Management Practices and SOC Dynamics during Rural–Urban Transformations

Subjects: Soil Science | Agricultural Economics & Policy

Contributor: Virna Estefania Moran-Rodas, Verena Preusse, Christine Wachendorf

Rapid urbanization and agricultural intensification are currently impacting the soils of many tropical countries. Bangalore is a growing megacity experiencing both issues and their derived ecological and socio-economic effects. Fertilization increases SOC concentrations, especially when mineral fertilizer is combined with additional farmyard manure. Single mineral fertilizer and a combination of mineral fertilizer and farmyard manure are commonly applied in Bangalore. Conservation practices, such as reduced tillage and mulching, are applied by 48% and 16% of households, respectively. Farm and household characteristics, including market integration, are the most important determinants of management decisions that affect SOC.

Keywords: rurality ; mineral fertilization ; irrigation ; mulching ; tillage ; crop choice

1. Crop Choice and Diversification

Crop diversity is a critical factor in food security because having a variety of crops means that at least some crops will yield despite harsh climate conditions, insect outbreaks, and other natural disasters [1]. Patil et al. [2] reported 82 distinct crops in Bangalore. Among the different categories, cereals and pulses are the main crop choice for farmers in Bangalore, finger millet and maize being the major crops. Commercial crops, such as fruits, vegetables, fodder, and horticultural crops, complement the range [2]. Market proximity supports the production of high-value crops [3]. Proximity to Bangalore city increases the likelihood of farmers choosing vegetables, suggesting that the primary market is a main decision factor [2]. Crop type may interact with fertilization level and water management and may affect the quality of plant residues potentially returned to the soil [4]. Nitrogen and lignin contents are major determinants of decomposition rates [5], with N_2-fixing plants playing important roles in a substitution of mineral N fertilizer. High-quality residues increase microbial anabolic activity [6][7][8], promoting the production of microbial residues, thus increasing the C sequestration in soils [9]. Furthermore, crops differing in root traits may impact SOC dynamics via various processes, e.g., finer roots and more branched root systems as well as mycorrhiza infections increase the aggregate stability mainly through the physical enmeshment of soil particles, which increases resistance to soil erosion [10]. In annual cropping systems, species with high root to shoot ratios, such as pigeon pea and finger millet, which are traditionally grown in Bangalore, show higher contributions to SOC compared to plants with lower root shoot ratios, such as maize [8][11]. Perennial crops generally deposit more C than annual species due to their permanent and deeper root systems, promoting the stabilization of SOC [12][13]. These effects are mainly observed in tree plantations, hedges, and agroforestry systems, such as home gardens and alley cropping systems [14][15][16][17][18][19]. However, studies of Bangalore´s perennial representatives are lacking.

2. Application of Crop Residues and Mulching

Residue return and mulching are practices oriented toward enhancing soil quality and crop yields by increasing SOC inputs, improving a soil's structure and water holding capacity [12][20] while preserving soil moisture [21][22]. Depending on the quality of the residue and turnover rates, the return of nutrients by mulching may even directly increase yields [6]. Furthermore, mulched crop residues provide protective litter layers against erosion [5]. Mulching is practiced not only with harvest residues but also with tree pruning from leguminous trees and shrubs that increase C and N inputs into the soil [23]. Thus, legume plants are considered four times more often by tropical agricultural studies analyzing the effects of substrate quality and nutrient release than non-legume species [24]. In India, mulching is preferred for fruit orchards, flowers, and vegetables rather than for traditional food crops [25]. Despite the potential need for and positive effects of mulch, especially in rainfed systems, its use is not frequent in India [26].

In the tropics, lower C inputs into soil are partly caused by higher demands for crop residues for alternative uses, such as livestock feeding, fuel, and fiber [27]. This is particularly true in India where, besides livestock feeding, there is a great demand to use residues for energy, especially for cooking [12][28][29]. This lack of available crop residues is a major constraint for mulch applications as it is restricted cultivation during the dry season that causes increases in bare fallow and erosion [12][28]. Thus, low yields and reduced residue returns generate negative feedback loops with respect to SOC [12]. In this context, a higher urban demand for crop products and land may provide motivation to reduce bare fallow by using frequent cover crops, increasing crop productivity. In any case, all the abovementioned factors reflect a need to identify viable supplementary sources of nutrients, measures against soil erosion, [5] and viable alternative sources of fuel and fiber.

3. Use of Organic Manures and Fertilizers

Besides mulching, the application of organic manures increases nutrient cycling and C inputs into soil. Urban cattle in Bangalore are stallfed with purchased or farm-produced concentrates, while in rural locations, during the daytime, animals are allowed to graze on nearby vacant lands and on agricultural farmland. In both systems, dung collections and applications in crop production are low, highlighting a need to strengthen crop–livestock links by using back transfers of some of the products [29]. There is also a need to more efficiently manage urban cattle disposals that pollute water [29]. Thus, the recycling of cattle manure will prevent water pollution and will close C and nutrient cycles in agriculture. Green roughage is produced on a daily basis from the city environment and green spaces, while dry roughage is often purchased weekly and stored. In addition, unused vegetable and food wastes and compounded cattle feed or individually mixed concentrate are fed [29], demonstrating the trade-offs between the crop residues used for mulching and feed. Besides the low dung return rate, a low frequency and amount of organic fertilizer application as well may be due to utilizations for further purposes, such as energy [30][31]. In places where the availability of farmyard manure (FYM) is a major concern due to a decline in the livestock population, crop residues, compost, and municipal biosolids are considered alternative organic material inputs for sustainable crop production [32]. In India, the use of byproducts, such as press cake from the alternative biofuel species Jatropha, has increased plant yields and SOC accumulation [33]. Compost and biochar are potentially more efficient at increasing SOC storage because on top of improvements in soil quality and productivity, they are decomposed more slowly than fresh plant residues [13][20]. However, compost and biochar are less commonly applied in India, and few studies have included comparisons between compost and other organic amendments in relevant cropping systems [34][35][36], while none have included biochar. In irrigated rice-based cropping systems, the prominent means of maintaining SOM has historically been the incorporation of green manures, animal waste, and crop residues [6]. Under the specific dryland conditions of Bangalore, further analyses are required to compare the effects of different fertilizers on C sequestration.

Organic fertilizer is progressively supplemented or substituted with mineral fertilizer. An increased availability of mineral fertilizer and subsidized prices are probably important factors increasing such applications in many regions of the world [30][37]. The application of mineral fertilizers and combinations with organic amendments are recommended to counteract nutrient exports with harvested crops and nutrient losses during cultivations, while increasing soil aggregations, SOC contents, and water retentions of soils [12][20][38]. An N fertilization effect on SOC fractions has not been observed in the short term [8][39][40], whereas long-term individual studies demonstrated positive effects of N fertilization on SOC. However, the positive effects may be outweighed by negative effects due to increased N_2O emissions at high fertilization levels [41]. In nutrient-limited soils, fertilization is recommended for sufficient plant growth with a high potential for increasing C inputs in these soils [13]. Once a soil has improved in quality, yields are maintained by using a smaller input of fertilizer [20][42] as there is a threshold at which plant yields level off, despite increasing amounts of fertilizer being applied [42].

The potential of using manures and crop residues for short-term N provisions is limited in light of the manures' and residues' low N availabilities and N contents, the latter of which are often lower than 2%, although they can provide long-term benefits in maintaining SOM [5]. Contrasting results observed in individual studies comparing farmyard manure (FYM) with mineral fertilizers or combinations of the two were probably due to differing contents of nutrients in organic manures and biotic as well as abiotic soil properties. Nonetheless, for tropical croplands, manure applications have been some of the most successful practices for increasing SOC compared to mineral fertilization, conservation tillage, and the application of crop residues alone [27].

4. Water Management

In India, approximately one third of the country's arable land is irrigated, and increases in crop yields have been observed after irrigation [12]. However, access to water is limited and costly, emphasizing the importance of rainfed agriculture. Irrigation may induce contrasting effects on C sequestration. Introducing irrigation in dryland areas can increase C inputs [13][43] while enhancing decomposition rates. Likewise, the frequency of irrigation and intensities of wetting and drying cycles affect the soil's physical properties and microbial decomposition [6], thus regulating C sequestration. The rapid mineralization of crop residues under optimal soil moisture conditions may explain why systems under irrigation do not effectively increase soil organic carbon stocks [27]. Furthermore, the effects of irrigation interact with other management measures as irrigated crops often receive higher fertilization rates and other chemical farm inputs with implications for soil health and the environment [44]. However, the possible negative effects of irrigation, such as increased erosion rates and nutrient losses, are often overlooked [43].

Nevertheless, water conservation practices, such as compartmental bunding, implementing ridges and furrows, and mulching, all increase plant yields and SOC stocks in Bangalore´s agricultural soil [22][45], maintaining the positive effects of improved water availability on agriculture. In terms of irrigation, the adoption of efficient irrigation techniques, such as drip irrigation, in Bangalore may be linked to crop choice decisions, while not all crops can be drip irrigated [2].

The irrigation sources in Bangalore are diverse, ranging from relatively less polluted rivers and underground sources to city wastewater [46][47]. With wastewater, nutrients and organic matter are applied [46], but access to water is the most limiting factor, especially for systems based on natural reservoirs that are constantly depleted [2][47]. Despite water's primary importance in most soil processes, published studies regarding water management and its relation to SOC dynamics are surprisingly scarce compared to studies concerning other practices, such as fertilization and mulching.

5. Tillage

In India and other countries in Southeast Asia, moldboard plow tillage is frequently applied in crop rotations [48]. Soil disruption and intensive tillage practices are classified as immediate causes of SOC declines, so reduced and zero tillage are important mitigation practices to prevent SOC losses [12][13][14][20]. Tillage alters water interception and infiltration, soil porosity, aeration, aggregate distribution, and microclimates, increasing decomposition rates [6][12]. Conservation tillage, leaving 30% or more of a soil's surface with crop residue [49], is a good conservation strategy enhancing soil quality, yields, and thus SOC [12]. Zero tillage practices are defined as the complete absence of tillage and have been demonstrated to have great potential in increasing SOC accumulations worldwide [50]. In maize systems, zero tillage [51][52] and reduced tillage [53] have presented the highest increases in SOC. Studies about tillage's effects on SOC in India showed increased SOC levels for reduced tillage and non-tillage practices compared to conventional tillage in 90% of cases. Nevertheless, Powlson et al. [20] suggested that increases in SOC from reduced tillage appear to be much smaller than previously claimed and can be overestimated considering differences in the depth, bulk density, and depth distribution of SOC between tillage treatments.

References

1. Leff, B.; Ramankutty, N.; Foley, J.A. Geographic Distribution of Major Crops across the World: Global Crop Distribution. Glob. Biogeochem. Cycles 2004, 18, 1–27.
2. Patil, V.S.; Thomas, B.K.; Lele, S.; Eswar, M.; Srinivasan, V. Adapting or Chasing Water? Crop Choice and Farmers' Responses to Water Stress in Peri-Urban Bangalore, India: ADAPTING OR CHASING WATER? Irrig. Drain. 2019, 68, 140–151.
3. Drechsel, P.; Zimmermann, U. Factors Influencing the Intensification of Farming Systems and Soil-nutrient Management in the Rural-urban Continuum of SW Ghana. Z. Pflanzenernähr. Bodenk. 2005, 168, 694–702.
4. Seneviratne, G.; Van Holm, L.H.J.; Kulasooriya, S.A. Quality of Different Mulch Materials and Their Decomposition and N Release under Low Moisture Regimes. Biol. Fertil. Soils 1997, 26, 136–140.
5. Palm, C.A.; Gachengo, C.N.; Delve, R.J.; Cadisch, G.; Giller, K.E. Organic Inputs for Soil Fertility Management in Tropical Agroecosystems: Application of an Organic Resource Database. Agric. Ecosyst. Environ. 2001, 83, 27–42.
6. Yadvinder-Singh; Bijay-Singh; Timsina, J. Crop Residue Management for Nutrient Cycling and Improving Soil Productivity in Rice-Based Cropping Systems in the Tropics. In Advances in Agronomy; Elsevier: Amsterdam, The Netherlands, 2005; Volume 85, pp. 269–407. ISBN 978-0-12-000783-7.
7. Fontaine, S.; Barot, S.; Barré, P.; Bdioui, N.; Mary, B.; Rumpel, C. Stability of Organic Carbon in Deep Soil Layers Controlled by Fresh Carbon Supply. Nature 2007, 450, 277–280.
8. Moran-Rodas, V.E.; Chavannavar, S.V.; Joergensen, R.G.; Wachendorf, C. Microbial Response of Distinct Soil Types to Land-Use Intensification at a South-Indian Rural-Urban Interface. Plant Soil 2022, 473, 389–405.
9. Liang, C.; Schimel, J.P.; Jastrow, J.D. The Importance of Anabolism in Microbial Control over Soil Carbon Storage. Nat. Microbiol. 2017, 2, 17105.

10. Bardgett, R.D.; Mommer, L.; De Vries, F.T. Going Underground: Root Traits as Drivers of Ecosystem Processes. Trends Ecol. Evol. 2014, 29, 692–699.
11. Manjaiah, K.M.; Voroney, R.P.; Sen, U. Soil Organic Carbon Stocks, Storage Profile and Microbial Biomass under Different Crop Management Systems in a Tropical Agricultural Ecosystem. Biol. Fertil. Soils 2000, 32, 273–278.
12. Lal, R. Soil Carbon Sequestration in India. Clim. Chang. 2004, 65, 20.
13. Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G.P.; Smith, P. Climate-Smart Soils. Nature 2016, 532, 49–57.
14. Oelbermann, M.; Paul Voroney, R.; Gordon, A.M. Carbon Sequestration in Tropical and Temperate Agroforestry Systems: A Review with Examples from Costa Rica and Southern Canada. Agric. Ecosyst. Environ. 2004, 104, 359–377.
15. Mapa, R.B.; Gunasena, H.P.M. Effect of Alley Cropping on Soil Aggregate Stability of a Tropical Alfisol. Agrofor. Syst. 1995, 32, 237–245.
16. Tian, G.; Kang, B.T.; Kolawole, G.O.; Idinoba, P.; Salako, F.K. Long-Term Effects of Fallow Systems and Lengths on Crop Production and Soil Fertility Maintenance in West Africa. Nutr. Cycl. Agroecosyst. 2005, 71, 139–150.
17. Follain, S.; Walter, C.; Legout, A.; Lemercier, B.; Dutin, G. Induced Effects of Hedgerow Networks on Soil Organic Carbon Storage within an Agricultural Landscape. Geoderma 2007, 142, 80–95.
18. Radrizzani, A.; Shelton, H.M.; Dalzell, S.A.; Kirchhof, G. Soil Organic Carbon and Total Nitrogen under Leucaena Leucocephala Pastures in Queensland. Crop Pasture Sci. 2011, 62, 337.
19. Nath, A.J.; Brahma, B.; Sileshi, G.W.; Das, A.K. Impact of Land Use Changes on the Storage of Soil Organic Carbon in Active and Recalcitrant Pools in a Humid Tropical Region of India. Sci. Total Environ. 2018, 624, 908–917.
20. Powlson, D.S.; Whitmore, A.P.; Goulding, K.W.T. Soil Carbon Sequestration to Mitigate Climate Change: A Critical Re-Examination to Identify the True and the False. Eur. J. Soil Sci. 2011, 62, 42–55.
21. Liu, D.L.; Zeleke, K.T.; Wang, B.; Macadam, I.; Scott, F.; Martin, R.J. Crop Residue Incorporation Can Mitigate Negative Climate Change Impacts on Crop Yield and Improve Water Use Efficiency in a Semiarid Environment. Eur. J. Agron. 2017, 85, 51–68.
22. Chaudhary, R.S.; Somasundaram, J.; Mandal, K.G.; Hati, K.M. Enhancing Water and Phosphorus Use Efficiency Through Moisture Conservation Practices and Optimum Phosphorus Application in Rainfed Maize–Chickpea System in Vertisols of Central India. Agric. Res. 2018, 7, 176–186.
23. Srinivasarao, C.; Lal, R.; Kundu, S.; Babu, M.B.B.P.; Venkateswarlu, B.; Singh, A.K. Soil Carbon Sequestration in Rainfed Production Systems in the Semiarid Tropics of India. Sci. Total Environ. 2014, 487, 587–603.
24. Seneviratne, G. Litter Quality and Nitrogen Release in Tropical Agriculture: A Synthesis. Biol. Fertil. Soils 2000, 31, 60–64.
25. Bhardwaj, R.L. Effect of Mulching on Crop Production under Rainfed Condition—A Review. Agri. Rev. 2013, 34, 188.
26. Lal, R. Managing Soil Water to Improve Rainfed Agriculture in India. J. Sustain. Agric. 2008, 32, 51–75.
27. Fujisaki, K.; Chevallier, T.; Chapuis-Lardy, L.; Albrecht, A.; Razafimbelo, T.; Masse, D.; Ndour, Y.B.; Chotte, J.-L. Soil Carbon Stock Changes in Tropical Croplands Are Mainly Driven by Carbon Inputs: A Synthesis. Agric. Ecosyst. Environ. 2018, 259, 147–158.
28. Manna, M.C.; Ghosh, P.K.; Acharya, C.L. Sustainable Crop Production Through Management of Soil Organic Carbon in Semiarid and Tropical India. J. Sustain. Agric. 2003, 21, 85–114.
29. Prasad, C.S.; Anandan, S.; Gowda, N.K.S.; Schlecht, E.; Buerkert, A. Managing Nutrient Flows in Indian Urban and Peri-Urban Livestock Systems. Nutr. Cycl. Agroecosyst. 2019, 115, 159–172.
30. Thilakarathna, M.; Raizada, M. A Review of Nutrient Management Studies Involving Finger Millet in the Semi-Arid Tropics of Asia and Africa. Agronomy 2015, 5, 262–290.
31. Agegnehu, G.; Amede, T. Integrated Soil Fertility and Plant Nutrient Management in Tropical Agro-Ecosystems: A Review. Pedosphere 2017, 27, 662–680.
32. Sathish, A.; Ramachandrappa, B.K.; Shankar, M.A.; Srikanth Babu, P.N.; Srinivasarao, C.; Sharma, K.L. Long-Term Effects of Organic Manure and Manufactured Fertilizer Additions on Soil Quality and Sustainable Productivity of Finger Millet under a Finger Millet-Groundnut Cropping System in Southern India. Soil Use Manag. 2016, 32, 311–321.
33. Anand, K.G.V.; Kubavat, D.; Trivedi, K.; Agarwal, P.K.; Wheeler, C.; Ghosh, A. Long-Term Application of Jatropha Press Cake Promotes Seed Yield by Enhanced Soil Organic Carbon Accumulation, Microbial Biomass and Enzymatic Activities in Soils of Semi-Arid Tropical Wastelands. Eur. J. Soil Biol. 2015, 69, 57–65.

34. Sharma, K.L.; Grace, J.K.; Srinivas, K.; Venkateswarlu, B.; Korwar, G.R.; Sankar, G.M.; Mandal, U.K.; Ramesh, V.; Bindu, V.H.; Madhavi, M.; et al. Influence of Tillage and Nutrient Sources on Yield Sustainability and Soil Quality under Sorghum–Mung Bean System in Rainfed Semi-arid Tropics. Commun. Soil Sci. Plant Anal. 2009, 40, 2579–2602.

35. Nayak, P.; Patel, D.; Ramakrishnan, B.; Mishra, A.K.; Samantaray, R.N. Long-Term Application Effects of Chemical Fertilizer and Compost on Soil Carbon under Intensive Rice–Rice Cultivation. Nutr. Cycl. Agroecosyst. 2009, 83, 259–269.

36. Srinivasarao, C.; Kundu, S.; Kumpawat, B.S.; Kothari, A.K.; Sodani, S.N.; Sharma, S.K.; Abrol, V.; Ravindra Chary, G.; Thakur, P.B.; Yashavanth, B.S. Soil Organic Carbon Dynamics and Crop Yields of Maize (Zea Mays)–Black Gram (Vigna Mungo) Rotation-Based Long Term Manurial Experimental System in Semi-Arid Vertisols of Western India. Trop. Ecol. 2019, 60, 433–446.

37. Chianu, J.N.; Chianu, J.N.; Mairura, F. Mineral Fertilizers in the Farming Systems of Sub-Saharan Africa. A Review. Agron. Sustain. Dev. 2012, 32, 545–566.

38. Banger, K.; Toor, G.S.; Biswas, A.; Sidhu, S.S.; Sudhir, K. Soil Organic Carbon Fractions after 16-Years of Applications of Fertilizers and Organic Manure in a Typic Rhodalfs in Semi-Arid Tropics. Nutr. Cycl. Agroecosyst. 2010, 86, 391–399.

39. Yagi, R.; Ferreira, M.E.; da Cruz, M.C.P.; Barbosa, J.C.; Araújo, L.A.N. de Soil Organic Matter as a Function of Nitrogen Fertilization in Crop Successions. Sci. Agric. 2005, 62, 374–380.

40. Vineela, C.; Wani, S.P.; Srinivasarao, C.; Padmaja, B.; Vittal, K.P.R. Microbial Properties of Soils as Affected by Cropping and Nutrient Management Practices in Several Long-Term Manurial Experiments in the Semi-Arid Tropics of India. Appl. Soil Ecol. 2008, 40, 165–173.

41. Tian, H.; Lu, C.; Melillo, J.; Ren, W.; Huang, Y.; Xu, X.; Liu, M.; Zhang, C.; Chen, G.; Pan, S.; et al. Food Benefit and Climate Warming Potential of Nitrogen Fertilizer Uses in China. Environ. Res. Lett. 2012, 7, 44020.

42. Oldfield, E.E.; Bradford, M.A.; Wood, S.A. Global Meta-Analysis of the Relationship between Soil Organic Matter and Crop Yields. SOIL 2019, 5, 15–32.

43. Sojka, R.E.; Bjorneberg, D.L.; Strelkoff, T.S. Irrigation-Induced Erosion. In Agronomy Monographs; Lascano, R.J., Sojka, R.E., Eds.; American Society of Agronomy; Crop Science Society of America; Soil Science Society of America: Madison, WI, USA, 2007; pp. 237–275. ISBN 978-0-89118-264-1.

44. Environmental Management & Policy Research Institute. State of Environment Report Karnataka. 2015. Available online: https://karunadu.karnataka.gov.in/forestsecretariat/Downloads/SoER_2015.pdf (accessed on 8 January 2021).

45. Patil, S.L.; Sheelavantar, M.N. Effect of Cultural Practices on Soil Properties, Moisture Conservation and Grain Yield of Winter Sorghum (Sorghum Bicolar L. Moench) in Semi-Arid Tropics of India. Agric. Water Manag. 2004, 64, 49–67.

46. Patil, S. Urbanisation and New Agroecologies. Econ. Political Wkly. 2018, 53, 71–77.

47. Kulkarni, T.; Gassmann, M.; Kulkarni, C.M.; Khed, V.; Buerkert, A. Deep Drilling for Groundwater in Bengaluru, India: A Case Study on the City's Over-Exploited Hard-Rock Aquifer System. Sustainability 2021, 13, 12149.

48. Ghimire, R.; Lamichhane, S.; Acharya, B.S.; Bista, P.; Sainju, U.M. Tillage, Crop Residue, and Nutrient Management Effects on Soil Organic Carbon in Rice-Based Cropping Systems: A Review. J. Integr. Agric. 2017, 16, 1–15.

49. Conservation Technology Information Center (CTIC). Tillage Type Definitions. 2002. Available online: https://www.mssoy.org/uploads/files/ctic.pdf (accessed on 1 March 2022).

50. Mehra, P.; Baker, J.; Sojka, R.E.; Bolan, N.; Desbiolles, J.; Kirkham, M.B.; Ross, C.; Gupta, R. A Review of Tillage Practices and Their Potential to Impact the Soil Carbon Dynamics. In Advances in Agronomy; Elsevier: Amsterdam, The Netherlands, 2018; Volume 150, pp. 185–230. ISBN 978-0-12-815175-4.

51. Pandey, C.B.; Chaudhari, S.K.; Dagar, J.C.; Singh, G.B.; Singh, R.K. Soil N Mineralization and Microbial Biomass Carbon Affected by Different Tillage Levels in a Hot Humid Tropic. Soil Tillage Res. 2010, 110, 33–41.

52. Kushwa, V.; Hati, K.M.; Sinha, N.K.; Singh, R.K.; Mohanty, M.; Somasundaram, J.; Jain, R.C.; Chaudhary, R.S.; Biswas, A.K.; Patra, A.K. Long-Term Conservation Tillage Effect on Soil Organic Carbon and Available Phosphorous Content in Vertisols of Central India. Agric. Res. 2016, 5, 353–361.

53. Kumar, A.; Mishra, V.N.; Biswas, A.K.; Somasundaram, J. Soil Organic Carbon, Dehydrogenase Activity and Fluorescein Diacetate as Influenced by Contrasting Tillage and Cropping Systems in Vertisols of Central India. JEB 2018, 39, 1047–1053.