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Interactive comment on "Agropedogenesis: Humankind as the 6th soil-forming factor and attractors of agrogenic soil degradation" *by* Yakov Kuzyakov and Kazem Zamanian

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CommentsâČř1,2 on the publication entitled "Agropedogenesis: Humankind as the 6th soil-forming factor and attractors of agrogenic soil degradation" by Yakov Kuzyakov and Kazem Zamanian in ''Biogeosciences Discuss., https://doi.org/10.5194/bg-2019-151. Manuscript under review for journal Biogeosciences. Discussion started: 8 May 2019. âČřBy 1.Dr. D. K. Pal, Former Principal Scientist, Division of Soil Resource Studies, ICAR-NBSS&LUP, Amravati Road, Nagpur 440033, India. Email: paldilip2001@yahoo.com 2. Dr. Ashim Datta, Scientist, Division of Soil and Crop Management, ICAR-CSSRI, Karnal 132001, India. Email: ashimdatta2007@gmail.com

Comments are made on three important aspects based on research made on Indian tropical soils. (a)The first one is on the accumulation of soil organic carbon (SOC) by growing agricultural crops in soils of semi-arid tropical (SAT) climate of India showing no sign of soil degradation. (b)The second one is on the resilience of SAT sodic soils through anthropogenic activities (6th factor of soil formation) showing pedogenic processes that are reverse to what was proposed in the conceptual model of agropedogenesis. (c) The third one is to compete with the idea of acidification (lowering of soil pH) under agricultural crops is considered as a sign of soil degradation in model concept of agropedogenesis. (a) Soils as a unique natural capital, provide multiple benefits to humans, and are the foundation of agriculture and deliver multiple soil ecosystem services. It is expected that global food production will grow by 50% by the year 2030 and by 100% by the year 2050 in order to fulfil the demands of a growing world population and changing food consumption patterns (Godfray et al., 2010). It is often feared that the current long-term agricultural systems may damage the natural capital. Therefore, a need is always felt to mitigate the negative effects of agriculture on soils through 'sustainable intensification of agriculture', which would maintain the increasing trend of the current agro-ecosystems by sustaining natural capital stocks and also by minimizing adverse effect on environment (Baulcombe et al., 2009; Godfray et al., 2010; Koch et al., 2013; Lal, 2009). Projections indicate that 80% of crop production growth in developing countries up to 2030 will be derived through intensification (FAO, 2009). However, there are evidences to indicate that increasing agricultural intensification can erode ecosystem services (Power, 2010; Tilman et al., 2001, 2002). Continuous agriculture as the powerful anthropogenic activities by human beings to produce more food stocks, may thus cause degradation of soils, which Kuzyakov and Zamanian (2019) described as ''Agropedogenesis", and these authors consider this degradation as the 6th soil -forming factor. They have identified a set of 'master properties' (bulk density and macroaggregates, soil organic matter content and pH, microbial biomass and basal respiration), which are especially sensitive to land use and determine the other properties during agropedogenesis. It is an emerging conceptual model in soil science and thus stands for its universal acceptability by highlighting some case studies where several decades and century long agricultural practices are prevalent in the world history of agriculture especially when the intensification is being realized without degrading soil natural capital and ecosystem services. Halting of degradation of soils demanded the practices to change to more sustainable practices (Baulcombe et al., 2009) by using the non-renewable resources to renewable inputs (Sandhu et al., 2015), such as organic fertiliser (manure, compost), renewable energy and biologically based technologies for pest control. Such shift in practice is already under way in tropical soils of many agriculturally based countries including Indian sub-continent. Therefore, it will be important to showcase and also to share some soil carbon research accomplished in India following the recommendations of the National Agricultural Research System (NARS), which suggests no sign of soil degradation in terms of agropedogenesis as conceptualized and proposed by Kuzyakov and Zamanian (2019). It is realized that the carbon content in soils changes depending on the land use system and time. There is an increasing concern all over the world about the decline in soil productivity and the impoverishment of soil organic carbon (SOC) caused by intensive agriculture. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) of the Indian Council of Agricultural Research (ICAR), through organized research initiatives, sponsored by national and international organizations, has developed datasets of SOC for two important crop production zones, viz. the Indo-Gangetic Plains (IGP) (52.01 M ha, occupied mainly by Entisols, Inceptisols, Alfisols, Mollisols, Vertisols and their intergrades, Pal, 2017) and the black soil region (BSR) (76.4 M ha, occupied mainly by Vertisols and their intergrades and Alfisols, Pal, 2017) in the semi-arid tropics (SAT) (Bhattacharyya et al., 2014; Mandal et al., 2014). The datasets for 1980 and 2005 indicate an overall increase in SOC stock in the Benchmark spots under agriculture, practised for the last 25 years. This suggests that the agricultural management practices advocated through NARS for the last 25 years did not cause any decline in SOC in the major crop growing zones of the country (Bhattacharyya et al., 2007). Results of long-term fertilizer experiments with rice-based double or triple cropping systems indicate soil's capacity

to store greater C, and maintain higher C in passive pools and that active fraction of soil C can be used as an indicator of soil health. The application of NPK plus FYM emerged as a cost-effective technology for Indian farmers (Pathak et al., 2011; Mandal et al., 2008; Datta et al., 2017, Krishna et al., 2018) because the application of organic amendments builds up the SOC pool which enhances the quality of the soil, ecosystem services of soils, water and combats climate change (Lal, 2011; Christensen et al., 2009). However, management interventions of the NARS have caused depletion of soil organic carbon in some Mollisol of the IGP and they are presently classified as Alfisols having no other form of degradation. These Alfisols' ecosystem service in producing bumper wheat crop is still maintained. Additionally, to produce bumper rice, wheat and potato crops the IGP soils under cultivation for the last three decades used all modern agricultural implements and irrigation, which caused a rise in bulk density (BD) in the subsoils (Chandran et al., 2014; Tiwary et al., 2014). Although the rise in BD is responsible for plateauing or decline in the yield of the subsequent crop like wheat, it helped in maintaining yield of rice in rainy season and also in sequestering more SOC under sub-merged condition (Bhattacharyya et al., 2007; Sahrawat et al., 2005; Mandal et al., 2008; Pal et al., 2015). Paradoxically, the short and long-term experiments on Indian tropical soils reported during the past decades and in recent times indicate that these soils have reached a quasi-equilibrium stage and seldom show OC content (0-30 cm) > 1%. It is noted that even the SOC content (0-30 cm depth) of a long-term experiment (LTE) of 28 years on SAT Vertisols (with clay smectite $\sim$ 90%) using sorghum-wheat cropping system with recommended doses of NPK fertilizers plus FYM (10t ha-1) show a value of 0.73% only (Datta et al., 2018). The increase in OC in SAT agricultural soils (maximum up to $\leq$ 1% in 0-30 cm depth) through NARS interventions (Bhattacharyya et al., 2007, 2008) appears enough to provide ecosystem services in growing self-sufficiency in food production and food stocks since independence. The NARS interventions since post-green revolution period have helped in increased OC sequestration in all soil types and have not caused any degradation as evidenced from the retention of their original US Taxonomic soil orders (Pal, 2017). Also, such soils did not lead to increased emissions of greenhouse gases to any alarming proportion (Pal et al., 2015). However, it is intriguing that why the SAT soils (non-acidic, calcareous and dominated either by mixed or smectitic clay minerals) under decades long NARS management for agricultural crops, do not have OC > 1%? This scenario affirms that anthropogenic interventions by humankind in tropical soils of India under SAT environment are far from being qualified to be the 6th soil factor of soil formation in the model of 'agropedogenesis', proposed by Kuzyakov and Zamanian (2019). (b) Canal irrigation was introduced at the end of the 19th century to minimize the problem of aridity and to stabilize crop yields in the north western part of the IGP. This resulted in the expansion of the cultivated area. However, introduction of irrigation during the dry climate without the provision of drainage led to soil salinization and alkalinisation within a few years, due to rise in the groundwater table containing high proportion of sodium relative to divalent cations and/or high residual alkalinity. In addition, the use of groundwater with high sodicity hazards for irrigation has resulted in the extension of sodic soils (Abrol, 1982a, b). Apart from these kinds of salt-affected soils as an effect of anthropogenic activities, sodic soils interspersed with non-sodic or less sodic soils also occur in unirrigated areas of the SAT parts of the IGP and BSR regions. Therefore, anthropogenic activities in the IGP and BSR areas are not the only reason for the development of sodic soils (Pal et al., 2009a, b, 2016). The soils of the SAT regions in general are calcareous and, on many occasions, they are also sodic either in the subsoil or throughout the depth of soil profile (Pal et al., 2000; 2006). Calcareousness of these soils is due to the pedogenic formation of calcium carbonate. The formation of pedogenic calcium carbonate (PC) in the arid climate enhances the pH and also the relative abundance of Na^+ ions on soil exchange sites and in the solution; and the Na^+ ions in turn cause dispersion of the fine clay particles. The dispersed fine clays translocate in soils as the formation of PC creates a Na^+-enriched chemical environment conducive for the deflocculation of clay particles and their subsequent movement downward. Therefore, the formation of PC and the clay illuviation are two concurrent and contemporary pedogenetic events, resulting in an increase in relative proportion of sodium, causing

increased sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) and pH values with depth. Thus, the formation of PC is a basic natural degradation process, which exhibits the regressive pedogenesis by capturing atmospheric CO_2 (Pal et al., 2013; 2016). Sodic black soils (Sodic Haplusterts), which are impoverished in OC but are rich in $CaCO_3$, show enough resilience under improved management (IM) system (without adding gypsum and FYM) of the International Crops Research Institute for Semi-Arid Tropics (ICRISAT). The average grain yield of the IM system over thirty years was five times more than that in the traditional management (TM) system (Wani et al., 2003). Due to the improvements in physical, chemical and biological properties of soils after adaptation of the IM system, the poorly drained black soil (Sodic Haplusterts) now qualify for well drained soils (Typic Haplusterts). Continuous release of higher amount of Ca^{2+} ions during the dissolution of $CaCO_3$ under the IM system, compared to slower rate of formation of $CaCO_3$, provide enough soluble Ca^{2+} ions to replace unfavourable Na^+ ions on the soil exchange sites. Higher exchangeable Ca/Mg ratio in soils under IM system improved the saturated hydraulic conductivity (sHC) for better storage and release of soil water during the dry spell between rains. Adequate supply of soil water helped in better crop productivity and higher OC sequestration (Pal et al., 2012a, b). The improvement in Vertisols' sustainability suggests that the IM system is capable of mitigating the adverse effect of climate change. This management protocol though slow as compared to the gypsum-aided one, is however cost-effective and farmer-friendly. This technology helps to realize the benefit of the presence of $CaCO_3$ as an ecosystem engineer during the reclamation of sodic soils. Role of PC as an ecosystem engineer is also evidenced during the reclamation processes of IGP sodic soils even after the addition of gypsum. Sodic soils (Natrustalfs) of NW part of the IGP, after their reclamation by gypsum, improve in terms of their morphological, physical and chemical properties so much that these soils are now reclassified as well-drained and OC-rich normal Alfisols (Haplustalfs). Significant improvement in SOC stock and other soil properties was observed under different land uses in reclaimed alkali soils of North West India (Datta et al., 2015). Such remarkable resilience could be possible even with the low amount of added gypsum, suggesting that the added gypsum does not enrich soil solution by the required amount of $Ca2+$ ions to replace Na ions on the soil exchange sites. The fulfilment of Ca saturation could be possible by the dissolution of PC during the growing of the rice crop under submerged conditions (Pal et al., 2016). It was observed that the rate of dissolution of PC was much higher than its rate of formation in the top 1.0 m soil depth (Pal et al., 2009a; 2012b; 2016). Even after becoming normal soils as Haplustalfs and Haplusterts both IGP and Vertisols are still calcareous. In view of its slow rate of dissolution, it is quite likely that Ca-ions enriched chemical environment would allow neither Haplustalfs nor Haplusterts to transform to any other soil order so long CaCO3 would continue to act as a soil modifier. Positive role of CaCO3 in both the reclamation and sequestration of OC in SAT soils may benefit the maintenance of soil health of the farmlands (Pal et al., 2016). The above discussion makes it clear that anthropogenic interventions to make sodic soils resilient and also sustainable for production of agricultural crops is a unique case of 6th factor of soil formation which contrasts the degradation process of the agropedogenesis model proposed by Kuzyakov and Zamanian (2019). (c) For a long time, acid soils were considered to be chemically degraded because of their high acidity (pH «6.5), which is caused by the profuse chemical weathering under humid tropical (HT) climate. Moreover, they are often conceived to be typical soils that have less soil fertility generally, which however strongly contrasts with their OC enrichment (> 1%) in the surface horizons (Pal et al., 2014). They occupy about 9.4% of the total geographical area of the Indian sub-continent (ICAR-NAAS, 2010). Soils of HT climate in the states of Kerala, Goa, Karnataka, Tamil Nadu and North East Hill areas are strongly to moderately acidic Alfisols, Ultisols and Mollisols and their further weathering in HT climate would finally close at kaolin dominated soils with considerable amount of layer silicate minerals (Pal et al., 2014) and thus are siliceous in nature (especially the Ultisols of Kerala and acidic Alfisols of Goa) (Chandran et al., 2004; 2005; Varghese and Byju, 1993). This suggests that silica is insoluble in acidic soil medium and thus causes an incomplete desilication process in these acidic HT soils. It is interesting to note that the

amount of SiO2 and its molar ratios of Ultisols of Kerala (Chandran et al., 2005) and acidic Alfisols of Goa (Chandran et al., 2004) are comparable with some of the Oxisols reported from Puerto Rico (Jones et al., 1982), Brazil (Buurman et al., 1996; Muggler, 1998), and other regions of the World (Mohr et al., 1972). However, in the acidic Alfisols, Ultisols and Mollisols, the process of desilication no longer operates in present day conditions because the pH of the soils is well below the threshold of 9.0 (Millot, 1970). Interestingly, in such million years old soils, desilication and transformation of kaolin to gibbsite is pedogenetically impossible (Chandran et al., 2005; Pal, 2017) and thus it will be an equally impossible proposition for further degradation of Ultisols: they would however continue to provide ecosystem services in supporting agriculture, horticulture, forestry, tea, coffee and spices (Sehgal, 1998; Pal et al., 2014, Pal, 2017). This novel insight however contrasts with the representation of degradation of Ultisols to agriculturally unproductive Oxisols at the last stage of advanced stage of soil weathering (Smeck et al., 1983; Lin, 2011) and finally reaching the thermodynamic equilibrium. The formation and persistence of HT soils on the other hand, provide an example that in an open system such as the soil, the existence of a steady state seems a more useful concept than based on equilibrium in a rigorous thermodynamic sense (Bhattacharyya et al., 1999; 2006, Chandran et al., 2005; Pal, 2017). The present health of such soils indicate that they are SOC rich and have less Al-saturation in surface horizons due to the downward movement of Al as organo-metal complexes or chelates, but have higher base saturation than the subsurface horizons (Pal et al., 2014). Despite acidity many such soils show dominance of Ca 2+ and Mg2+ ions on soil exchange complex due to addition of alkaline and alkaline metal cations through litter fall (Nayak et al., 1996; Reza et al., 2018). Such OC-rich acid soils are not kaolinitic as they are dominated by kaolin mineral (a mixed mineral) as their clay CEC is > 24 cmol (p+) kg-1 as determined by BaCl2-TEA for total acidity plus bases by NH4OAc, pH 7 method, (Smith, 1986) and do respond to management interventions that are being made in various land use plans. In view of their excellent support for food production for centuries in the Indian sub-continent and elsewhere (Velayutham and Pal, 2016) it would be wise to dispel the myth that the lowering of pH or soil acidification is a sign of soil degradation. Finally, it is realized that the above three major pedological and edaphological issues of SAT and HT soils of the tropical world are worthy of consideration in finalising the role of humankind as the 6th soil forming factor and agrogenic degradation, and also to develop the universally acceptable model on agropedogenesis. References Abrol, I. P.: Reclamation and management of salt-affected soils, in Review of soil research in India. Part 11, 12th International Congress Soil Science, New Delhi, pp. 635-654, 1982b. Abrol, I. P.: Reclamation of waste lands and world food prospects, in Whither soil research, Panel Discussion Papers, 12th International Congress Soil Science, New Delhi, pp. 317-337, 1982a. Baulcombe, D., Crute, I., Davies, B., Dunwell, J., Gale, M., Jones, J., Pretty, J., Sutherland, W., Toulmin, C.: Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture, The Royal Society, pp72. 2009. Bhattacharyya, T., Chandran, P., Ray, S. K., Pal, D. 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