Journal of Agricultural Sciences and Engineering Volume 5 Issue 4 (2023), pp 202-212

Journal of Agricultural Sciences and Engineering

Journal homepage: www.jase.samipubco.com

Original Research

Effect of rainfall gradient and previous crop on weed flora diversity in pearl millet (*Pennisetum glaucum* [L.]) crop under Sudano-sahelian conditions of Senegal

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Citation Samba Laha KA, Baboucar BAMBA, Moustapha. GUEYE, Ousmane SAWANE, Mame Samba MBAYE, Kandioura NOBA. 2023. Effect of rainfall gradient and previous crop on weed flora diversity in pearl millet (Pennisetum glaucum [L.]) crop under Sudano-sahelian conditions of Senegal. Journal of Agricultural Sciences and Engineering, 5(4), 202-212.

https://doi.org/10.48309/jase.2023.180069

ARTICLE INFO

Received: 2023-02-13
Accepted: 2023-04-29
Available Online: 2023-05-09

Checked for Plagiarism: Yes.

Peer reviewers approved by:
Dr. Mohammad Mehdizadeh

Editor who approved publication:
Dr. Amin Baghizadeh

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Keywords:
Pearl millet, Previous crop, Rainfall gradient , Senegal, Weed flora

ABSTRACT

A study was conducted to determine the effect of climate gradient and previous crop on weed flora structure in pearl millet crop. Thus, floristic surveys were carried out during 2016 and 2017 crop years on station in Sahelian, Sudano-sahelian and Sudanian zones of Senegal. The results revealed that flora consisted of 81 species distributed in 59 genera and 19 families. Higher number of species were recorded in Sudanian zone (Kolda and Séfa) with respectively 61 and 45 species and the lowest number of species were found at Vélingara in Sudano-sahelian zone (28 species) and Sinthiou Malème in sahelian zone (28 species). According to previously crop, the higher number of species was registered in previous fallow (64 species) followed by previous pearl millet (57 species). In previous mucuna and peanut, flora is 14 percent lower than species recorded in previous fallow. Spectrum analysis indicated that the flora is largely dominated by therophytes, which includes 81.5% of the recorded species. It's presence in pearl millet field was higher in Sahelian zone (93%) followed by Sudano-sahelian zone (89%) and Sudanian zone (Kolda and Séfa) with respectively 80 and 84% of recorded species. Domination of therophytes is more accurate in plot with previous fallow (86%) followed by previous millet (82%), previous peanut (81%) and previous mucuna (79%). Also, it was observed a decreasing of perennial species from Sudanian to Sahelian zone.

Introduction

In Senegal, among the traditional crops, pearl millet represents one of the most important cereals in terms of area harvested and production (DAPSA, 2017). It is the staple food of the Senegalese population, particularly in countryside. In Senegal, cereals contribute 65% of the calories and 61% of protein, like other sahelian countries. It is after peanut, the second rainy crop in terms of area and production (ANSD, 2014). In fact, pearl millet production is estimated around 612,563 tons per year and accounts for 31% of national cereal production (DAPSA, 2017). In Eastern Senegal and Casamance, it is widely growing during rainy season and occupies with sorghum, 75 percent of arable lands. However, despite this importance, pearl millet production has continued to decline over the year (Bamba et al. 2019). Yields are generally low around 650 kilograms per hectare. This situation results from several factors such as drought, low soil fertility and weed infestation. Weeds compete with crops for resources such as nutrients, water, space and light (Caussanel, 1989). Weed infestation is considered as one of the most important constraint that limits yields in savannah zone of Africa. Many estimates of lost production have been recorded for tropical crops. Weed infestation account for 10 to 56 per cent reduction in yield in Africa while 9.7 percent of production losses in the world (Koch et al., 1982, Le Bourgeois and Marnotte, 2002). In Senegal, yield losses in pearl millet due to inadequate weed control can range up 30% (Noba et al. 2004). However, Chaudhary et al. (2018), reported that the magnitude of losses depends on crop cultivars, the nature, and strength of weeds, spacing, duration of weed infestation, environmental conditions and management exercises. Chemical herbicides could provide an effective weed control but still limited by their high cost and their negative effects on non-target organisms and ecosystems balance (Mennan et al. 2020). Manual and mechanical weeding is by far the most widely used method of weed control in pearl millets but consumes more than half of the farmer’s time and limits arable land extension (Le Bourgeois and Marnotte, 2002). Therefore, it becomes necessary to find out integrated methods of weed control for increasing crop production and maintained ecosystem balance. However, knowing weed biology and ecology remain necessary before elaboration of any management strategies. Our investigation aimed to evaluate the effect of different types of previous crop on weed flora structure in pearl millet field through a rainfall gradient from Sinthiou Malème in Sahelian zone where the less rainfall is recorded to Kolda and Séfa in Sudanian zone where the high rainfall is noticed.

Materials and Methods

Materials

This study was carried out in four research stations, Sinthiou Malème, Vélingara, Kolda and Séfa. Sinthiou Malème (13° 49'N, 13° 55 'W) is situated in the region of Tambacounda, in the north of Eastern Senegal. Climate is Sahelian with a rainy season (mid-July to late September or mid-

October). Over the period 1981-2010, the annual rainfall is 685 mm. Cumulative rainfall is 548 mm in 43 rainy days in 2016, 736 mm in 35 rainy days in 2017. Soils texture are sandy.

The district of Kolda (12° 53 'N, 14° 57'W) is located in Upper Casamance. The climate is Sudanian with alternating rainy season from June to October and a dry season for the rest of the year. Over the period 1981-2010, the annual rainfall is 1191 mm. Cumulative rainfall is 1192 mm in 54 rainy days in 2016 and 1336 mm in 2017. Soil texture varies from sandy-clay to clay. Vélingara (13° 07'N, 14° 09'W) is situated in the district of Kolda, in south-eastern Senegal. The climate is Sudano-Sahelian with alternating rainy season from late June to earlier October and a dry season for the rest of the year. Over the period 1981-2010, the annual rainfall is 855.7 mm. Cumulative rainfall is 738.5 mm in 59 rainy days in 2016 and 863 mm in 2017. Soil texture varies from sandy-clay to clay. Séfa (12 ° 47'N, 15 ° 32 'W) is located in Southern Senegal (District of Sédhiou, Middle Casamance). Climate is Sudanian with a rainy season (June to October) and a dry season (November to May). Over the period 1981-2010, the annual rainfall is 1034 mm in the town of Sédhiou. Cumulative rainfall in 2016 is 982 mm in 44 rainy days and 911 mm in 2017. Soils are sandy, acidic and low fertility.

Methods

Floristic survey was carried out in 2016 and 2017 crop years in four stations which two located in sudanian zone, one in sudano-sahelian or intermediate zone and one in sahelian zone. Weed assessments was made in field with an average area of 0.25-0.5 hectare. The first inventory began at 15 days after pearl millet emergence, the second at second hoeing and the last inventory just before harvest. The "field tower" technique, which consists of recording all species in a defined area, has been adopted (Le Bourgeois, 1993). Botanical identification was done by analysis of the external morphological characteristics of plant parts and according to literature (Merlier and Montégut, 1982; Le Bourgeois et Merlier, 1995). The floristic list with families and species was organized according to the classification system established in the Angiosperm Phylogeny Group III guidelines (APG III, 2009). For the biological spectrum, Raunkier's classification adapted to the tropical zone was used (Lebrun, 1966). This classification distinguishes 6 biological forms (Table 1).

Table 1. Biological types of weeds in tropical zone.

Life forms	Code	Signification
Phanerophytes	P	Woody plant that the renewal bud above 50 cm from soil surface.
Chamephytes	C	Woody plant or suffrutescent perennial that the renewal bud situated at 50cm above of the soil.
Hemicryptophytes	H	Perennial plant that the renewal bud is at the soil surface.
Geophytes	G	Plant that the renewal bud is buried within the soil.
Therophytes	T	Annual plants that form their spores or seeds within only one period of life.
Parasitical plants	Par	Annual or Perennial plant that derives some or all of its nutritional requirements from another

Results and Discussion

Structure of the flora

The results revealed that flora consisted of 81 species distributed in 59 genera and 19 families (Table 2). Higher number of species were recorded in sudanian zone (Kolda and Séfa) with respectively 61 and 45 species and the lowest number of species were found at Vélingara in Sudano-sahelian zone (28 species) and Sinthiou Malème in sahelian zone (28 species). According to previously crop, the higher number of species was registered in previous fallow and pearl millet with respectively 64 and 57 species. However, species recorded in previous mucuna and peanut is 14 percent lower than in previous fallow. The families with the highest species richness were Fabaceae (16%), Poaceae (13%) and Cyperaceae (11%) which account for 40% of the listed species. Dicotyledons form was the most important form. It represents the majority of species (65.9%), genera (69.5%) and families (78.9%). Dominance of dicotyledons is more marked at Vélingara (70%), followed by Kolda (67%), Sinthiou Malème (59%) and Séfa (57%).

Biological Types

Biological spectrum analysis indicated that the flora is largely dominated by therophytes, which includes 81.5% of the recorded species. It's presence in pearl millet field was 80, 84, 89 and 93% respectively in Sudanian zone (Kolda and Séfa), Sudano-sahelian zone (Vélingara) and Sahelian zone (Sinthiou Malème). Domination of therophytes is more accurate in plot with previous fallow (86%) followed by previous millet (82%), peanut (81%) and mucuna (79%) (Figure 1). Hemicryptophytes and phaneropytes contain respectively 7.4 and 6.2% of the flora, while the presence of geophytes and parasitic plants remain low. It was observed a decreasing of biological type diversity from Sudanian to Sahelian zone.

Effect of rainfall gradient and previous crop on the structure of flora

The observations of Figure 2_A indicate that most of the information is provided by axis 1. The perennial and dicotyledonous variables are positively correlated with this axis and form the same group with Kolda district in Sudanian zone. On the other hand, the monocotyledonous and annual variables are negatively correlated to this axis. Séfa, Sinthiou Malème and Vélingara zones form the same group with these variables. Factorial correspondence analysis was applied to the matrix previous crop x weed species (Figure 2_B). The arrangement of the PCA shows a very clear separation along axis 1, of two groups. The first group G1 is composed by the previous Peanut and Mucuna and species like *Cyperus esculentus, Stylochaeton hypogaeus* which seem subservient. The second group is formed by species such as *Dicrostachys cinerea*, *Andropogon pseudapricus*, *Piliostigma reticulatum* and the previous fallow.

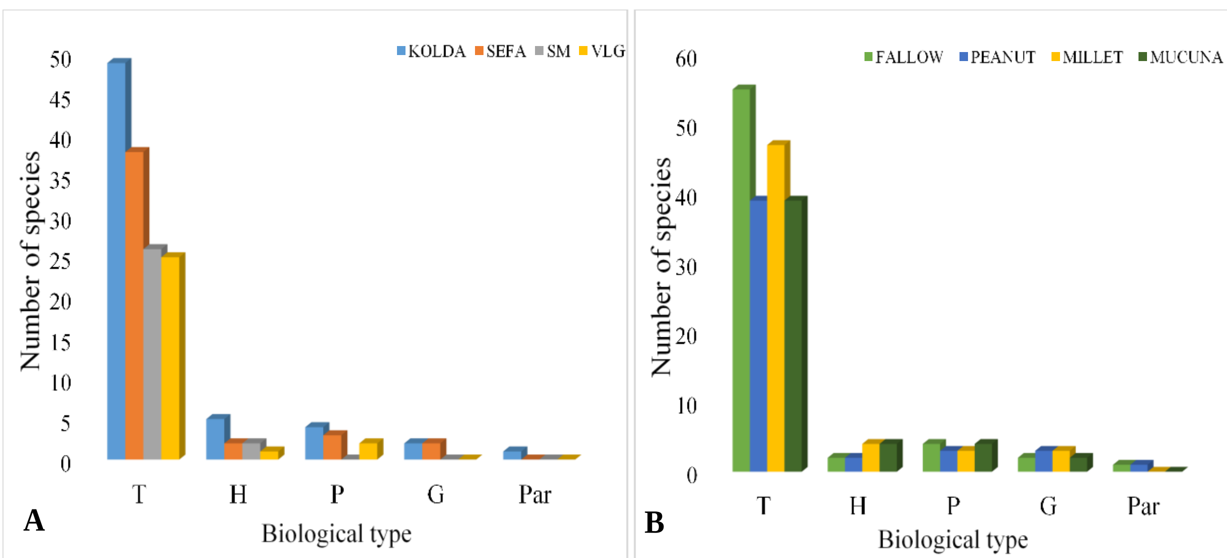
Table 2. Weed flora recorded in pearl millet crop.

Family	Weed species	C.T.	L.F.
Amaranthaceae	*Celosia trigyna* L.	D	T
Araceae	*Stylochaeton hypogaeus* Lepr.	M	G
Asteraceae	*Acanthospermum hispidium* DC.	D	T
	Vernonia galamensis (Cass.) Less.	D	T
Combretaceae	*Combretum apiculatum* Sond	D	P
	Terminalia macroptera G. et Perr.	D	P
Commelinaceae	*Commelina benghalensis* L.	M	T
	Commelina gambiae (C.B. Clarke)	M	T
Convolvulaceae	*Ipomoea eriocarpa* R. Br.	D	T
	Ipomoea heterotricha F. Didr	D	T
	Ipomoea vagans Bak.	D	T
	Jacquemonthia tamnifolia (L.) Griseb.	D	T
	Merremia aegyptia (L.) Urban.	D	T
	Merremia pinnata (Hochst.) Hallier.	D	T
Cucurbitaceae	*Citrullus lanatus* (Thunb.) Mansf.	D	T
	Cucumis melo L.	D	T
Cyperaceae	*Cyperus amabilis* Vahl.	M	T
	Cyperus cuspidatus Kunth.	M	H
	Cyperus esculentus L.	M	G
	Cyperus iria L.	M	T
	Cyperus sphacelatus Rottb.	M	T
	Fimbristylis hispidula (Vahl) Kunth	M	T
	Kyllinga squamulata Thon.et Vahl.	M	T
	Mariscus squarrosus (L.) C.B.Clarke	M	T
	Pycreus flavescens (L.) P. Beauv. ex Rchb.	M	T
Euphorbiaceae	*Acalypha ciliata* Forssk.	D	T
	Chrozophora senegalensis (Lam.) A. Juss.	D	T
Fabaceae	*Aeschynomene indica* L.	D	T
	Alysicarpus ovalifolius (Schumach.) Léonard	D	T
	Cassia absus L.	D	T
	Cassia sieberiana DC.	D	P
	Crotalaria goreensis Guill.et Perr.	D	T
	Crotalaria retusa L.	D	T
	Desmodium hirtum Guill. & Perr.	D	T
	Dicrostachys cinerea (L.) Wight et Am.	D	P
	Indigofera arrecta A. Rich.	D	T
	Indigofera hirsuta L.	D	T
	Indigofera macrocalyx G. et Perr.	D	T
	Indigofera pilosa Poir.	D	T
	Indigofera pulchra Willd.	D	T
	Indigofera stenophylla G. et Perr.	D	T
	Piliostigma reticulatum (OC.) Hochst.	D	P
	Senna obtusifolia L.	D	T
	Sesbania pachycarpa DC.	D	T

Family	Weed species	C.T.	L.F.
	Stylosanthes fruticosa (Retz.) Alston	D	T
	Tephrosia bracteolata Guill. Et Perr.	D	T
	Tephrosia pedicellata Back.	D	T
Icacinaceae	*Icacina oliviformis* (Poir.) J. Raynal	D	G
Lamiaceae	*Hyptis suaveolens* (L.) Poit.	D	T
Malvaceae	*Corchorus tridens* L.	D	T
	Hibiscus cannabinus Hook. F.	D	T
	Sida linifolia Juss. ex Cav.	D	T
	Sida rhombifolia L.	D	T
	Triumfetta pentandra A. Rich.	D	T
	Urena lobata Linn.	D	H
Orobanchaceae	*Striga* ***hermonthica*** **(Delile) Benth.**	D	Par
Phyllanthaceae	*Phyllanthus amarus* Schumach. & Thonn.	D	T
Plantaginaceae	*Scoparia dulcis* L.	D	T
Poaceae	*Andropogon pseudapricus* Stapf.	M	T
	Brachiaria ramosa (L.) Stapf	M	T
	Brachiaria villosa (Lam.) A. Camus	M	T
	Cenchrus biflorus Roxb.	M	T
	Chloris pilosa Schum. **&** Thonn	M	T
	Dactyloctenium aegyptium Beauv.	M	T
	Digitaria horizontalis Willd.	M	T
	Digitaria exilis (Kippist) Stapf	M	T
	Eleusine indica (L.) Gaertn.	M	T
	Eragrostis aspera (J.) Nees	M	T
	*Eragrostis ciliaris (*L.) R. Br.	M	T
	Eragrostis tremula Steud.	M	T
	Paspalum scrobiculatum L.	M	H
	Pennisetum pedicellatum Trin.	M	T
	Setaria pumila (Poir.) Roem. & Schult.	M	T
Rubiaceae	*Diodia sarmentosa* Sw.	D	H
	Kohautia confusa (Hutch. & Dalziel) Bremek.	D	T
	Mitracarpus villosus (Sw.) DC.	D	T
	Spermacoce radiata (DC.) Sieb. Ex Hiern.	D	T
	Spermacoce stachydea (DC.) Hutch. **&** Dalz.	D	T
	Oldenlandia corymbosa L.	D	T
Vitaceae	*Ampelocissus multistriata* (Baker) Planch.	D	H
	Cissus palmatifida (Baker) Planch.b	D	H

C.T.= Cotyledon type; L.F = Life forms; G= Geophytes; H= Hemicryptophytes; P= Phanerophytes; Par= Parasitical plant; T= Therophytes; D= Dicotyledons; M= Monocotyledons.

Our results highlighted first that *Fabaceae*, *Poaceae* and *Cyperaceae* were the most represented family with nearly half of recorded species. Success of Fabaceae and Poaceae is in agreement with several studies in the tropics (Traoré and Maillet, 1992; Le Bourgeois, 1993) particularly in Senegal (Akpo, 2000; Noba et al. 2004; Bassène et al. 2014) and was a typical characteristic of weed flora under farming system in Sudano-sahelian zone of Africa (Traoré, 1992). Furthermore, Fabaceae are characterized by the longevity of their seeds which can remain viable for a very long time in the soil while the importance of Poaceae is mainly due to their high seed production capacity even under unfavorable conditions (Baskin, 1998; Le Bourgeois et Merlier, 1995). High proportion of sedges is related to their adaptation on anthropic pressure and agricultural practices. Also, for these weed species, both sexual and vegetative mode of reproduction are operative for their proliferation (Ljevnaić Mašić et al. 2015; Le Bourgeois and Merlier, 1995). Besides, for some species rhizomes were also the means of vegetative propagation. Present at more than 65%, broadleaf weeds contain 54 species while monocotyledons are represented by 28 species and 8 families. This proportion between dicotyledons and monocotyledons is related by several authors including Traoré and Maillet (1992) in Burkina Faso, Le Bourgeois (1993) in Northern Cameroon and Bassène et al. (2014) in Senegal. This similarity in floristic composition indicates a monotony in the floristic diversity and composition of weed communities under Sudano-Sahelian conditions of Africa (Le Bourgeois and Guillerm, 1995).



G= Geophytes; H= Hemicryptophytes; P= Phanerophytes; Par= Parasitical plant; T= Therophytes.

Figure 1. Effect of climate gradient (A) and previous crop (B) on weed flora life forms.

It indicates that, except for parasitical plants (Le Bourgeois and Marnotte, 2002), there is no specific weed flora for a specific crop, but rather for edapho-climatic parameters and agronomic practices. This study showed an increasing of weed diversity in previous fallow compared to a low number of weed species recorded in previous mucuna and peanut. This result was in conformity with the findings of Ikuenobe and Anoliefo (2003) who reported that fallow increased weed diversity. In the other hand, mucuna is a cover crops and Masilionyte et al., (2016) reported that cover crops have a strong competitive ability to smother weeds and emerged volunteer plants. One of the direct effect of competition is reduction of seedbank which may affected emerged weed in next growth year. During the present investigation it was observed that therophytes was the higher biological type. This results support Noba et al. (2004); Sarr et al, (2007), Bassène et al. (2014) who observed that therophytes were the most common biological type in Senegalese farmers field. It is mainly due to their adaptation to fragile ecosystems (Loudya et al. 1995). According to Bourgeois et al. (2019), therophytes were the mostly weeds because of some adaptability among them higher specific leaf area, sunny and dry environments. They also have a very short life cycle, sometimes a few weeks. This dominance of therophytes is more marked at Sinthiou Malème and Séfa. Larger proportions of annual species in sahelian zone compared to sudanian zone can be explained by the fact that the proportion of therophytes decreased from dryland to wetland (Traoré and Maillet, 1992). In Séfa, higher proportion of annual species mainly small sedges showed the effect of long period of exploitation on weed flora structure even in zone where water is not a constraint. This study also revealed the abundance of perennial species in plots with previous fallow compared to previous millet, peanut and mucuna. Indeed, fallow gives time for perennial species to growth while in crop fields, they are systematically suppressed by farmers.

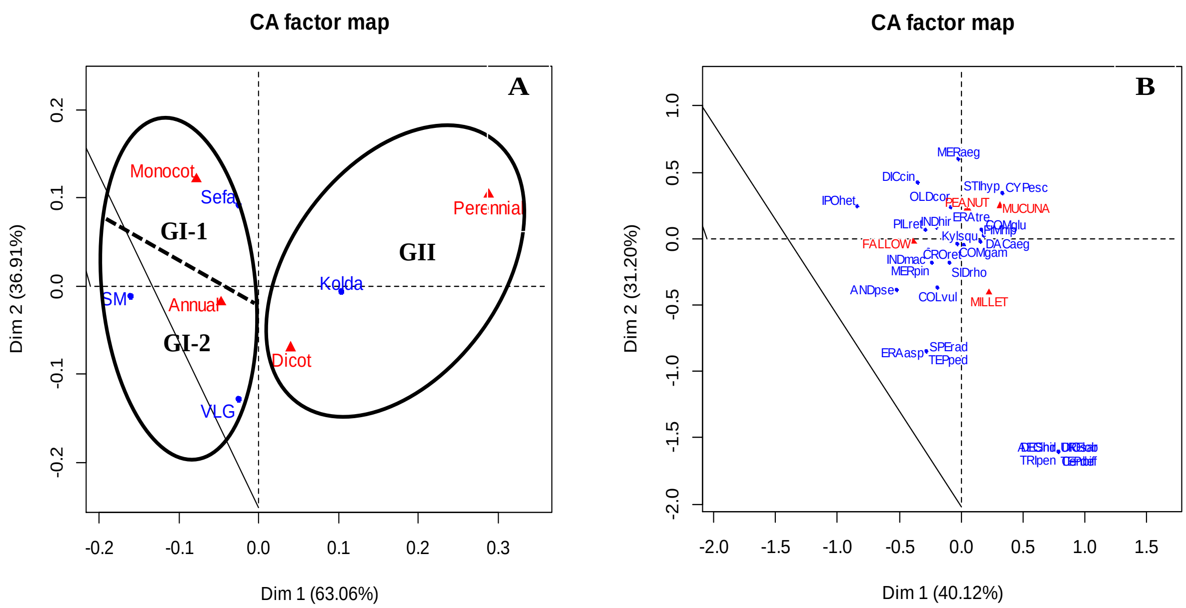


Figure 2. Effect of rainfall (A) and previous crop (B) on weed flora structure

Conclusion

The floristic inventory reported 81 species belonging to 59 genera and 19 families. Fabaceae, Poaceae and Cyperaceae were the most represented botanical families with respectively 16, 13 and 11 percent of recorded species. Higher number of species were recorded in sudanian zone (Kolda and Séfa) with respectively 61 and 45 species and the lowest number of species were found in intermediate and sahelian zones. According to previously crop, the higher number of species was registered in previous fallow (64 species) followed by previous pearl millet (57 species), mucuna (49 species) and peanut (48 species). Dicotyledons form represented the majority of species (65.9%), genera (69.5%) and families (78.9%). Also, the study showed that therophytes dominated in all agroecological zone but their proportion increased from wetland to dryland. Indeed, perennial species are more common in previous fallow compared to others. This study also highlighted the importance of annual species in area that have been exploited for a very long time. Thus, despite an annual rainfall up to 1,000 mm, a higher rate of annual species were recorded at Séfa. Overall from this study, we can conclude that rainfall gradient, previous crop and long-term exploitation play a key role in weed flora composition, structure and distribution.

Acknowledgement

We are very much grateful to Kolda Livestock Research Center/Senegalese Institute for Agricultural Research for facilities.

Conflicts of Interest

The authors state that they have no conflict of interest.

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