fodder production, identifying the nutrient that is deficit in ground water and correcting it would provide a better solution. Further studies in this aspect are needed. This study further emphasized the fact that pH of 7.5 was ideal for hydroponic fodder production. Ground water from Chennai having pH 7.5 gave the maximum biomass yield. This water source also had nutrients either resembling 25 per cent or 50 per cent below basal dose fixed to identify nutrient requirements. Further studies on utilizing various ground water sources with modification are needed to get meaningful conclusion.

Designing, fabricating and testing hydroponic fodder production unit. The blueprint of the designed hydroponic fodder production unit is presented in Plate 1.

The complete hydroponic fodder production unit was eight feet long, three feet broad and had a height of eight feet. The dismountable frame of the unit was made of vertical and horizontally placed poly vinyl chloride (PVC) pipes. The pipes used for vertical frame were of 1½ inches thickness and those used for horizontal frames were of 1 inch thickness. The vertical frames were hinged with the horizontal frames using 1½ inches four way connectors with bush, 1 inch elbow and 1 inch Tee. The unit had nine racks and the height of the racks varied. For the first three racks the height was 5½ inches, for 4th and 5th rack the height was 5¾ inches, for 6th and 7th rack the height was 7 inches and for 8th and 9th racks the height was 8 inches.

Perforated plastic fodder growing trays (72 numbers) with a dimension of (l x b x h) 60 x 45 x 8 cm, made of high density polyethylene were placed on the frames. Sequential transfer of the trays from lower to upper rack manually was possible, according to the type of hydroponic fodder produced. The unit was provided with automatic irrigation system with sprinkler pipes connected to a water tank (capacity - 200 litres). The sprinkler pipes were provided for each of the racks and ran along the horizontal frames. Each rack was provided with four sprinklers. Thus, in total the entire unit had 36 sprinklers. The head pressure was created using a ½ HP motor. The sprinklers were connected to a timer that was programmed to irrigate water once in three hours for a period of 15 seconds. The unit could be set up in a green house with shade net of visibility 70 per cent. The unit can produce 18.18 kg of hydroponic fodder maize and 6.73 kg of hydroponic fodder horse gram per day for feeding ruminants.

The development of hydroponic fodder production system comes at a time when India is facing serious deficiencies in availability of fodder, due to the annual increase in livestock population and corresponding decrease of available arable lands and deficiency of water resources. The facility for the production of hydroponic fodder can be hi-tech or low cost as per the financial status of the farmer and availability of building material. Large numbers of farmers in India are producing hydroponic green fodder using different types of low cost greenhouses with varying results (Naik *et al.,* 2015). For popularization of hydroponics, it is very important to provide scientific proven technology to farmers and create awareness on its use. More cost-efficient structures and materials; to reduce requirements of purchased energy; to new cultivars more appropriate to semi controlled environments is needed. Only then the technology will be taken up at field level by farmers. Al-Kodmany (2018) reported that for hydroponic fodder production materials used for the system can be low cost and locally provided. The operational systems like irrigation, cooling and lighting are controlled and can be maintained at a low cost.

Considering the above stated facts, the hydroponic fodder production unit designed in this study had the favorable following features: it could be dismantled and mantled easily, conveniently transported, withstand day to day wear and tear, easy to operate and had capacity for sustained fodder production. Moreover, the schedule for fodder production (hydroponic fodder maize and hydroponic fodder horse gram) using the fabricated unit was evolved to ease its day to day operation. The unit possessed the capability of fodder production on par with other devices under field conditions.

CONCLUSIONS

The study established that if nutrient supplementation is to be done, a pH of 7.5 is ideal for nutrient solution. However, ground water without addition of any nutrients supported significantly ($P<0.05$) highest fresh biomass yield (kg / kg of seed) for both hydroponic fodder maize (3.89 ± 0.09) and hydroponic fodder horse gram (5.50 ± 0.14). On comparing different water sources for hydroponic fodder production, water from Chennai district, resembled water with added nutrients at 25 per cent lower than basal dose and supported maximum fresh biomass yield (3.48 ± 0.01 kg / kg of seed) compared to water sources from Thiruvallur and Kancheepuram districts.

The fabricated hydroponic fodder production unit, shrouded with 70 per cent shade net, occupying 24 square feet, made of dismountable poly vinyl chloride (PVC) pipes with 72 fodder trays, with an automatic irrigation system. This unit can produce 18.18 kg of hydroponic fodder maize and 6.73 kg of hydroponic fodder horse gram per day for feeding ruminants.

FUTURE SCOPE

Optimal nutrient requirements and water sources for other districts can also be studied for other fodder crops under hydroponic mode.

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Conflicts of Interest. None.

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