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Full Length Research Paper

Quantity-intensity characteristics of Potassium (K) in relation to potassium availability under different cropping system in alluvial soils

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Potassium availability to the plant is influenced by internal soil properties and other external properties. Quantity intensity characteristics are one of the satisfactory measures of potassium dynamics and its availability. So quantity intensity characteristics of potassium were studied to quantify the potassium availability in three different cropping systems viz., paddy-paddy, banana and paddy-pulse based. Three soil profiles were studied in each cropping system and soil samples were collected horizon wise for laboratory analysis. Q/I parameters were estimated by the method adopted by Beckett (1964a). Analysis of variance was performed to compare the impact of cropping system and pedons on different chemical and nutrient properties of soils. Significantly high organic carbon (0.47%) and available nitrogen (271.10 kg/ha), medium available phosphorus (17.00 kg/ha) and available potassium (230.50 kg/ha) recorded in paddy-pulse cropping system compared with other cropping system. Banana based cropping system recorded significantly higher clay (41.2%), soil reaction (8.24) and potassium fixing capacity (84.32%). The results of Quantity-Intensity (Q/I) dynamics studies shows that paddy-pulse based cropping system recorded high labile K K_L (0.49 c mol (p+)/kg) and Potential buffering capacity PBC^K (45.67 c mol (p+)/kg) whereas paddy-paddy cropping system recorded PBC^K of 16.81 c mol (p+)/kg which needs frequent potassium fertilization. The results showed that most of the soil properties including K dynamics were greater extent influenced by changes in cropping systems which consecutively affects the potassium availability.

Key words: Quantity intensity (Q/I) characteristics, cropping systems, soil properties, K dynamics.

INTRODUCTION

The Q/I relation of soil describes the relation between K availability or intensity (I) in soil to the amount (Q) present in soil, that is, changes of K sorbed to changes of K in solution concentration (Uddin et al., 2011). The potassium content in soil depends mainly on type and degree of soil weathering and the forms in which it exist

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in the soil (Havlin et al., 1999). Hence the K availability in the soil solution (intensity) and the inherent capacity of the soil to buffer this concentration against changes are among the important parameters that determine effective availability of K to plants (Grimme, 1976; Raheb and Heidari, 2012). In some cases even though the soil contain considerable amount of total K, the availability to plants are negligible. This is because the availability of K to plants depends not only on its availability but also on its dynamics viz., intensity, capacity, and renewal rate in soils. Finally, knowing the equilibrium constants is vital for predicting the status and supply of K for plant (Lindsay, 1979). Misunderstanding of theses dynamics leads to mismanagement of soil fertility. Potassium potential (PP) is one of the intensive characteristics of soil potassium dynamics which describes the intensity of potassium release from the soil solid phase into the soil solution. Lamm and Nafady (1971). However, to assess the conditions of potassium uptake by plants, the extensive parameters, that is, the contents of potassium and other soil properties (Ca+Mg) are also required (Woodruff, 1955). In this case, the activity ratio AR_e^K or $aK/\sqrt{a}$ (Ca+Mg)/2 described by Beckett (1964) is one of the satisfactory measures of the K dynamics and its availability because it measures both the chemical potential of labile K present to the chemical potential of labile (Ca+Mg) in the same soil.

The same time different soil having same AR_e^K values may not possess the capacity for maintaining AR_e^K when soil K is depleted (Diatta et al., 2006). The PBC^K characterizes soil capacity to resist changes in the content of available potassium under the impact of natural and anthropogenic factors (Zharikova, 2004).

Soil properties vary in vertical and lateral directions with landscape position, soil forming factors and land use (Momtaz et al., 2009). Land use systems significantly affected the clay, the silt and the sand fractions and affect the distribution and supply of soil nutrients by directly altering soil properties like exchangeable basic and acidic cations (Stutter et al., 2004), soil exchange chemistry (Chien et al., 1997) and water retention characteristics (Malgwi and Abu, 2011). The forms and dynamics of soil potassium greatly influenced by changes in land use which is often involve changes in vegetative cover and biomass production (Awdenegest et al ., 2013). Since K is largely required for paddy (*Oryza sativa*) crop next to nitrogen, major paddy growing alluvial soils of Thamirabarani command area of Tamil Nadu was identified to measure the potassium dynamics in relation to K availability. A good knowledge of the spatial variability of soil as it relates to topography and land use is essential for good land evaluation, which is a prerequisite for sound land use planning (Amusan et al., 2006). With this background an attempt was made to relate the potassium availability parameters with the quantity intensity characteristics under three differentcropping systems in alluvial soils of Thamirabarani command area of Tamil Nadu.

QUANTITY-INTENSITY ISOTHERMS - INTERPRETATION AND RELEVANCE

Figure 1 typically represents the relation between changes in the amount of soil labile K (Quantity factor) and the activity ratio (AR_e^K) (Intensity factor). It means that it measures changes in the amount of labile K in the soil to the amount held in the soil.

ΔK represents the difference between the K concentrations of a solution before and after the addition of soil. It is convenient to measure changes in the amount of labile K in the soil, not against a zero state of the soil with no labile K, but relative to the amount held in the field soil.

The intercept of the curve with the activity ratio axis ($\Delta K=0$) gives the value of the activity ratio of potassium (AR_e^K) in soils. It is a measure of availability or intensity of labile K in soil. Schouwenburg and Schuffelen (1963) theorized that if the AR_e^K value is less than 0.001 moles lit^{-1}, the adsorbed K will be at edge positions and if it is > 0.01, K will be adsorbed at planar positions.

It has upper linear part and lower curved part. The lower curved part appears to describe, the exchange reactions of labile K held at sites (edges of clay particles and to wedge sited of weathered micas) which shows more specific affinity for K. The lower curvature at the low values of AR_e^K was due to the release of fixed K from the soil particle. The upper linear portion of the curve has been ascribed to non specific sites (planar surface) for K.

$\Delta K°$ is the measure of potassium adsorbed on p-positions (non specific positions on outer crystal surfaces) and considered to be available for plants. Kx represents the capacity of the specific sites, that is, potassium adsorbed on e-positions (specific exchange positions occur on the edges, bends and projected parts of crystal surfaces) is less available for plants (Medvedeva, 1975).

The amount of ΔK at $AR_e^K=0$ represents labile potassium (K_L) in adsorption curves. It characterizes the total pool of labile potassium in particular soils ($\Delta K°+Kx$). This parameter showed the amount of K which is readily available and is capable of ion exchange during period of equilibrium between soil colloids and soil solution.

The slope of $\Delta Q/\Delta I$ measures the amount of labile K that can be removed before AR_e^K falls by more than a given amount that is gradient of the linear part of the graph has been generally represents Potential Buffering Capacity (PBC^K) of the soil. It is generally a measure of the ability of the soil to maintain the intensity of K in the soil solution. The PBC^K is related to sorption–desorption processes acting in the soil. The range of its values is divided into very low (<20), low (20–50), medium (50–100), elevated (100–200) and high (> 200). Soils with highest PBC^K values were characterized by the lowest percent K saturation, indicative of higher potential to replenish K concentration in soil solution. Removal of adsorbed K from the non specific planner surface sites by cropping increased the buffer capacities, indicating that

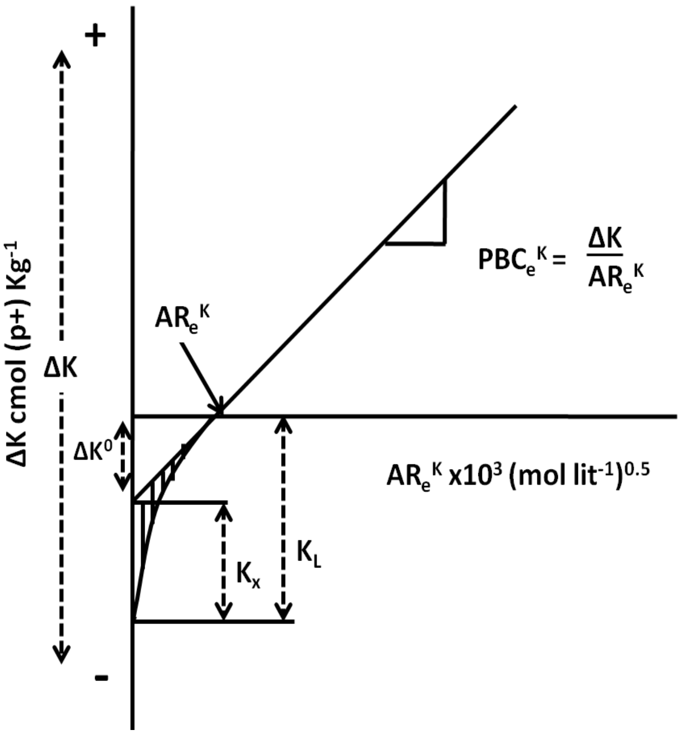

Figure 1. Quantity-Intensity isotherms - Interpretation and relevance.

higher energy sites became involved as the number of cropping increased.

MATERIALS AND METHODS

Study area and sample collection

The study was conducted in Thamirabarani command area of Tamil Nadu, India located between 76° 24' and 78° 24' East longitude and 8° 20' to 9° 0' North latitude. The geology is granite gneiss. This area has a typical monsoonic climate with a mean annual precipitation is 75.9 cm. The mean annual temperature is 33.5°C and it is lowest in the month of December (29.9°C) and highest in May (37.1°C). The mean soil temperature is about 22°C. The difference between the mean summer and mean winter soil temperature is more than 5°C. The soil temperature regime is megathermic. The soil map of Tamil Nadu prepared by NBSSLUP was used as a base map for selection of sampling sites. From that five major soil units were identified representing ninety per cent of the study area. The cropping pattern in the study area is paddy-paddy, paddy-pulses and banana based cropping system and the length of growing period is 90 to 120 days. Soil survey followed by sample collections was carried out representing all the cropping system in the study area following standard procedure. Three sites were identified for each cropping system and soil profile was studied for its morphological characters and ten surface samples were collected randomly from each cropping system for laboratory analysis (Soil survey staff, 2008). Soil samples were analyzed for physico chemical properties using standard methods (Jackson, 1973). Water soluble K was determined by Mac Lean (1960) method and the exchangeable K (Kex) was assessed by the method adopted by Stanford and English (1949).

Potential buffering capacity (PBC_K)

For the determination of K potential the method developed by Beckett (1964a) and as adopted by Palaniappan (1972) and Ramanathan (1977) was adopted. To a series of 100 ml shaking bottles 5 g soil samples were taken. To each shaking bottle with soil, 40 ml of 0.0125 M $CaCl_2$ solutions was added. To these, 10 ml portions each of varying KCl concentrations were added to make up the final concentrations of $CaCl_2$ to 0.01 M. The concentrations of KCl used were 0, 0.25, 0.5, 1.0, 2.0, 3.0 and 5.0 milli moles. Another sample of 0.5 g was also weighed into the shaking bottle and 50 ml of 0.01 M $CaCl_2$ was added. The bottles with contents were shaken for 1 h, kept overnight and centrifuged at 2000 rpm from 10 min. The supernatant solution was filtered and analyzed for K using flame photometer. Calcium and magnesium were estimated by the versenate titration method. From the concentrations of K, Ca and Mg, the activity ratio ${}^{a}K$ / ${}^{a}Ca+Mg$ was calculated by Debye – Huckel formulae as proposed by Beckett (1964).

The difference between the amount of K added and recovered in the extract solution in me per 100 g of soil was also calculated (ΔK). The AR^K was then plotted against ΔK. The Q / I curve resolves into lower curved part and the upper linear part. The difference between the lower and upper part represents the K held at specific sites (K_X) at zero activity ratio. Further an extension of the lower curved part to the ΔK axis given the total amount of K in labile pool (K_L). The linear part of the curve was interpolated to the X-axis and this X intercept would represent the equilibrium activity ratio (AR_e^K) when ΔK is zero.

The linear part was also interpolated to intersect the Y-axis and this Y-intercept would represent the amount of K held in the soil on sites, or surfaces of which the exchange equilibrium is described by the linear part of Q/I Relation (-ΔK). The other Q/I parameters calculated are as follows.

$$PBC^K = \frac{-\Delta K^0}{AR_e^K}$$

Where,
PBC^K = Potential buffering capacity
$-\Delta K^0$ = Labile K (Quantity of K released or the part of labile K that is located on the planar surface)
AR_e^K = Equilibrium activity ratio to K.

RESULT AND DISCUSSION

Soil properties

There are three types of soils found in the study area. One is deep imperfectly drained cracking clay soils occurring on gently sloping lands with moderate erosion (Fine montmorillonitic vertic ustropepts) and utilized only for banana. Whereas in lowlands the soils are deep imperfectly drained calcareous gravelly clay soils (Fine loamy mixed typic ustropepts) and it is associated with paddy followed by paddy cropping system. Deep, well drained gravelly loam soil found on gently sloping lands (Fine loamy mixed typic ustrothents) has land use of rice followed by pulses (Table 1). The soil of all the three cropping systems found as alkaline with the mean range between 8.01 to 8.59. Even though the soils are having high pH they are not saline soil because the EC was found < 2.5 dSm^{-1} with the mean range between 0.17-

Table 1. Different soil unit under three different cropping system.

S/N	Cropping system	Soil Unit	Description
1	Paddy-pulses	Fine loamy mixed typic ustrothents	Deep, well drained gravelly loamy soils on gently sloping lands, moderately eroded
2	Banana	Fine montmorillonitic vertic ustropepts	Deep imperfectly drained cracking clay soils on gently sloping lands with moderate erosion
3	Paddy-paddy	Fine loamy mixed typic ustropepts	Deep imperfectly drained calcareous gravelly clay soils on nearly level lowlands, slightly eroded

Table 2. Soil properties under three different cropping system.

Cropping system	Statistical parameters	pH	EC (dS m^{-1})	OC %	Available nutrients (kg ha^{-1})		
					N	P	K
	Mean	8.59	0.43	0.38	194.60	15.40	186.90
Paddy-paddy	SD	0.41	0.33	0.12	69.54	4.31	26.93
	CV	**4.80**	**80.39**	**30.17**	**35.54**	**27.96**	**13.72**
	Mean	8.24	0.26	0.43	245.00	13.20	208.60
Banana	SD	0.57	0.17	0.31	61.33	4.21	31.25
	CV	**6.97**	**66.56**	**73.08**	**25.03**	**31.87**	**14.98**
	Mean	8.01	0.17	0.47	271.10	17.00	230.50
Paddy-pulses	SD	0.48	0.11	0.21	49.95	4.94	23.74
	CV	**5.96**	**51.62**	**46.44**	**19.31**	**27.61**	**9.66**

0.43 dSm^{-1}. Soil organic carbon content was low (< 0.5%) in all the cropping sequence and it is comparatively high in paddy-pulse cropping sequence (0.47%) might be organic residue addition from pulses (Table 2). Same wise all the available major nutrients were found high (N: 271 kg ha^{-1}, P: 17 kg ha^{-1} and K: 230 kg ha^{-1}) in paddy-pulse cropping system. The biological nitrogen fixation by nodules in pulses and addition of huge biomass might be the reason for the increased amount available nutrients under paddy-pulse cropping system.

Q/I parameters

Equilibrium activity ratio of K (AR_e^K)

The AR_e^K values are the status of immediately available K (Taiwo et al., 2010) and its pattern under three different cropping systems (Tables 3 and 4) shows that the AR_e^K value was high in paddy-paddy cropping system followed by banana and paddy-pulse. Equilibrium activity ratio of the soils studied were ranged from 5 to 10 × 10^3 (mol/lit)$^{0.5}$ which was low but higher than the suggested minimum of 5 × 10^{-4} (mol L^{-1})^{½} by Beckett and Webster (1971). From that it can be theorized that K was preferentially held at inner positions of the clay particles because the AR_e^K values are between than 0.01 to 0.001 moles lit^{-1} (Schouwenburg and Schuffelen, 1963). The high amount of clay content (> 40%) in soil banana cropping system increases the K fixation and thereby reduced the AR_e^K values (Sharma and Mishra, 1989). The higher value (9.2 × 10^3 (mol/lit)$^{0.5}$) of labile K (AR_e^K) in paddy-paddy cropping system might be due to greater K release into soil solution because these soils contain comparatively low amount of exchangeable calcium and magnesium values which intern increase the AR_e^K values.

K held at specific sites (K_X)

K_X indicates the number of sites showing specific affinity for K, and it was higher in paddy-pulse cropping system (0.29 c mol (p+)/kg). Even though soils of paddy-pulse cropping system contain less clay content, one of the reasons for its higher Kx value is because of its organic matter content (0.47%). The lower amount of labile K (0.41 c mol (p+)/kg) in soils of banana cropping system is due to the more retention of K because of the presence of montmorillonite nature of clay. The K_X value of paddy-paddy cropping system exceeds 50% of K_L, probably because of percolative water regime as well as because of biogenic potassium uptake (Zharikova, 2001).

Labile K (K_L)

The labile K represents the amount of K capable of ion

Table 3. Different fraction of potassium under three different cropping system.

Cropping system	Statistical parameters	K Fractions (ppm)					
		H2O sol K	Kex	Boiling 1N HNO_3 K	Knex	Lattice K	Total K
	Mean	22.1	70.4	810.9	740.6	2776.6	3517. 1
Paddy-paddy	SD	3.6	11.4	143.2	151.9	681.8	620.1
	CV	**16.2**	**16.2**	**17.5**	**20.3**	**27.1**	**18.8**
	Mean	24.7	78.5	780.2	701.8	3336.6	4038.0
Banana	SD	3.1	9.9	95.8	95.5	915.2	923.8
	CV	**12.7**	**12.7**	**12.3**	**13.6**	**27.4**	**22.9**
	Mean	26.1	83.1	818.7	735.6	5309.3	6044.9
Paddy-pulses	SD	4.6	14.5	117.8	118.4	544.8	570.9
	CV	**17.5**	**17.5**	**14.3**	**15.9**	**13.2**	**11.5**

Table 4. Quantity-intensity parameters under three different cropping system.

Soil unit	AR_e^K x10^3 $(mol/lit)^{0.5}$	K_X	K_L	ΔK^0	PBC^k	Kex	Ex.Ca	Ex.Mg	K Fixed (%)	Clay (%)
		c mol (p+)/kg								
Paddy-paddy	9.20	0.23	0.44	0.15	16.81	2.26	15.7	7.35	82.94	38.8
Banana	7.40	0.24	0.41	0.18	24.32	1.74	17.0	11.4	84.32	41.2
Paddy-pulse	5.50	0.29	0.49	0.25	45.67	1.85	17.6	9.20	73.30	24.2
SD	1.9	0.0	0.0	0.1	15.0	0.3	1.0	2.0	6.0	9.2

exchange during the equilibrium between soil solids and solution. The total amount of K in the labile pool ranged from 0.41 to 0.49 c mol (p+)/kg in soil. The higher levels of labile K indicate that higher amount of loosely bonded K^+ ions present in exchangeable site. The lower amount of labile K in soils of banana cropping system (0.41 c mol (p+)/kg) than others is due to the more retention of K because of the presence of montmorillonite nature of clay minerals. In all the cropping system, K_L values were lower than the exchangeable K (Kex) (1.74 to 2.26 c mol (p+)/kg) indicating there by that potassium of these soils should be released basically via exchange processes than solubility or diffusion. This implies that any addition of K in these soils could result a significant partition of K to the soil exchangeable portion and tend to have less capacity to fix potassium (Poudel and west, 2005).

ΔK^0

Traditionally, change in solution K (ΔK) has been attributed to the change in the amount of K adsorbed by or released from the soil solid phase. In paddy-pulse cropping system, the ΔK^0 generally became more negative (0.25 c mol (p+)/kg) because there was a greater release of soil K into soil solution resulting in large pool of labile K. The result indicates the soil had high power of K release compared to other soils. The lower value in paddy-paddy cropping system (0.15 c mol (p+)/kg) indicates it had a strong ability to absorb K. The contents of both easily exchangeable and labile potassium (ΔK^0 and $-K_L$, respectively) are also high in the paddy-pulse cropping system.

Potential buffering capacity (PBC^K)

Potential buffering capacity is a measure of the ability of a soil to maintain a given K and this suggest that in higher range the soils would be able to maintain relatively higher activity ratio of the soil K when there is any K stress, whereas the lower value would be susceptible to rapid changes in the AR_e^K, signifying frequent K fertilization (Wang et al., 2004). It was ranged from 16.81 c mol (p+)/kg in paddy-paddy cropping system to 45.67 c mol (p+)/kg in paddy-pulse cropping system. Zharikova (2004) divided the values of PBC^k into very low (20 cmol kg^{-1} $(molL^{-1})$ ½) to high (> 200 cmol kg^{-1} $(molL^{-1})$ ½). The high soil PBC^k value is an indication of good K availability, whereas a low PBC^k soil would suggest a need for frequent K fertilizer application (LeRoux and Sumner, 1968). Consequently this study concluded that application of K fertilizer is necessary in paddy followed by paddy cropping system in split levels. In addition it was found that there is no relationship between soil clay content and PBC^K. Even though the paddy-paddy

Table. 5. Correlation between different soil Q/I characteristics.

Soil characteristics	ARe^K	K_x	K_L	ΔK^0	PBC^K
K_x	0.411				
K_L	0.478	0.602			
ΔK^0	-0.922*	-0.035	0.777		
PBC^K	0.979**	-0.317	0.557	0.946*	
WS-K	0.069	-0.130	-0.131	-0.061	-0.112
Ex. K	0.631	-0.210	0.392	0.655	0.751
Clay	-0.549	0.694	0.214	-0.279	0.542
Sand	0.602	-0.570	-0.062	0.371	-0.576
pH	-0.187	0.517	0.384	0.074	-0.004
OC %	0.705	-0.200	0.377	0.629	0.682
CEC	0.491	0.914*	0.434	-0.177	0.476
Ca	-0.223	0.637	0.767	0.458	0.231
$CaCO_3$	-0.240	0.673	0.874	0.563	0.272

cropping system has registered high clay content (38.8%) the PBC^K was found low (16.81 c mol (p+)/kg). It might be because of the influence organic matter content. Organic matter may possess a lower surface area than previously thought, and the interaction between organic matter and inorganic clays tends to reduce the surface area of the latter (Pennell et al., 1995). This implies that it is not the available total area of exchange surface that controls the PBC^K, as originally suggested by Beckett and Nafady (1967, 1968). Rather, it is the available total area of high K-affinity surfaces that determines the PBC^K in the soil.

Correlation

There was a positive correlation between AR_e^K with exchangeable K (0.631) and water soluble K (0.069) (Das et al., 1993). It is because of increased available potassium saturation gives rise to increase in AR_e^K. The same time AR_e^K had significant negative correlation with Ca (-0.223) and $CaCO_3$ (-0.240) (Table 5). It is because of the fact that higher Ca and $CaCO_3$ activity decreased the activity of K in soil, thereby decreasing AR_e^K. The Kx value of soil had positive correlation with clay content (0.694) and negative correlation with sand content of soil (-0.570). Soils with higher clay content have higher exchange surface offered a selective or specific binding sites for K compared to other soils which were light in texture (Dutta and Joshi, 1990). K_L was positively correlated with soil organic carbon (0.377), exchangeable potassium (0.392) and clay (0.214) (Scott, 1968).

The PBC of different soils is roughly proportional to CEC which is seen from the small positive (0.476) value to CEC, and clay (0.542) which increases as the K–depletion is prolonged. Beckett and Nafady (1968) pointed out that the buffering capacity of a soil depends primarily on the surface area available for ion exchange and, to a lower degree, on the character and charge density of soil surfaces. Since major exchange surfaces in soils include inorganic clays and organic humic substances, it is expected that soils which receive more crop residues would exhibit higher PBC values than others. Correlation showed that whenever exchangeable sites are more in soils, intendancy and capability of them for K adsorption is more. As result, potential buffering capacity of soil also will increase.

Conclusion

The present study revealed that cropping systems are significantly affecting most of the soil properties and intern affecting the availability of soil potassium in the study area. Paddy followed by pulse cropping system had better potassium availability compared to others because of high biomass return from the pulse crop which facilitates high labile potassium. In addition the PBC^K of paddy followed pulse cropping system suggested less frequent application potassium fertilizer compared to paddy-paddy cropping system has low PBC^K require frequent application of potassium fertilizer. So apart from amount of potassium present in the soil, the availability of potassium to plants is mostly influenced by the soil properties. So identifying, quantifying and monitoring these properties and its changes are necessary to prevent soil degradation and to improve soil and land management. So estimation of available potassium by quantity intensity parameters will give better estimation of plant available potassium and its causes.

Conflict of Interest

The authors have not declared any conflict of interest.

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