

**Research Report:**

**Technical Assessment of the  
Carbon Sequestration Potential of  
Managed Turfgrass in the United States**

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## **Executive Summary**

Managed turfgrass (i.e., residential lawns, golf courses, parks, commercial landscapes, greenbelts, and the like that are subject to regular maintenance) are ubiquitous in the United States. Citizens clearly value such areas for their aesthetic, recreational and utility benefits. This independent study, which relied on peer-reviewed research and studies conducted by others, demonstrates that, within bounds of scientific certainty, managed turfgrass is a viable foot soldier in combating the environmental challenges of global climate change.

The study's goal was to assess the carbon intake and net carbon benefit of taking responsible care of managed U.S. turfgrasses. While the overall response to increasing carbon in the atmosphere will no doubt require many different prevention, stabilizing, and mitigation approaches, this study shows that even the household lawn, and other managed turfgrass areas, if properly cared for and maintained, provide significant carbon sequestration benefits.

After reviewing the direct carbon sequestration of grasses and their root systems, we found that managed lawns sequester, or store, significant amounts of carbon, capturing **four times** more carbon from the air than is produced by the engine of today's typical lawnmower. The study also finds that well-managed turfgrasses that are cut regularly and at the appropriate height, fed with nutrients left by grass clippings, watered in a responsible way, and not disturbed at the root zone actively pull pollutants from the air, creating a greater carbon benefit.

### **KEY REPORT STATISTICS**

- Perennial managed grassland systems, such as turfgrass with minimal disturbance (i.e. residential lawns, golf courses, parks, commercial landscapes, greenbelts, and the like), sequester the greatest amounts of carbon; meaning, roots can grow deeper and soak up even more carbon.
- For an average, managed lawn, turfgrass captures **four times the carbon** from the air than the carbon output of a typical mower.
- If one compares a well managed lawn to a poorly managed lawn or unmanaged grasslands, the net carbon intake of a well managed lawn is **five to seven times higher** than the carbon output of mowing.

- The largest amount of carbon intake occurs with the recycling of nitrogen contained in grass clippings; meaning, leave clippings on the ground to break down and recycle.
- To maximize carbon intake benefits, lawns and other turfgrass areas must be managed by cutting grass, leaving grass clippings, and responsible watering.

*Note: The study does not delve into the strategies that could be developed and implemented in order to maximize carbon sequestration benefits; such strategies are best developed in more local or regional contexts.*

## **A. Goals and Focus of Study**

This technical paper describes the methodology and conclusions of a literature survey and study focused on the net carbon sequestration<sup>1</sup> benefit in managed US turfgrasses such as in residential lawns, golf courses, parks, commercial landscaping, greenbelts, and the like. The focus is managed turfgrass as opposed to unmanaged grasslands and similar regularly unattended vegetation.

In particular, it highlights the significant additional sequestration benefits from managed turfgrass as opposed to unmanaged ones. The methodology considers only the direct carbon sequestration potential of the grasses, their root systems, and the soil organic carbon within the first several inches of the ground surface as well as the expected carbon emissions from fuel consumption due to managing such turf using either gasoline-powered mowers or larger rider mowers. I did not evaluate indirect carbon impacts such as due to creation and transportation of the fertilizer necessary for management of the turf.<sup>2</sup> Conversely, the numerous benefits of turfgrass are also not considered. As such, this study focuses on the carbon sequestration potential of managed turfgrass, without consideration of the other likely benefits or drawbacks of turfgrass.

The methodology is straightforward. Net carbon sequestration potential is estimated from the difference of carbon sequestration potential and carbon emissions associated with managing the grass by mowing. This analysis is first conducted on a per unit area (acre or hectare) basis. The analysis relies on previously published studies in the literature for sequestration as well as estimated values for carbon emissions. Once the per unit area net sequestration value is calculated, it is applied across estimates of total turfgrass under management in the US, as estimated by other studies. The overall US turfgrass is assumed to be managed by either walk-behind or rider mowers. Results show that there is significant carbon sequestration benefit to managed turfgrasses and that these benefits are significantly greater than those associated with unmanaged vegetated areas.

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<sup>1</sup> In this context, the term "sequestration" means the storage of carbon so it will not be released to the atmosphere.

<sup>2</sup> It should be noted however, that other studies have found that the carbon emissions from fertilizer production and transportation are much less than the carbon sequestration potential in turfgrass. Milesi, et. al report that carbon emissions due to these fertilizer inputs range, under well managed turfgrass scenarios, from 11%-28% of the sequestration potential.

In order to standardize the analysis, all values are discussed in units of carbon (not carbon dioxide, CO<sub>2</sub>) per unit area (hectare<sup>3</sup>) per year. Values reported in other units (such as CO<sub>2</sub> or different area bases) are converted to carbon per hectare per year. Since emissions from gasoline powered internal combustion engines contain very small quantities of methane, nitrous oxide and other greenhouse gases, only carbon dioxide emissions are accounted for in this analysis, with likely minor error in the CO<sub>2</sub>-equivalent emissions.

## **B. Background**<sup>4</sup>

Neglecting reservoirs such as ocean sediment, marine biota, etc., carbon moves primarily among four major reservoirs: the oceans, the atmosphere, the geosphere, and the terrestrial biosphere (soils plus vegetation). Oceans (deep and shallow) are the largest global carbon pool, storing approximately 38,000 giga tons (Gt) of carbon, followed by the geologic pool of a little under 3,700 GtC, the soil organic pool (vegetation soil and detritus) of approximately 2,300 GtC, and the atmospheric pool of approximately 760 GtC.<sup>5</sup> The geologic pool interacts with the atmosphere through volcanism and fossil fuel burning. Much of the oceanic carbon pool is thought to be “inert” on timescales shorter than millennia. Much less is known about carbon cycling in soil than in any of the other main carbon reservoirs.<sup>6</sup>

In simple terms, carbon flows between soil and the atmosphere occur via the processes of photosynthesis and respiration. Photosynthesis is the process by which plants convert carbon dioxide from the atmosphere into carbohydrates, which can then be further converted to plant structural components or other necessary compounds. These carbon compounds enter the soil when plants die or shed leaves and litter, or through the process of root growth. Upon entering the soil the carbon is primarily stored as soil organic matter (SOM).<sup>7</sup> Leaves and residues deposited on the soil can break down rapidly via microbial respiration, thereby releasing carbon dioxide into the atmosphere. Some carbon, however, is not broken down, or is only partially degraded, and then converted to new carbon compounds by soil microorganisms. This carbon can become either physically or chemically stabilized or made resistant to further decay, thereby

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<sup>3</sup> 1.0 hectare is 10,000 square meters. It is approximately 2.471 US survey acres.

<sup>4</sup> Excerpted from “The potential for carbon sequestration in grass seed cropping systems in western Oregon: the state of the science as reported in the literature as of December, 2006,” by Danya Rumore, et. al. March 1, 2007

<sup>5</sup> Figure 7.3 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 2007.

<sup>6</sup> Schlesinger, W.H., (1999), Carbon Sequestration in Soils, Science, Vol. 284, 2095.

<sup>7</sup> Soil Organic Carbon (SOC) is approximately 58% of SOM. See “Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data,” Yaling Qian et. al., Agron. J. 94:930–935 (2002).

sequestering carbon from the atmosphere in the form of soil organic carbon.<sup>8</sup> Grassland soils can store relatively large amounts of soil organic carbon (SOC) due to their fertility and lack of disturbance.

### **C. Estimates of Carbon Sequestration In Unmanaged Grasses**

The fact that adoption of proper land management practices can result in substantial carbon sequestration in the soil has been widely recognized in the agricultural literature for the last several decades.<sup>9</sup> Numerous researchers have suggested optimizing agricultural management practices as well as grassland management practices in order to enhance such sequestration over the years. As a point of comparison with later discussion on managed turfgrass sequestration (and to show the benefits of such management of turfgrass), this section will summarize some of the literature and estimates of carbon sequestration in unmanaged lands. Much of this discussion is taken from the available open literature.

First, the literature contains many studies and estimates of carbon sequestration in unmanaged wildlands, including the US Conservation Reserve Program (CRP)<sup>10</sup> land. Unmanaged, in this context, refers to letting grasslands grow without conversion to and from cropland or agricultural usage. It is well recognized that the sequestration potential for such land is generally low given low to intermediate rainfall, prior history of erosion in many cases, frequent disturbances of the soil, poor nitrogen input, etc. The Intergovernmental Panel on Climate Change (IPCC) has previously recognized that conversion of marginal agricultural land, for example, to grassland as having medium potential for carbon dioxide mitigation.<sup>11</sup> Conversion of cropped land to perennial grassland tends to increase SOC storage due to increased SOM formation (a result of high root carbon production), improved aggregation, and better soil structure due to lack of soil disturbance.

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<sup>8</sup> A key point to note is that the amount of carbon sequestered in soils is linked to the amount of nitrogen available in the system (either naturally, or through fertilizer application). This is because SOM has a fairly constant C:N ratio of 10-20 (Brady and Weil 2002).

<sup>9</sup> See Cole, V, et. al., 1996. Agricultural Options for Mitigation of Greenhouse Gas Emissions. In Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the IPCC, R.T. Watson, et. al., eds. Cambridge Univ. Press.

<sup>10</sup> This is a program by the US Dept. of Agriculture. "It encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife plantings, trees, filterstrips, or riparian buffers." See <http://www.nrcs.usda.gov/programs/crp/>.

<sup>11</sup> IPCC (1996). Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the IPCC. Cambridge Univ. Press.

Although research consistently shows increases in SOC sequestration due to conversion of cropland to grassland, estimated sequestration rates and total SOC values range widely, perhaps in part because of the availability of nitrogen. As mentioned earlier, for any carbon sequestration, there must be a readily available source of nitrogen. Gebhart et al. (1995) documented mean soil accumulation rates of 0.07-0.54 tons C/acre/yr due to conversion of USA cropland to grassland seeded for set-aside programs. For the UK, Tyson et al. (1990) reported a mean soil carbon accumulation rate of 0.33 tons C/acre/yr as a result of conversion of agricultural land to planted grassland. In New Zealand, Haynes et al. (1991) recorded a mean soil carbon accumulation rate of 0.45 tons C/acre/yr. In a study of soil carbon changes in cultivated land converted to grasses in east-central Saskatchewan, Mensah et al. (2003) estimated a net carbon gain of 0.3-0.4 tons C/acre/yr in the surface six inches of soil. Their study reported concentrations of  $26.5 \pm 1.8$  tons C/acre for the restoration treatments compared to  $23.5 \pm 1.2$  tons C/acre for the cultivated treatment. In eastern Oregon, Machado et al. (2006) found that after 73 years, grassland pasture with no tillage and large amounts of grass residue had higher SOC content than conventionally-tilled winter wheat systems, with 36.4 tons C/acre in grass pasture versus 22.5 tons C/acre for conventional tillage winter wheat fallow systems and 33.4 tons C/acre for fertilized conventional tillage continuous crop winter wheat systems. Variable amounts are in part due to variations in sampled depth of soil and variable time periods over which measurements were taken. In general, perennial grassland systems with minimal disturbance (i.e. no frequent tilling) and high vegetative root mass sequester greater amounts of carbon, relative to croplands. This demonstrates the benefits of less frequent tilling in accumulating soil organic carbon

Reduced tillage slows decomposition of SOM and can stabilize carbon in soils, leading to increased soil carbon. Sperow et al. (2003) found the soil carbon gain from use of no-till in the eastern corn belt to be 0.09-0.27 tons C/acre/yr.

A synthesis compiled by Conant et al. (2001) suggests that between 0.05 to 1.36 tons C/acre/yr can be sequestered in surface soils during the first 40 years following improved management practices. Lal's compilation indicates that manuring or fertilization can lead to sequestration of 0.03 to 2.01 tons C/acre/yr.



## **D. Estimates of Carbon Sequestration Potential In Managed Turfgrass**

There are several studies where carbon sequestration has been measured in managed turfgrass. In this context, managed refers to turfgrass that is cared for with proper water, fertilizer, and mowing inputs so as to ensure healthy turfgrass. This summary will rely on the studies that were found on the subject which include field measurement studies as well as biogeochemical modeling studies conducted by other researchers.

Focusing first on the results of measurements and associated modeling, researchers<sup>12,13</sup> have concluded that turfgrass may be making substantial contributions to sequester atmospheric carbon due to high plant productivity and lack of soil disturbance. In one study, the rate and capacity of soil carbon sequestration was determined from 15 golf courses that were near metropolitan Denver and Fort Collins, CO, and one golf course near Saratoga, WY, as a surrogate of urban turfgrass systems. The oldest golf course was 45 years old and the newest was 1.5 years old. Findings of relevance from this study include:

- Total carbon sequestration continued for up to 45 years in putting greens at an annual average rate of 804 pounds per acre ( $0.9 \text{ Mg C ha}^{-1} \text{ year}^{-1}$ ), and for about 31 years in fairways at an annual average rate of 1,072 pounds per acre ( $1.1 \text{ Mg C ha}^{-1} \text{ year}^{-1}$ ).
- The most rapid increase of carbon sequestration occurred during the first 25 to 30 years after turfgrass establishment.
- Carbon sequestration in turf soils occurs at a significant rate that is comparable or exceeds those reported for US land that has been placed in the CRP (e.g., native grasses).

These field data-based conclusions were validated by using a computer model designated as the CENTURY model. Model analysis, along with historic weather and soil-testing data from the golf courses near Denver and Fort Collins, CO, further indicate that turfgrass systems can serve as a carbon sink following establishment. Model predictions of soil organic carbon accumulation for fairways and for putting greens compared well with observed soil organic carbon values.

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<sup>12</sup> Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data, Yaling Qian et. al., *Agron. J.* 94:930–935 (2002).

<sup>13</sup> Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model, W. Bandaranayake, et. al., *Agron. J.* 95:558–563 (2003).

- The CENTURY model estimated that 10 to 14 tons per acre (23 to 32 Mg ha<sup>-1</sup>) of soil organic carbon were sequestered in the top eight inches (0 to 20 cm) of soil over a period of 30 years.

Other researchers have modeled the carbon sequestration potential using the BIOME-BGC model.<sup>14</sup> Using this ecosystem process model the growth of turfgrasses was modeled for 865 sites across the 48 conterminous states under different management scenarios, including either removal or recycling of the grass clippings, different nitrogen fertilization rates and two alternative water irrigation practices. The results indicate that well watered and fertilized turfgrasses act as a carbon sink, even assuming removal and bagging of the grass clippings after mowing.

The model simulation results from this study referring to the carbon accumulating in soils in the four different management scenarios (as well as a control scenario) are reported in Table 1. The values represent the range in simulated soil C accumulation over the 18-year period of climate data for the 865 locations used in the study. A comparison of the results under the four management shows that nitrogen fertilization increases the accumulation of carbon in the soil. For a certain amount of nitrogen input through fertilization, the carbon accumulations were larger when cycling of the grass clippings was simulated, since the onsite decomposition of the mowed grass clippings returned nitrogen back to the soil. For each scenario, differences in the maximum–minimum range were related to other factors such as growing season length. The control scenario in the study produced the lowest carbon accumulation (an average of 88 g C/m<sup>2</sup> over 18 years). The low number of mowing counts produced by the model in this scenario suggests that in most locations (most of the simulation sites except a few in the northeastern US) it would be impossible to grow a lawn as a monoculture of turfgrasses with no irrigation and fertilization. If turfgrasses reach a Leaf Area Index<sup>15</sup> (LAI) of 1.5 only 6-7 times in areas where the growing season is as long as 300-360 days, then it is probable that between subsequent cuts there would be several opportunities for non-turf species to invade the surface and prosper over time.

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<sup>14</sup> A Strategy for Mapping and Modeling the Ecological Effects of US Lawns, C. Milesi, et al.,

<sup>15</sup> In simple terms, the Leaf Area Index is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. The LAI ranges from 0 for bare ground to 6 for a dense forest. [www.wikipedia.org](http://www.wikipedia.org).

The largest carbon accumulation was simulated for modeled scenario referred to as Cycled-146N in the study. Abundant fertilization (146 kg N/ha/yr) and the recycling of the nitrogen contained in the clippings left to decompose on the site produced an average carbon accumulation potential of 1978 g C/m<sup>2</sup> over 18 years. The second largest soil carbon accumulations were simulated for scenarios Cycled-73N and Cycled-73N-PET, with an average reduction of 43% in carbon accumulation when compared with that simulated for Cycled-146N but with 50% less fertilizer. For Cycled-73N and Cycled-73N-PET the different water management strategies had no significant effect on the carbon cycle. In scenario Removed-146N, where the clippings are not left on the lawn but rather removed, the soil carbon accumulation was 60% less than in scenario Cycled-146N, although the same amount of external nitrogen was applied. Obviously no internal nitrogen recycling was allowed to take place because of the removal of the clippings. The modeled unmanaged or control scenario predicted sequestration in the range of -0.08 to +0.07 Mg C/ha/yr.

Based on the studies above, Table 1 tabulates the various estimates for carbon sequestration in managed turfgrass as well as unmanaged grasslands. For this study, an average value of 1.03 Mg C/ha/yr was chosen for managed turfgrass, based on field measurements. This is comparable to the Cycled-146N case modeled using the BIOME-BGC model (average of 1.065 Mg C/ha/yr).

### **E. Estimate of Carbon Emissions from Mowers**

Table 2 shows the calculations of carbon dioxide emissions (later reported as carbon basis) from walk behind as well as rider mowers. Gasoline was assumed to be the fuel. Typical values of fuel use for walk behind mowers (1.0 gallon per acre) and rider mowers (0.75 gallon per acre) were obtained from a major equipment manufacturer. It was assumed that the turf area would require weekly mowing, for a period of 9 months out of the year. Based on this, as shown in the table, the carbon emissions due to mowing range from 0.18 Mg C/ha/yr (for rider mowers) to 0.23 Mg C/ha/yr (for walk behind mowers).

### **F. Net Sequestration Benefit Estimate**

Based on the data discussed above and presented in Table 1 and 2, the net, per area, carbon sequestration benefit is estimated to be approximately 0.86 Mg C/ha/yr (for areas managed with rider mowers) to 0.80 Mg C/ha/yr (for areas managed by walk-behind mowers). Comparing

these with the values for the emissions due to the mowers, it should be noted that the net benefit is approximately four times greater than the carbon emissions due to mowing.

### **G. Comparison of Sequestration Benefits of Managed Versus Unmanaged Grasses**

Comparing the various estimates of carbon sequestration discussed in the previous sections, the mean value of sequestration in managed turfgrass is 1.03 Mg C/ha/yr (with a range, from modeling studies of 0.64 to 1.49 Mg C/ha/yr). As noted above, even the high range of modeled unmanaged sequestration in turfgrass was only 0.07 Mg C/ha/yr (with a low of -0.08 Mg C/ha/yr – indicating a negative benefit). Thus, the difference in sequestration benefit or incremental benefit due to management ranges from 0.96 Mg C/ha/yr (comparing, conservatively, the mean managed sequestration of 1.03 Mg C/ha/yr to the maximum unmanaged sequestration of 0.07 Mg C/ha/yr) to 1.42 Mg C/ha/yr (comparing the maximum values of sequestration from managed (1.49) and unmanaged (0.07) scenarios). Comparing these increased sequestration benefits (0.96-1.42 Mg C/ha/yr) against the emissions associated with such management due to mowing (0.18-0.23 Mg C/ha/yr), it is clear that the “cost” of such management is more than compensated

for by the benefits. In fact, the incremental sequestration benefits of turfgrass management via mowing are anywhere from 5 to 7 times the emissions due to mowing.

### **H. Estimate of Total Turfgrass Area in the United States**

Although there have been anecdotal estimates of the area occupied by lawns in the US over the years, a recent study, using satellite data and GIS mapping techniques provides a detailed estimate of this value.<sup>16</sup> In this study, relating turfgrass area to fractional impervious surface area, it was estimated that potentially  $163,812 \pm 35,850$  km<sup>2</sup> or  $63,280 \pm 13,842$  square miles of land are cultivated with some form of lawn in the continental United States. The study notes that this is area three times larger than that of any irrigated crop.

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<sup>16</sup> A Strategy for Mapping and Modeling the Ecological Effects of US Lawns, C. Milesi, et al.,

## **I. Estimate of Annual US Net Sequestration Benefit Due to Managed Turfgrass**

The total US lawn area was assumed to be maintained by either walk-behind or rider mowers. For simplicity, the area maintained by other means such as electric lawn mowers or manual reel-type mowers was neglected, as this is likely to be small.

First, the total lawn area associated with single family residential houses was estimated using most recent US Census data (2005). Using the reported number of detached and attached single family houses, as well as average lot sizes and house sizes, it was estimated that the average lawn size was 0.25 acre/home. This estimate is consistent with that reported by others. Using this value, the total area associated with residential houses is calculated, as shown in Table 3A. It was assumed that 80% of this area is maintained by walk-behind mowers and the balance 20% is maintained by rider mowers. Further, it was assumed that all of the area not associated with residential lawns (i.e., total lawn area minus residential lawn area) is entirely maintained by rider mowers. Using this data and the net sequestration values discussed in Section E above, the total net sequestration in managed turfgrass for the US was estimated to be approximately 13.6 Tg C/yr.

## **J. Summary**

In summary, the paper shows that there is potential for significant carbon sequestration in turfgrass such as lawns and golf courses provided that they are properly cared for: managed lawns sequester, or store, significant amounts of carbon, capturing **four times** more carbon from the air than is produced by the engine of today's typical lawnmower. This is an incremental benefit above and beyond the other numerous benefits of such turfgrass.

The study also finds that the carbon sequestration of turfgrasses can be maximized by measures such as cutting regularly and at the appropriate height, feeding with nutrients left by grass clippings, watering in a responsible way, and not disturbing grass at the root zone – all these measures help grass actively pull pollutants from the air, creating a greater carbon benefit.

**RANAJIT (RON) SAHU, Ph.D, QEP, CEM (Nevada)**

**CONSULTANT, ENVIRONMENTAL AND ENERGY ISSUES**

**EXPERIENCE SUMMARY**

Dr. Sahu has over seventeen years of experience in the fields of environmental, mechanical, and chemical engineering including: program and project management services; design and specification of pollution control equipment; soils and groundwater remediation; combustion engineering evaluations; energy studies; multimedia environmental regulatory compliance (involving statutes and regulations such as the Federal CAA and its Amendments, Clean Water Act, TSCA, RCRA, CERCLA, SARA, OSHA, NEPA as well as various related state statutes); transportation air quality impact analysis; multimedia compliance audits; multimedia permitting (including air quality NSR/PSD permitting, Title V permitting, NPDES permitting for industrial and stormwater discharges, RCRA permitting, etc.), multimedia/multipathway human health risk assessments for toxics; air dispersion modeling; and regulatory strategy development and support including negotiation of consent agreements and orders.

He has over sixteen years of project management experience and has successfully managed and executed numerous projects in this time period. This includes basic and applied research projects, design projects, regulatory compliance projects, permitting projects, energy studies, risk assessment projects, and projects involving the communication of environmental data and information to the public.

He has provided consulting services to numerous private sector, public sector and public interest group clients. His major clients over the past seventeen years include various steel mills, petroleum refineries, cement companies, aerospace companies, power generation facilities, lawn and garden equipment manufacturers, spa manufacturers, chemical distribution facilities, and various entities in the public sector including EPA, the US Dept. of Justice, California DTSC, various municipalities, etc.). Dr. Sahu has performed projects in over 44 states, numerous local jurisdictions and internationally.

In addition to consulting, Dr. Sahu has taught and continues to teach numerous courses in several Southern California universities including UCLA (air pollution), UC Riverside (air pollution, process hazard analysis), and Loyola Marymount University (air pollution, risk assessment, hazardous waste management) for the past fifteen years. In this time period he has also taught at Caltech, his alma mater and at USC (air pollution) and Cal State Fullerton (transportation and air quality).

Dr. Sahu has and continues to provide expert witness services in a number of environmental areas discussed above in both state and Federal courts as well as before administrative bodies.

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Table 1 - Estimates of Carbon Sequestration					
Value	Reported Units	Value	Converted Units	Refs.	Comments
0.9	Mg C/ha/yr	0.9	Mg C/ha/yr	[1]	Turf - Greens
1.1	Mg C/ha/yr	1.1	Mg C/ha/yr	[1]	Turf - Fairways
1.1	Mg C/ha/yr	1.1	Mg C/ha/yr	[2]	Perennial Grasslands
		<b>1.03</b>			Average of Above
27	g C/m <sup>2</sup> /yr	0.27	Mg C/ha/yr	[4]	Milesi - Removed 146N - Low
60	g C/m <sup>2</sup> /yr	0.6	Mg C/ha/yr	[4]	Milesi - Removed 146N - High
64	g C/m <sup>2</sup> /yr	0.64	Mg C/ha/yr	[4]	Milesi - Cycled 146N - Low
149	g C/m <sup>2</sup> /yr	1.49	Mg C/ha/yr	[4]	Milesi - Cycled 146N - High
37	g C/m <sup>2</sup> /yr	0.37	Mg C/ha/yr	[4]	Milesi - Cycled 73N - Low
67	g C/m <sup>2</sup> /yr	0.67	Mg C/ha/yr	[4]	Milesi - Cycled 73N - High
37	g C/m <sup>2</sup> /yr	0.37	Mg C/ha/yr	[4]	Milesi - Cycled 73N PET - Low
67	g C/m <sup>2</sup> /yr	0.67	Mg C/ha/yr	[4]	Milesi - Cycled 73N PET - High
-8	g C/m <sup>2</sup> /yr	-0.08	Mg C/ha/yr	[4]	Milesi - Control - Low
7	g C/m <sup>2</sup> /yr	0.07	Mg C/ha/yr	[4]	Milesi - Control - High
0.6	Mg C/ha/yr	0.6	Mg C/ha/yr	[3]	Cultivated Lands Reseeded to Grass - Increase Only
0.07	tons C/acre/yr	0.16	Mg C/ha/yr	[5]	Cropland to Grassland - Low
0.54	tons C/acre/yr	1.21	Mg C/ha/yr	[5]	Cropland to Grassland - High
0.33	tons C/acre/yr	0.74	Mg C/ha/yr	[6]	Cropland to Grassland - UK
0.45	tons C/acre/yr	1.01	Mg C/ha/yr	[7]	Cropland to Grassland
0.3	tons C/acre/yr	0.67	Mg C/ha/yr	[8]	Cultivated Land to Grasses - Canada - Low
0.4	tons C/acre/yr	0.90	Mg C/ha/yr	[8]	Cultivated Land to Grasses - Canada - High
0.05	tons C/acre/yr	0.11	Mg C/ha/yr	[9]	Low
1.36	tons C/acre/yr	3.05	Mg C/ha/yr	[9]	High
0.03	tons C/acre/yr	0.07	Mg C/ha/yr	[10]	Low
2.01	tons C/acre/yr	4.51	Mg C/ha/yr	[10]	High

References for Table 1

- [1] Bandarnayake, W., et. Al., (2003), Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model, Agron. J. 95:558-563.
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- [4] Milesi, C., et al (????), A Strategy for Mapping and Modeling the Ecological Effects of US Lawns
- [5] Gebhart (1995)
- [6] Tyson (1990)
- [7] Haynes et al (1991)
- [8] Mensah et al (2003)
- [9] Conant (2001)
- [10] Lal (2003)

<b>Unit Conversions</b>				
1	hectare	=	10000	m2
1	acre	=	4046.86	m2
1	acre	=	0.404686	hectares
1	km2	=	100	ha
1	Tg	=	1000000	Mg
1	Mg	=	1000000	g
1	acre	=	43560	sq. ft.



<b>Table 2 - Estimate of Carbon Emissions From Lawn Mowing</b>					
Equipment	Rider Mower	Walk-Behind Mower	Units	Refs.	Comments
Typ. Fuel Use	0.75	1	gal/acre	[11]	
CO <sub>2</sub> Emissions	19.564	19.564	lb CO <sub>2</sub> /gal	[12]	Assumed Gasoline as Fuel
Fuel Use	29.25	39.00	gal/ac/yr		Assumed Weekly Mowings for 9 Months/Year
CO <sub>2</sub> Emissions	572.25	763.00	lb CO <sub>2</sub> /ac/yr		
C Emissions	156.07	208.09	lb C/ac/yr		
C Emissions	385.65	514.20	lb C/ha/yr		
C Emissions	0.18	0.23	Mg C/ha/yr		

[11] Source: Major Equipment Manufacturer [12] World Resources Institute

<b>Unit Conversions</b>				
1	hectare	=	10000	m <sup>2</sup>
1	acre	=	4046.86	m <sup>2</sup>
1	acre	=	0.404686	hectares
1	km <sup>2</sup>	=	100	ha
1	Tg	=	1000000	Mg
1	Mg	=	1000000	g
1	acre	=	43560	sq. ft.

<b>Table 3 - Net Sequestration Benefits</b>					
	Rider Mower	Walk-Behind Mower	Units	Refs.	Comments
Net Sequestration Benefit From	0.858	0.800	Mg C/ha/yr		
Total US Lawn Area	163812		km <sup>2</sup>	[4]	
	16381200		ha		
Fraction of Lawns Mowed By	0.52	0.48	-		Cross-check
Area of US Total Lawns Mowed By	8521453	7859747	ha		See Calculations Below
Net Sequestration Benefit By	7313519	6286902	Mg C/yr		
Total Net Sequestration Benefit	13600420		Mg C/yr		
	13.6		<b>Tg C/yr</b>		

[4] Milesi, C., et al, A Strategy for Mapping and Modeling the Ecological Effects of US Lawns

<b>Unit Conversions</b>				
1	hectare	=	10000	m2
1	acre	=	4046.86	m2
1	acre	=	0.404686	hectares
1	km2	=	100	ha
1	Tg	=	1000000	Mg
1	Mg	=	1000000	g
1	acre	=	43560	sq. ft.

<b>Table 3A - Lawn Area Support Calculations</b>				
Single Houses - detached	69996000		units	[13]
Single Houses - attached	6158000		units	[13]
Total	76154000		units	Very similar to Owner Occupied Structures
Median Lot Size	0.36		ac	[13]
Median Square Footage	1795		sq. ft.	[13]
	0.04		ac	
Average Lot - Built Area	0.32		ac	
Acerage Lawn Size	0.25		ac	Assumed; considering other areas that are not lawn
Lawn Area in Single Houses	24277322		ac	
	9824684		ha	
Fraction of Lawns in Single Homes	0.60		frac	Using Milesi total estimate
Percent Single Family Lawns Mowed By Riders	0.2		frac	Assumed
Area Single Family Mowed By Riders	1964937		ha	
Area Single Family Mowed By WBM	7859747		ha	

[13] US Census Bureau, American Housing Survey.

<b>Unit Conversions</b>				
1	hectare	=	10000	m2
1	acre	=	4046.86	m2
1	acre	=	0.404686	hectares
1	km2	=	100	ha
1	Tg	=	1000000	Mg
1	Mg	=	1000000	g
1	acre	=	43560	sq. ft.