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ORIGINAL ARTICLE

Implementation and modelling of turf grass management options to improve soil carbon sequestration in a semi-arid environment

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Abstract
Soil organic carbon (SOC) sequestration under turfgrass could be part of a climate change mitigation strategy but has, to date, not received much attention in Pakistan. This study is about the potential of turfgrass to sequester SOC in a semi-arid environment under a range of management options such as altering grass clip and fertiliser management. Grass clip management treatments consisted of either retaining the clippings or removing them, which was supplemented by a different mowing regime or, in the second year, by a fertiliser treatment. Grass height (productivity) and composition, SOC, nitrogen, temperature and rainfall were measured. In the first year, little difference in the productivity and SOC between the treatments was found. In the second year the addition of urea and the retention of clippings resulted in substantial increases in grass productivity of more than 4500 kg ha^{-1} to 8500 kg ha^{-1} year^{-1} as well as small increases (0.2%) in the SOC. Using the CENTURY soil carbon model, reasonable agreement was achieved between the observed and modelled grass productivity and SOC, as long as external sources of extra nitrogen were included. Extending the turfgrass management to 50 years into the future, it was estimated, using the CENTURY model, that 44 Mg ha^{-1} SOC could be sequestered through retaining grass clippings and with the addition of fertiliser. With these simple grass management options, a good opportunity is available locally to contribute to mitigation strategies to combat global warming.

Keywords Pakistan · Climate change mitigation · Grass clipping management · Soil organic carbon

Introduction

Soil organic matter plays a significant role in the fertility and the management of soils. In addition, the sequestration of soil organic carbon (SOC) reduces greenhouse gases (GHG), particularly carbon dioxide, and combats climate change (Lal 2017). Increasing SOC are the objectives of many mitigations' efforts promoted by the Integovernmental Panel on Climate Change (IPCC) and many other bodies, be they governmental or non-governmental (IPCC 2013). Increases in the SOC can be achieved in several ways, for example, by the growing of trees (Phankasem et al. 2012), the implementation of no-till or zero-till farming (Ogle et al. 2019) or by specific turfgrass management (Qian and Follett 2012). The latter is of particular interest given the sheer magnitude of the areas covered by turfgrass. NASA (2005) published data on turfgrass and stated that there was more lawn than irrigated corn in the United States. Diep (2011) estimated that in the USA alone, at that time, about 16 million ha were covered by turfgrass. Also, by applying mitigation efforts to urban areas it would enable urban people to be actively involved in climate change mitigation efforts.

Turfgrass areas have a large potential to sequester SOC, even by such simple means of not collecting the turfgrass clippings after each mowing operation (Harivandi et al. 2001; Qian et al. 2003). In a multiple year study Singh (2007) developed sustainability indices (SI) for turf management in the context of carbon sequestration and found that lowering the amount of N fertiliser and returning the grass clipping improved the SI of turfgrass systems. Qian and Follett (2010) demonstrated the opportunity that exists to increase SOC by 25 to 59% after 50 years by retaining grass clippings and altering the fertiliser regimes. This work was based on field-measured data and then extrapolated to 50 years using the CENTURY model. Zirkle et al. (2011) estimated that depending on the management practices, SOC sequestration in home lawns ranged from

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25 g C m^{-2} $year^{-1}$ for a minimal input management option to 204 g C m^{-2} $year^{-1}$ for an industry-standard best management practice. These results indicate that significant gains in SOC sequestration can be obtained through changing turf management.

On a global scale Pakistan is only a small emitter of GHGs, but it is on the receiving end of many of the consequences of climate change (Rahsid et al. 2020; Eckstein et al. 2021). In order to contribute to the global warming mitigation efforts, Pakistan has begun several initiatives to address the issue (UNEP 2021). Carbon sequestration through turfgrass management could be one of these initiatives, however, much of the work on the capacity of sequestering SOC in turfgrass has been carried out in climate regions and under conditions very different from those encountered in Pakistan. The study presented in this paper explores the potential of SOC sequestration in turfgrass in Lahore, Pakistan, as Lahore is considered to be a 'green-city' or a 'garden city'. Many areas of the city are congested and built-up but there are still considerable areas of public and non-public open space, often covered by turfgrass (Naz and Ashraf 2008).

The objectives of the study were two-fold: to explore the possibilities of increasing SOC under turfgrass under local semi-arid conditions and secondly considering what the SOC sequestration under turfgrass could look like when certain management options were applied over a longer period.

Material and methods

Study area

The study was conducted in the Botanical Garden of Forman Christian College University (FCCU) located in the middle of Lahore (31.5220° Lat, 74.3334° Long) from June 2017 until September 2019. In the garden, an area was set aside to be managed specifically for the purpose of carbon sequestration. The area of 50 m × 20 m was already an established lawn, which was divided in 32 smaller plots of 10 m × 3 m.

The soil type at the site is common for Punjab (Ahmad et al. 2019) and can be briefly described as an alkaline light brown loamy clay soil, with very little profile development over a depth of at least 100 cm except for the surface where some dark staining occurs.

Lahore has a hot semi-arid steppe climate with a distinct monsoon season with a BSh classification according to Köppen and Geiger (Climate-Data 2021). Winter rainfall occurs from time to time under an influence from a westerly direction, but most of the rainfall occurs during the monsoon, typically in July and August, coming from an easterly direction. Summer maximum temperatures prior to the onset of the monsoon can reach 40–45 °C with a low relative humidity (RH), while during the monsoon these temperatures decrease to 30–35 °C but with significant increase in RH. In winters minimum temperatures can be below zero for a short period of time just before sunrise, but during the day this is very rare. Minima of 5–10 °C would be normal for that time of the year.

Local turfgrass management is characterised by very low inputs, (very little fertiliser input) and regular mowing, after which the grass clippings are collected by manually sweeping the area and they are then removed. Mowing is done using a cage-roller cutter or when the grass gets too tall, using a rotary slasher.

Irrigation of the lawn consists of surface irrigation. Water is channelled from the nearby canal to the turf areas under gravity. Scheduling is not fixed but irrigation occurs roughly once a month. Duration of the irrigation is 24 h and about 100 mm is given during that time.

Several treatments were applied to the experimental lawn area. The main treatments consisted of removing (CL) or retaining grass clippings (NCL) after mowing. Removing the clippings was done immediately after mowing. The main treatment was then subdivided in either a special mowing regime in the first year, or different fertiliser regimes in the second year. The mowing regime consisted of mowing when the grass was about 4 cm tall (S) or when the grass was about 7 cm tall (T). The rationale being that long clippings would take longer to decompose compared to short clippings. The fertiliser regimes in the second year consisted of an application of urea (80 kg ha^{-1}) at the beginning (mid-April) and in the middle of the 'growing' season (mid-June) (F), or no additional fertiliser (NF). The growing season in Lahore is typically from early March to the end of October, following the temperature regime during the year.

Methodology

SOC was determined on a regular basis by taking three randomly spaced samples in the plots at two different depths: 0–5 cm and 5–10 cm, using a small tube corer. The SOC was determined by obtaining the fresh weight prior to oven drying at 105 °C for 24 h, then weighing again after drying to obtain the dry weight of the (DW_{105}), followed by incineration in a muffle furnace at 500 °C for 4 h for the SOC and then weighing again to obtain the weight of the soil without SOC (DW_{500}). The SOC was calculated from the difference between DW_{105} and DW_{500} as a fraction of DW_{500}.

Grass height was obtained using a lightweight polystyrene base plate (25 cm × 25 cm) to which a PVC pipe was attached with a rod fully inserted in the pipe. When placing the plate on the grass, the plate would gently rest on the top of the grass while the rod would pass through the plate and penetrate the grass. Grass height was determined from the height difference between the rod and the pipe and was used as a surrogate measure for grass biomass (AHDB 2021).

Grass height was usually measured just before mowing and shortly thereafter and then regularly between mowing.

Grass height was correlated to grass biomass through a calibration procedure. At a few different times during the growing season, small areas (30 cm × 30 cm) of short, medium and tall grass were selected. The grass height in those areas was measured and then the dry grass biomass in those areas was determined by cutting the grass close to the soil surface with a sharp knife, drying it in an oven at 60 °C for 24 h and then weighing it.

Soil nitrogen (Total Kjeldahl Nitrogen) was measured on the soil samples in the second year using the Kjeldahl method (Bremner and Mulvaney 1982).

Climate parameters were obtained on site using an automatic weather station that recorded the ambient air temperature with a PT100 sensor and recorded the rainfall with a tipping bucket rain gauge. The weather station consisted of a CR10X datalogger (CS 2021) that recorded an average reading every hour and was powered by a battery that was in turn charged continuously by a solar panel.

Each of the treatments (T, S, NCL and CL in year 1) and (F, NF, NCL and CL in year 2) with their interactions were replicated four times. Analyses of variance were conducted on the results using the Excel® statistical options.

Model

For the simulation of the SOC dynamics, the CENTURY soil organic matter model was used (Qian et al. 2003; Qian et al. 2010; Qian and Follett 2012). This model has received extensive scrutiny, has been well documented and used for similar purposes as presented in this study (Metherell et al. 1993, Parton and Rasmussen 1994) and Cong et al. 2014).

In short, the model receives input parameters that are determined and set by the operator. Climatic data can be either actual measured data or generated for longer term future simulations. The soil is compartmentalised in layers and the various balances: water, nitrogen (N), phosphorus (P), sulfur (S) and SOC are calculated for each layer. Various cropping and grassland systems can be used as well as different mowing, irrigation, fertilisation, and clip management regimes. The latter can be simulated by either removing the clippings from the input or by letting the grass clipping decompose, adding to the organic inputs the soil receives. Organic matter inputs both as plant residues and as soil organic matter (SOM), being the active pool, are determined by the microbial respiration rates. Following decomposition, the SOM products are distributed over a surface micro pool and three other SOM pools. These three pools: active (turnover rate of about a few months to years), slow (turnover rate of 20–50 years) and the passive pool with turnover rates of 400–2000 years, receive their respective fractions depending on the various decomposition rates set in the model. These are in turn dependent on different parameters such as temperature, soil moisture content, N status, clay content and other parameters. The time step of the model is a monthly time step.

The CENTURY input parameters that were changed, were related to the specific conditions encountered in Lahore, such as soil type, temperature, rainfall, SOC, crop/grass type, nutrition, timing and amount of irrigation and mowing with clippings retained or removed. The model needed to come to an equilibrium in terms of organic carbon cycling prior to the implementation of any scenarios. We simulated the situation prior to the establishment of the scenarios as 26 years of irrigated low input grass growing, and 50 years prior to that low input non-irrigated grass growing, both with grass clippings removed. For future scenarios, CENTURY was run for 50 years past 2019 whilst applying the various treatments. The input parameters were fine-tuned, so that the model outputs such as SOC and grass biomass production matched the actual field observations. With those selected parameters, the 50 year simulations were conducted.

Results

Weather

The changes in ambient temperature and rainfall during the two years of observations are presented in Fig. 1.

Variations in the hourly ambient temperature were substantial. On a diurnal basis the variation was as much as 20 °C. Particularly in winter this variation increased. Prior to the monsoon season, some times maximum daily temperatures were in excess of 45 °C, which are very high for the ambient air temperature, while in the wintertime minimum temperatures below 0 °C were also recorded. Maximum temperatures declined in the summer once the monsoon arrived.

Grass productivity

Grass height was correlated to grass dry biomass from the following equations, obtained in the respective growing seasons and presented in Fig. 2.

Correlations between grass dry biomass and the grass height were obtained with a good (Fig. 2A) to reasonable (Fig. 2B) R-squared and both seasons had similar linear relationships. These equations were used to convert grass height to above-ground biomass. Changes of this biomass over time are presented in Fig. 3.

Grass biomass varied greatly both in time and to some extent between the treatments, particularly in the second year. Grass height measurements started later in the second year due to a change in personnel doing the monitoring on a regular basis. In the first season there appeared

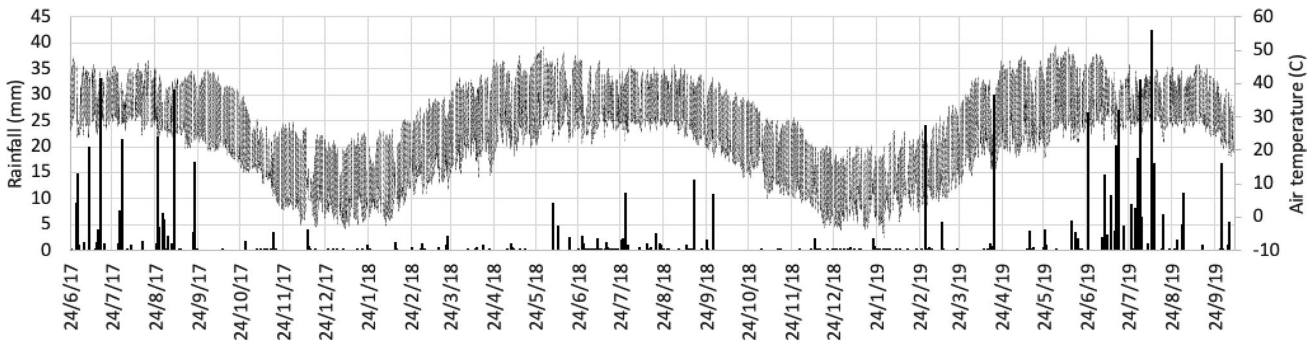


Fig. 1 Variations in the ambient hourly air temperature over a two year period and daily rainfall (vertical lines) over a two year period at FCCU

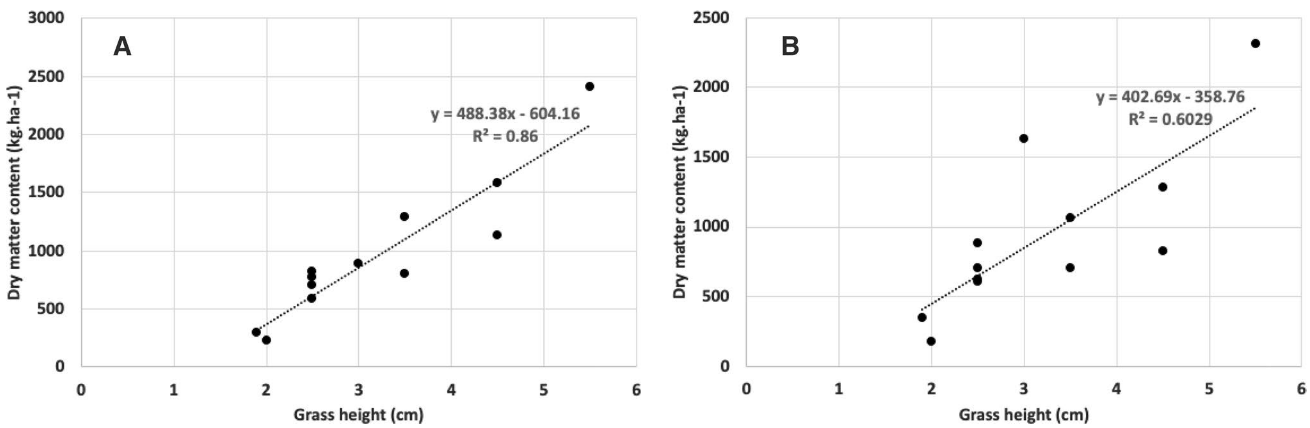


Fig. 2 Grass dry biomass as a function of grass height in the 2017—18 growing season (**A**) and the 2018–2019 growing season (**B**)

to be some treatment differences at the beginning with the NCL (long) retained and the Control producing the most biomass; but those differences disappeared after some time. In the early part of the second year, retaining the clippings (CL) did not have much impact on the biomass production (mainly during the period of slow growth) of the grass but following the application of the urea, large differences between treatments were immediately visible. These differences were maintained, and with the addition of the fertiliser, retaining the clippings (CL) also had an effect.

During the cooler months of the year, grass growth ceased and the composition of the swarth changed. The varieties of species in the summer and winter periods are presented in Table 1.

The grasses almost disappeared out of the swarth during the winter months, but returned without any specific management. During the winter months most of the weeds were prostrate weeds, particularly *Sagina procumbens* was dominant.

Soil

Changes in SOC content over time are presented in Fig. 4. The SOC of the upper soil layer (0–5 cm) was the highest in both seasons.

The SOC changes over time at a depth of 5–10 cm followed the same pattern as the SOC in surface layer, being higher in the summer months and then declining over the winter period. The differences in the SOC between the treatments in the 2017–2018 season were not significant enough to present them separately, but in the second season, the CL with the addition of urea had the highest SOC (6%) compared to 5–5.5% for the other treatments at the time fertiliser was applied.

Soil Kjehdal nitrogen of the soil surface layer, 0–10 cm was measured in the 2nd season because only then was N in the form of urea applied as a treatment. The results of three different occasions are presented in Fig. 5.

From Fig. 5, in February, after one and half seasons of retaining clippings (CL), the soil N was higher. Adding N

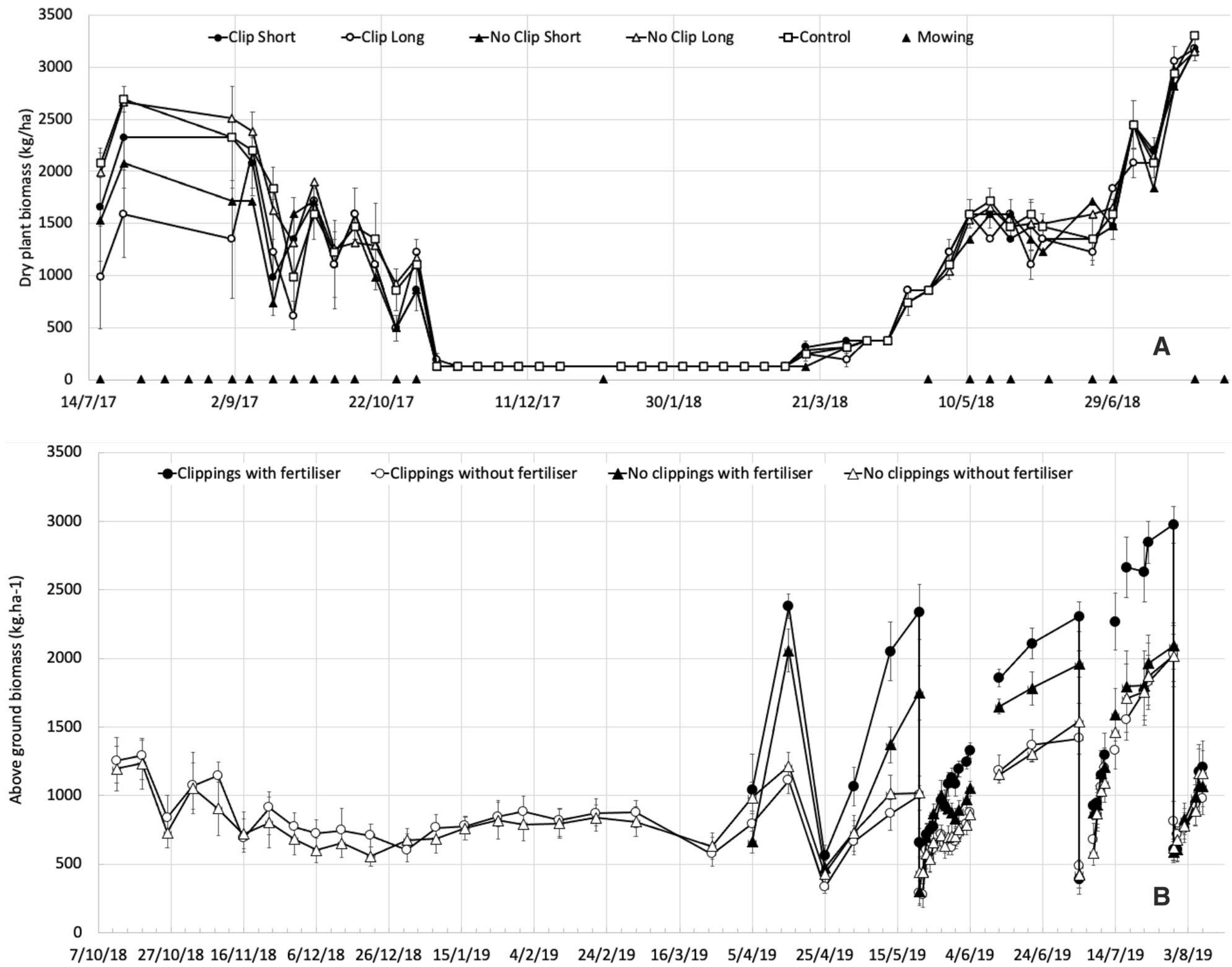


Fig. 3 Grass biomass changes over time for the 2017–2018 growing season (**A**), and for the 2018–2019 growing season (**B**). The length of the error bars is based on the magnitude of the standard deviation of the observations

Table 1 Composition of the swarth in two different periods during the trial in FCCU Botanical Gardens

Period	Scientific names (English and local names between brackets)
May–November (Summer)	*Cynodon Dactylon* (Bermuda grass, Khabbal), *Coronopus didymus* (Swine cress, Jangli balon), *Oxalis acetocella* (European wood sorrel, Khatti booti), *Poa annua* (Winter grass, Poa ghaas), *Dichanthium annulatum* (Dichanthium, Pehlwan), *Dachtyloctenium agyptum* (Egyptian finger grass), *Desmostachya bipinnata* (Deep root grass, Dab). *Oxalis corniculata* (Sleeping beauty, Khati Methi), *Brachiaria ramosa* (Sudan grass, Sudan ghaas)
November–May (Winter)	*Eclipta prostata* (Bitter weed, Bhangra), *Poa annua*, (Annual winter grass, Poa ghaas), *Alternanthra sessilis* (Alternanthra, Gandal booti), *Convolvulus arvensis* (Field bindweed, Lehli), *Coroponus didymus* (Swine cress, Jangli balon), *Sagina procumbens* (Pearlwort)

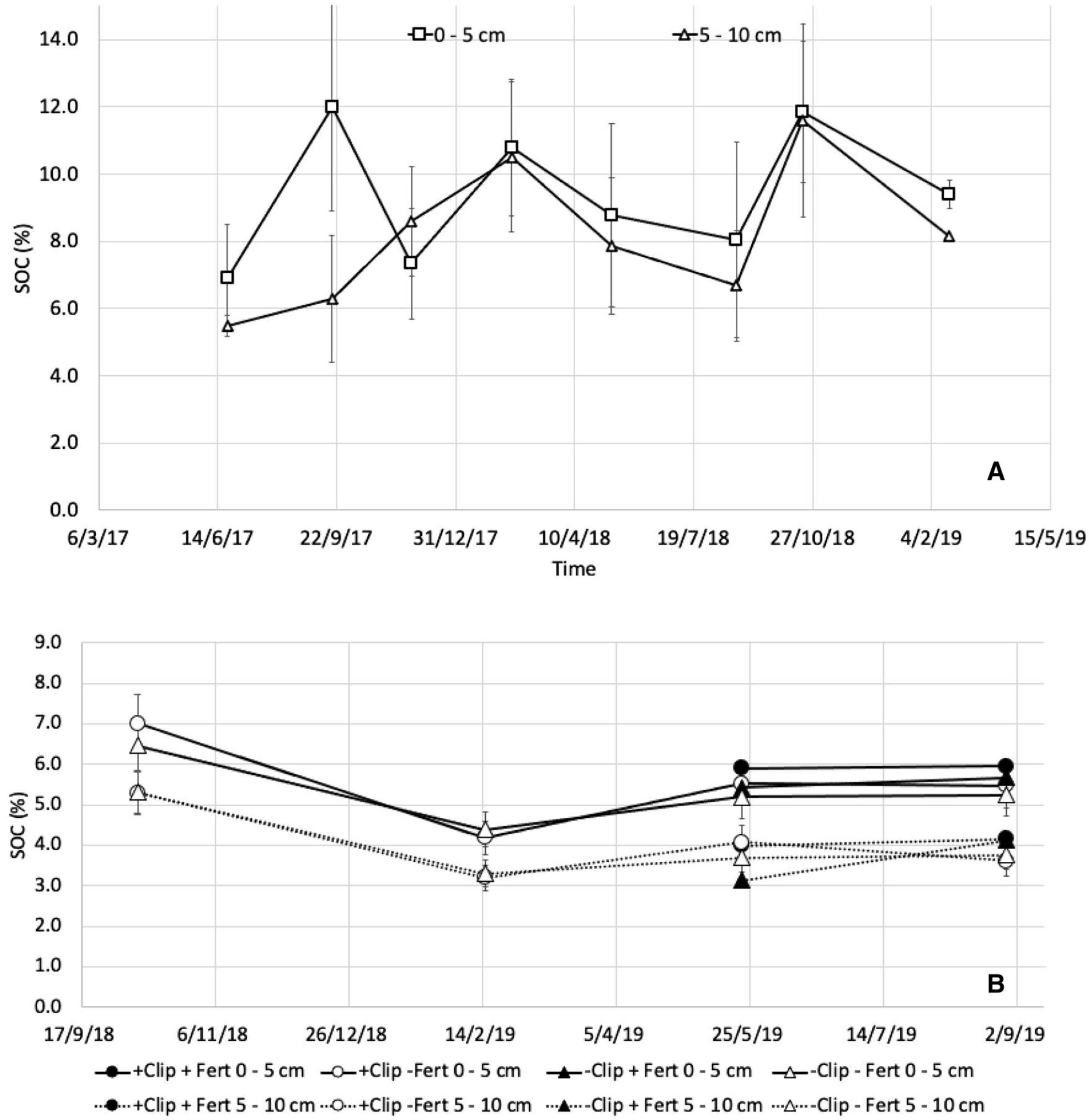


Fig. 4 Soil organic carbon content of the soil at various depths as indicated in the legends taken in the 2017–2018 season (**A**) and the 2018–2019 season (**B**). The length of the error bars is based on the magnitude of the standard deviation of the observations

increased its level in the soil, as was expected, while the zero-fertiliser treatment (NF) remained the same.

The carbon/nitrogen ratio (C/N) was calculated from the SOC and the N in the soil. The C/N ratio obtained on two different occasions is presented in Fig. 6.

Applying the urea in the middle of April had an impact on the C/N ratio measured in May 2019, while in August, much of the N had been used, leached out or volatilised, thereby increasing the C/N ratio again.

Model outcomes

The output of the CENTURY model contains a great number of different parameters. We focused on: the above-ground growing season accumulator C and the monthly total SOC or the sum of all the SOC pools. The above-ground C production was converted to dry biomass in kg ha^{-1}, assuming an average C content of the aboveground vegetation of 50%. The above-ground biomass of the grass is presented

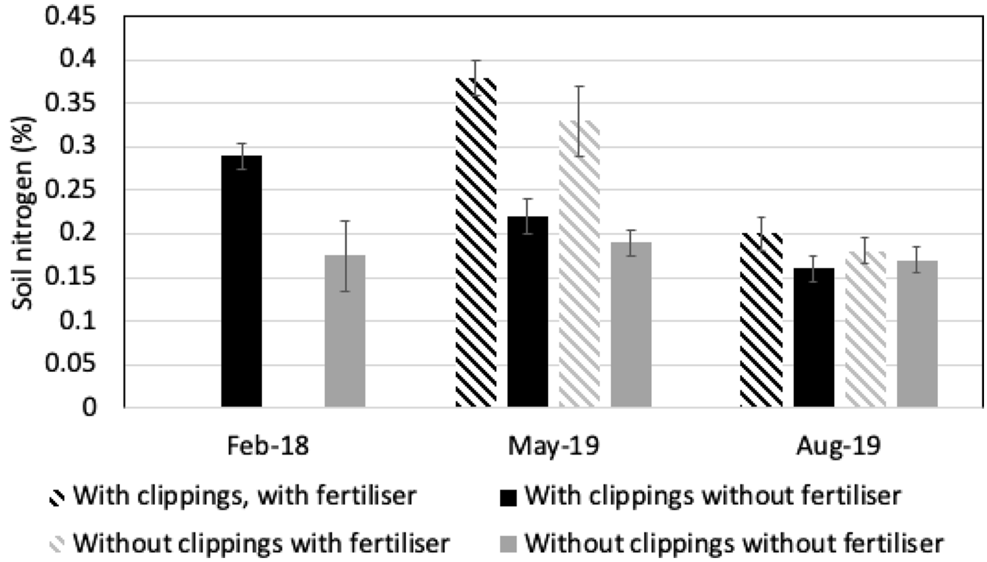


Fig. 5 Kjedahl soil N of the surface layer, 0–10 cm on three occasions as indicated. Nitrogen as a treatment was only applied in the middle of April 2019, hence sampling in Feb 2019 did not include the fertiliser as a treatment. The length of the error bars is based on the magnitude of the standard deviation of the observations

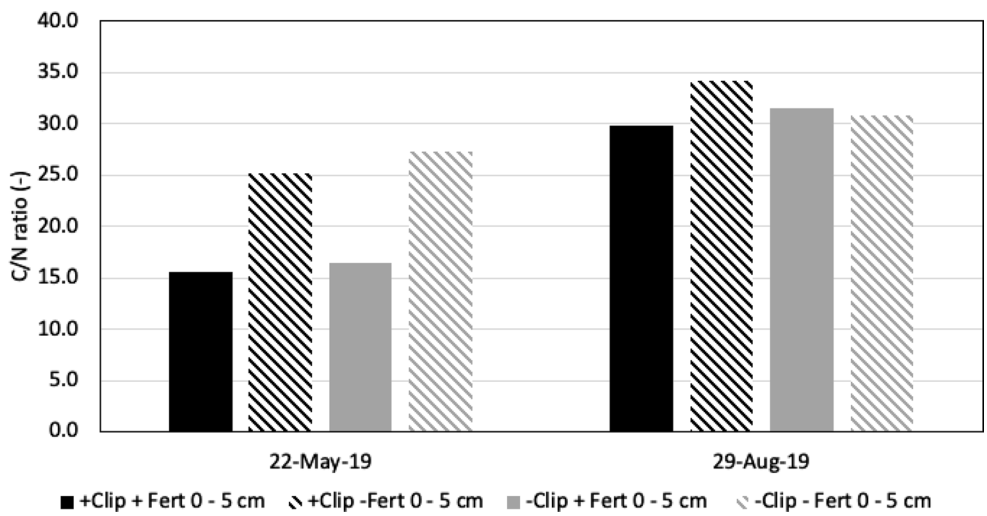


Fig. 6 C/N ratio on two different occasions for the four treatments as indicated in the legend

in Fig. 7. In this figure only the results from the 2018–2019 season are presented because of the more pronounced treatment responses and the availability of more frequent grass height measurements from which the cumulative grass growth curve was constructed.

There was reasonable agreement between the modelled above-ground biomass and the amount actually produced for the various scenarios, particularly the scenario of removing clippings (NCL) with F and the NF treatments. The CL_F treatment yielded close to 8500 kg ha^{-1} while the model did not predict more than 6000 kg ha^{-1}. The model in general predicted similar trends as were found in the field but under-predicted the final amounts of biomass produced.

The simulation and measurements of the entire period of grass growth over the three years are presented in Fig. 8. Monitoring started in the middle of 2017 and finished in September 2019. In 2017–2018 grass growth was measured but not to the same level of detail as was done in 2019, hence the cumulative growth curves were more difficult to construct compared to those for 2019.

In the middle of the 2017, summer grass productivity reached about 6000 kg ha^{-1} but then rapidly slowed down. Towards the summer 2018, there was rapid growth resulting in a grass productivity of 8000 kg ha^{-1}. For the period towards the winter (Nov–Feb) in 2018 monitoring only started in early October, then during the winter very little growth was detected. With the onset of the warmer weather in April 2019 rapid growth was observed again. In that period substantial differences were found between the treatments, ranging between 4000 and 8500 kg ha^{-1}.

Another outcome of the model is total amount of SOC. This was converted to a percentage SOC in the top 10 cm of the soil, based on a soil density of 1.1 kg dm^{-3} and it is assumed that most of the SOM would appear in the surface

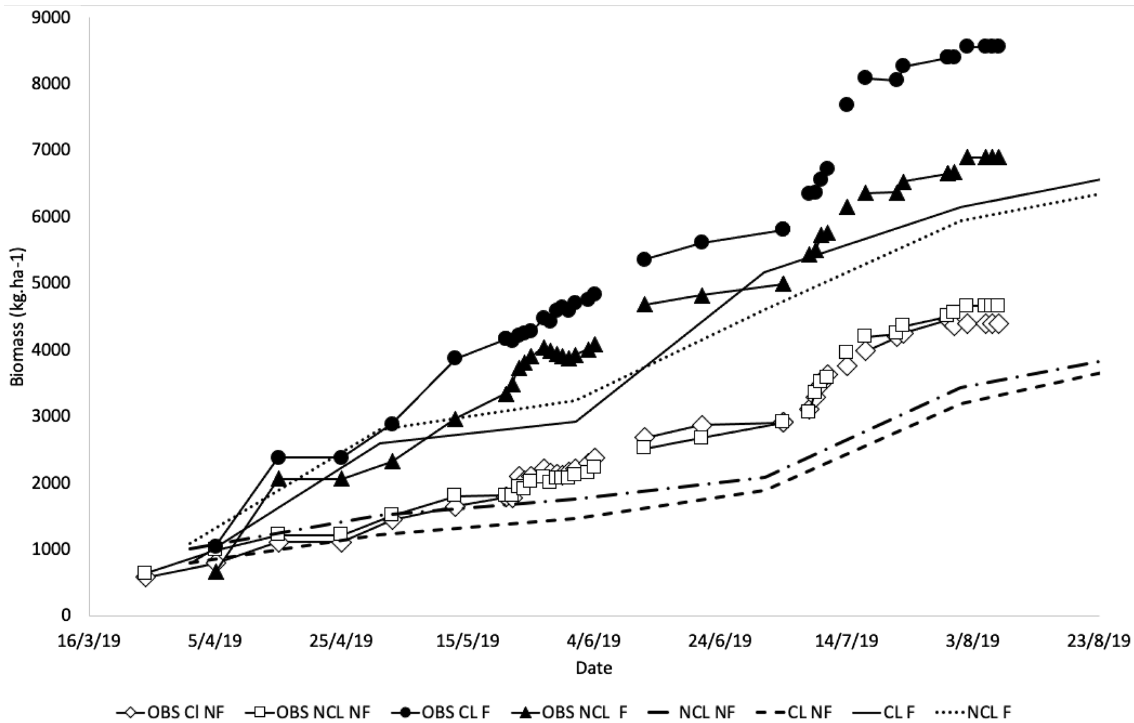


Fig. 7 Observed (OBS) and modelled cumulative above-ground dry biomass of the grass for different scenarios of turf grass management as indicated in the legend. *CL* clipping retained, *NCL* clippings removed, *F* fertiliser added in April and June and *NF* no fertiliser added

Fig. 8 Observed (OBS) and modelled cumulative above-ground dry biomass over a three year period for different scenarios of turf grass management as indicated in the legend. *CL* clipping retained, *NCL* clippings removed, *F* fertiliser added in April and June and *NF* no fertiliser added

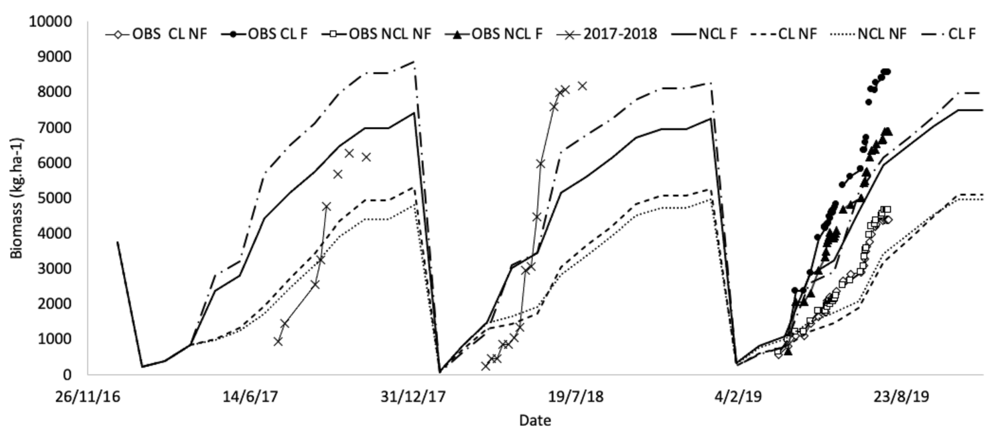
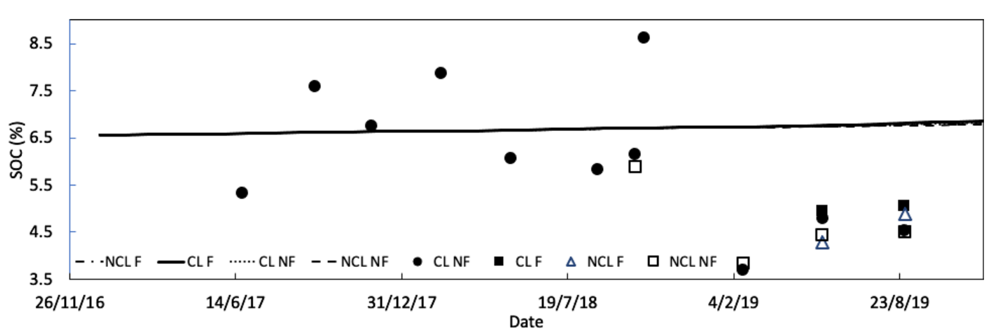


Fig. 9 Observed and modelled (M) SOC in the top layer: 0–10 cm of the soil profile under various scenarios of turf grass management as indicated by the legend in the figure. *CL* clipping retained, *NCL* clippings removed, *F* fertiliser added in April and June and *NF* no fertiliser added



layer. Changes measured in the soil and calculated by the model for the duration of the study are presented in Fig. 9.

There was a reasonable agreement between the observed and modelled SOC levels at an average of 6.5%, however the variations obtained in the SOC observations were not obtained with the model. In 2019 small but consistent increases of about 0.2% were found in the CL F treatment compared to the NCL NF treatment. Minor changes in the modelled SOC can be seen once the treatments were introduced in April 2019.

Using the CENTURY model, simulations were carried out for a 50 year period to see how much SOC could be sequestered over such a time frame. The SOC in the topsoil after 50 years, using four scenarios as indicated, are presented in Fig. 10.

At the end of that period, the SOC increased to 18% when both grass clipping are retained and fertiliser is applied, compared to only a small improvement (to 8%) in the SOC when management is not changed. Altering only one input would result in an improvement somewhere in-between.

Discussion

The climate of Lahore is typical for a semi-arid steppe climate with a monsoonal influence. Winter rainfall can be substantial but tends to be more erratic, and less certain. The temperature regime is rather extreme, ranging from extreme hot conditions in May and June to sub-zero condition in the winter months. This temperature regime drives much of the vegetative growth (Hatfield, 2017). With the onset of lower minimum temperatures vegetative growth of the grass stops and typical winter weeds are starting to dominate the swarth. These remain in place until the temperatures rise again and turf grass growth starts again. A distinction in swarth composition was only made visually and was not incorporated in dry matter production, nor in the modelling outputs.

Retention of the grass clipping started to pay dividends in the second year. This was reflected both in terms of increase in grass height, SOC and available N, compared to clippings removed without the addition of fertiliser. This confirms what others have found, most notably Heckman et al. (2000), Kopp and Guillard (2002), Qian et al. (2010). With the removal of grass clippings many nutrients are lost to the system. These were not assessed in this study, but Kopp and Guillard (2002) estimated that up to 98 kg N ha^{-1} $year^{-1}$ would be received by the swarth when clippings were retained out of a total requirement of 390 kg N ha^{-1} $year^{-1}$. By retaining the clippings synthetic fertiliser could be saved which is beneficial, even though from our observations, adding the fertiliser is more beneficial than retaining clippings by itself. Braun and Bremer (2019) found little benefit from higher fertiliser inputs compared to low management inputs in terms of carbon sequestration but their work did not include grass clipping management options.

The addition of urea at the beginning of the growing season in mid-April and again in mid -June, clearly had an impact on the grass growth resulting in a 112% increase in grass productivity. This was reflected in the SOC, N in the soil and the C/N ratio. The addition of the fertiliser reduced the C/N ratio which enhances microbial activity, the decomposition of the grass clippings, the freeing up of nutrients in the process and stimulates grass growth (Truong and Marschner 2018).

Grass clipping retention and the addition of fertiliser to turfgrass systems needs to be considered in the light of overall turf grass management costs and benefits. When no money is being spent on fertilisers then cost savings by

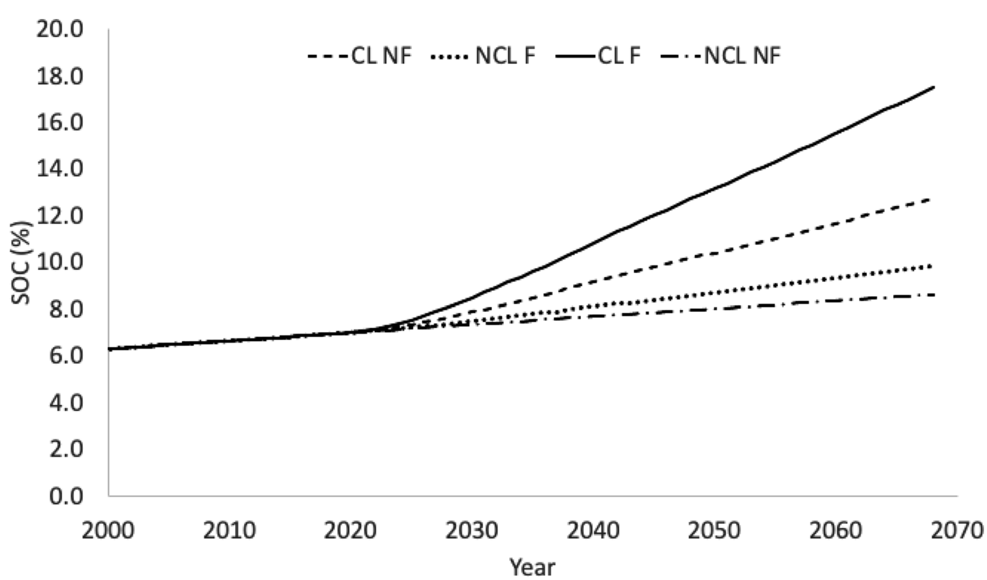


Fig. 10 Simulation results of the SOC in the top layer of the soil profile over a period of 50 years of applying the various scenarios of turf grass management as indicated in the legend. *CL* clipping retained, *NCL* clippings removed, *F* fertiliser added in April and June and *NF* no fertiliser added

retaining grass clippings are irrelevant. The requirement of 390 kg N ha^{-1} $year^{-1}$ as mentioned by Kopp and Guillard (2002) is based on commercial quantities in a system where high productivity is desired. Current turf grass management at a location such as the campus where little costs are incurred means cost savings are not very relevant. Currently carbon sequestration is not financially rewarded, therefore, any options perceived to increase the workload by retaining the grass clippings will be avoided.

Modelling the changes in productivity and SOC using CENTURY provided the basis to assess the potential of long-term carbon sequestration using turfgrass since reasonable agreement between measured and simulated productivity was achieved. Getting to that point, however, required a change of several of the model parameters because using the common input parameters, particularly available N, it was found that the model greatly underpredicted biomass accumulation particularly for NCL and NF, which produced more than 4000 kg ha^{-1} dry biomass in the garden. It appeared that the grass was getting nutrients from sources for which the model was not allowing. Altering the non-symbiotic soil N fixation, allowing for more N fixation in the warm and humid soil during the summer months, resulted in an addition of 42 kg ha^{-1} $year^{-1}$ nitrogen. This is very high but possible as noted by Roper and Gupta (2016). Another source of external N was considered and applied in the form of atmospheric N fixation through wet and dry deposition. Wu et al. (2018) measured N deposition in a polluted monsoon-affected embayment and found 132 mmol m^{-2} $year^{-1}$ of total dissolved N, which equated to 18.5 kg ha^{-1} $year^{-1}$ in the form of nitrate, ammonium, nitrite and dissolved organic N. Lahore is not an embayment but it is monsoon-affected and very polluted. Even in summer, ground level atmospheric concentrations of NO_2 easily exceed 75–100 μg.m^{-3} (Windy, 2021), which add to the precipitated N once the monsoon rains arrive. Uchiyama et al. (2017) also found a strong correlation between atmospheric NO_2, and the precipitation of NO_3^- with heavy rainfall.

A major consideration for doing this work has been to investigate the C sequestration potential as part of the mitigation efforts addressing climate change. Qian et al. (2010) estimated an additional 35 Mg ha^{-1} could be sequestered after 50 years using additional fertiliser and clippings retained scenario. Hamido et al. (2016) also indicated that with growing warm season turf grasses, significant amounts of C can be sequestered. Braun and Bremer (2019) concluded that the release of NO_2 as a greenhouse gas could be reduced through better N management but also that C sequestration could be increased through altering turf grass management. In our estimation, using the CENTURY model simulation results, after 50 years the SOC could be increased to 18% which equates to 44 Mg ha^{-1}. Clearly there is a lot of potential to sequester C in these turf systems but only when appropriate management of retaining clippings and some form of fertiliser management is adopted.

Many areas in Lahore are lacking meaningful public open spaces but there are still significant areas where gardens and parks are present and where turfgrass is being managed. Applying the simple practices such as retaining grass clippings and adding some fertiliser would improve C sequestration, hence contributing to the local efforts to mitigate climate change. Same model can also be applied in other parts of the world to sequester C in gardens and lawns.

Conclusion

This study investigated over a period of two years, the sequestration of SOC under turfgrass for different turf grass management options such as removing or retaining grass clippings, after mowing and or the addition of nitrogenous fertiliser. Results were then used to facilitate the simulation of SOC sequestration over a longer term. After two years, particularly following the addition of urea and with a retention of grass clippings, increases in biomass of 112% were obtained while the SOC increased by 0.2%. Following the calibration of the soil organic matter model, CENTURY, reasonable agreement with the observed data was obtained but only after allowing for the addition of extra N through an increase in non-symbiotic soil N fixation as well as the precipitation of atmospheric N. Using the model, it was concluded that after 50 years of retaining grass clippings after mowing with the addition of some fertiliser, 44 Mg ha^{-1} of SOC could be sequestered over that period. Using this simple but effective way of carbon sequestration, good opportunities exist at a local level to contribute to the efforts to mitigate global warming leading to environmental sustainability.

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Declarations

Conflict of interest No conflict of interest was identified in this work. Supporting data of this work will be made available upon request.

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