



Benefits of Landscapes Research 2022

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Environment

Air Purification

- Urban areas with complex vegetation structure (i.e. trees, shrubs, and turfgrass) provide the best air purification effects compared to just turf alone.¹
- Green roofs help with air purification and biodiversity.²
- Urban forests contribute “substantial” air purification services to cities, Baró et al. (2014) found them to have removed 305.6 metric tons of pollutants from the city of Barcelona in a single year.³
- Plush lawns trap smoke particles and more than 12 million tons of dust and dirt annually.⁴

¹ Viera, Joana et al. “Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks” *Environmental Research*, no. 160 (Jan. 2018), 306-313 <https://www.sciencedirect.com/science/article/pii/S0013935117316535>

² Tufvesson, Angela. “Green Roofs.” *Sanctuary: Modern Green Homes*, no. 21 (2012): 68-71. <https://www.jstor.org/stable/sanctuary.21.68>

³ Baró, Francesc, Lydia Chaparro, Erik Gómez-Baggethun, Johannes Langemeyer, David J. Nowak, and Jaume Terradas. “Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain.” *Ambio* 43, no. 4 (2014): 466-79. <https://www.jstor.org/stable/24709042>

⁴ 1996 Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

- It is estimated that the 30 million acres of lawns that exist in the U.S. remove 5% of carbon dioxide from the atmosphere. To determine the amount of carbon that one's lawn removes from the atmosphere multiply the square footage of one's lawn by the number designated to one's particular turf type:⁵

native grass:	.02418 lbs/ft squared *
non-irrigated fine fescue:	.01619 lbs/ft squared *
creeping bentgrass:	.01598 lbs/ft squared *
irrigated fine fescue:	.01496 lbs/ft squared *
Kentucky bluegrass:	.00922 lbs/ft squared *

**Calculation for native grass: (1.18 ton/10,000m²) X (m²/10.76ft²) X (2204.62 lbs/ton) =.02418 lbs/ft²*

- Grass is estimated to trap some 12 million tons of dust and dirt from the air annually. Just one acre of grass will absorb hundreds of pounds of fossil fuel created sulfur dioxide in a single year.⁶
- During the 1960s Chairman Mao of the People's Republic of China had a significant amount of turfgrass removed in order to "eliminate vestiges of Western civilization". Decades later China is still dealing with an escalated level of smog and dust, which has also increased the number of illnesses due to the disease, bacteria, and viruses which dust carries. Today China is making a tremendous effort to reestablish turf.⁷
- Smoggy days increase by 1% for every 1°C temperature increase. Because trees can lower temperatures in the summer, they can decrease smoggy days, thus aiding in air quality control. Each urban tree is estimated to catch up to 50 pounds of particulates annually. In a study of air purification, planting 500,000 trees in Tucson, Arizona was determined to take away 6,500 tons of particulates from the air. When compared to the average cost of particulate control methods, each tree's air purification was valued at an average of \$4.16, which equals \$1.5 million annually for the 500,000 trees.⁸
- Trees that give off shade can decrease road temperatures by up to 36°F and car gas tanks by up to 7°F. This decrease in fuel tank temperatures affects the 16% of car emissions that are classified as evaporative emissions, which create ground-level ozone. These evaporative emissions are temperature sensitive and have less of an effect when the temperature is cooler. A study in Sacramento, California suggested that shading 50% of paved areas would reduce 1% to 2% of hydrocarbon emissions from cars in the city.⁹
- "We find large potential for urban reforestation to increase PM10 and heat abatement." "Reforestation of each city's top 20% 'return on investment' sites could lower average annual PM10 concentrations by >2 µg/m³ for 3.4–11.4 million people and average maximum daily summer

⁵ Qian, Y.L., R Follett, and J Kimble. (2007) Estimating Soil Carbon Sequestration in Turfgrass Systems From Natural Carbon Isotopic Signatures. Department of Horticulture and Landscape Architecture, Colorado State University.

<https://a-c-s.confex.com/a-c-s/2007am/techprogram/P34802.HTM>

⁶ New England Turf, Inc. <http://www.newenglandturf.com/>

⁷ "Water Right: Conserving Our Water Preserving Our Environment". International Turf Producers Foundation.

http://www.realgreenlawns.com/austin_tx_texas/Austin_Lawn_Care_Guide/Water_Right_Book.pdf

⁸ F. Dwyer, John & McPherson, E & Schroeder, Herbert & A. Rowntree, Rowan. (1992). Assessing the benefits and costs of the urban forest. J. Arbor. https://www.fs.fed.us/psw/publications/mcpherson/psw_1992_mcpherson002.pdf

⁹ Dixon, K. K., and K. L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, WA). Washington D.C.: Transportation Research Board of the National Academies of Science. https://nacto.org/docs/usdg/benefits_and_risks_of_an_urban_roadside_landscape_dixon.pdf

temperatures by >2 °C for 1.7–12.7 million – effects large enough to provide meaningful health benefits – at a combined annual cost of \$102 million.”¹⁰

- Vegetation structure, composition, and management influence a green space’s ability to improve local climate and air quality. “We found that vegetation type characterized by a more complex structure (trees, shrubs and herbaceous layers) and by the absence of management (pruning, irrigation and fertilization) had a higher capacity to provide the ecosystems services of air purification and climate regulation. By contrast, lawns, which have a less complex structure and are highly managed, were associated to a lower capacity to provide these services.”¹¹
- For urban forest in Barcelona in 2008 (the peri-urban forest of Collserola): “Total air purification is estimated at 305.6 tons of removed pollutant per year with an economic value of 2.38 million USD per year. PM10 removal is the highest among the five air pollutants analyzed (i.e., CO, NO₂, PM10, O₃, and SO₂), accounting for 54% of the total biophysical value and 46% of the total economic value.”¹²
- Argument against oxygen generation but for air purification & carbon sequestration: “Is this oxygen production actually creating a significant environmental benefit in comparison with other environmental benefits of trees such as carbon sequestration and air pollution removal? In the coterminous United States, annual carbon sequestration by urban forests is estimated at 22.8 million metric tons (25.1 million tons) with a societal value of ≈\$460 million per year (Nowak and Crane 2002). Air pollution removal in the coterminous United States is estimated at 711,000 metric tons (784,000 tons) with a \$3.8 billion annual value (Nowak et al. 2006a). Oxygen production by U.S. urban forests is estimated at 61 million metric tons (67 million tons), but the value to society is negligible.” Also, oxygen generation VARIES: “This net oxygen production offsets oxygen consumption from between 2% of the human population in Jersey City, New Jersey, and New York, New York, to greater than 100% in Moorestown, New Jersey.”¹³

Carbon Sequestration

- Turfgrass can serve as a sink for CO₂. A rapid increase in carbon sequestration occurs in the first 25-30 years after turfgrass is established. Golf greens and fairways store nearly a ton of carbon per acre per year.¹⁴
- Turfgrasses are subjected to minimal soil disturbances after establishment which is a critical factor for carbon sequestration. Turfgrass can sequester atmospheric carbon at a high rate due to its high production and high root turnover. Carbon sequestration in turf soils is comparable to the rate of carbon sequestration for USA land that has been placed in the Conservation Reserve Program (CRP).¹⁵

¹⁰ Kroeger et al., Where the people are: Current trends and future potential targeted investments in urban trees for PM10 and temperature mitigation in 27 U.S. Cities (2018), Landscape and Urban Planning Volume 177

<https://www.sciencedirect.com/science/article/pii/S0169204618303542>

¹¹ Viera, Joana et al. “Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks” Environmental Research, no. 160 (Jan. 2018), 306-313) <https://www.sciencedirect.com/science/article/pii/S0013935117316535>

¹² Baró, Francesc, Lydia Chaparro, Erik Gómez-Baggethun, Johannes Langemeyer, David J. Nowak, and Jaume Terradas. "Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain." *Ambio* 43, no. 4 (2014): 466-79. <http://www.jstor.org/stable/24709042>.

¹³ “Oxygen Production by Urban Trees in the United States”, International Society of Arboriculture, *Arboriculture & Urban Forestry* 2007. 33(3):220-226, David J. Nowak, Robert Hoehn, and Daniel E. Crane https://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf

¹⁴ Follett, R.F. 2003. Are Golf Courses Holding the Carbon? Turfgrass as a “Sink” for CO₂. *Agricultural Research*. <https://agresearchmag.ars.usda.gov/ar/archive/2003/jun/golf0603.pdf>

¹⁵ Qjan, Y. and R.F. Follett. 2002. Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. *Agron. J.* 94:930-935. <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/agronj2002.9300>

- U.S. lawns remove 5% of carbon dioxide in the atmosphere.¹⁶
- A 16-inch tree sampled from an urban forest on average sequesters 34.6 pounds of carbon a year, the equivalent of 139 miles-worth of car emissions¹⁷
- Turfgrass is responsible for removing 20 million tons of carbon from the atmosphere. It is important to maintain turfgrass for it to sequester carbon at a normal rate, including irrigation and fertilization.¹⁸
- Turfgrass has more leaf surface area per square foot than most other foliage, making it one of the most productive plants at carbon sequestration. In fact, a turfgrass environment can sequester more carbon than a rainforest environment.¹⁹
- Protecting and tending to current carbon sinks is an important way to limit how much carbon is emitted into the atmosphere. For example, preserving current gardens, landscapes, and trees.²⁰
- Through their cooling effect, trees also reduce the amount of energy needed to run a household air conditioning system. In a tree-planting analysis in Tuscan, Arizona, it was determined that each tree planted would save 408 pounds of carbon each year. On a national level, three trees per every other single home family would save up to nine million tons of carbon a year.²¹
- In a study in Australia, it was found that mulched gardens had the highest potential for carbon sequestration when compared to other treatments.²²
- “An estimated 231 521 tons of carbon is stored within the above-ground vegetation of Leicester, equating to 3.16 kg C m⁻² of urban area, with 97.3% of this carbon pool being associated with trees rather than herbaceous and woody vegetation.” It is important to manage above-ground vegetation carbon stores.²³
- “Zoysiagrass golf course fairway turf had an average gross C sequestration rate of 1.01 Mg C ha⁻¹ yr⁻¹.” “Once total estimated hidden carbon costs was included, the average net sequestration rate was 0.412 and 0.616 Mg C ha⁻¹ yr⁻¹ in high management input and low management input, respectively, with no statistical differences.”²⁴
- “Turfgrass species with high photosynthetic activity during the summer, such as *C. dactylon* and *F. arundinacea* ‘Bingo, resulted in a high total SOC of 2.4 t SOC ha⁻¹ and 2.7 t SOC ha⁻¹, respectively, when compared with bare soil (0.9 t SOC ha⁻¹) at the end of the study.”²⁵
- Turfgrass and grasslands: “The average SOC sequestration rate for U.S. lawns was 46.0 to 127.1 g C/m²/year.” “Low management with minimal input (MI) included mowing only, a net SOC sequestration rate of 25.4 to 114.2 g C/m²/year.” “High management, based on university and

¹⁶ 2006 National Turfgrass Federation.

¹⁷ Nowak, et al. “Houston’s Urban Forest, 2015.” Resour. Bull. SRS-211. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station., 1 Jan. 1970, www.srs.fs.usda.gov/pubs/54109.

¹⁸ Bremer, Dale. “Carbon Sequestration in Turfgrass: An Eco-Friendly Benefit of Your Lawn .” Kansas Turfgrass Foundation Newsletter , Oct. 2007, www.walterreeves.com/uploads/pdf/turfsequestration.pdf.

¹⁹ STACHLEWITZ, RUSTY. “The ANSWER Is Turf.” American Nurseryman 205, no. 5 (March 2007): 24. <https://eurekamag.com/research/018/148/>

²⁰ Davies, Zoe G., et al. “Mapping an Urban Ecosystem Service: Quantifying above-Ground Carbon Storage at a City-Wide Scale - Davies - 2012 - Journal of Applied Ecology - Wiley Online Library.” Journal of Applied Ecology, John Wiley & Sons, Ltd (10.1111), 11 July 2011. <https://besjournals.onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2011.02021.x>

²¹ McPherson, E. Gregory. 1994. Cooling urban heat islands with sustainable landscapes. In: Platt, Rutherford H.; Rowntree, Rowan A.; Muick, Pamela C.; eds. The ecological city: preserving and restoring urban biodiversity. Amherst, MA: University of Massachusetts Press: 151-171. <https://www.fs.usda.gov/treearch/pubs/42252>

²² Livesley, S.J., Dougherty, B.J., Smith, A.J. et al. Urban Ecosyst (2010) 13: 273. <https://doi.org/10.1007/s11252-009-0119-6>

²³ Davies, Zoe G., et al. “Mapping an Urban Ecosystem Service: Quantifying above-Ground Carbon Storage at a City-Wide Scale - Davies - 2012 - Journal of Applied Ecology - Wiley Online Library.” Journal of Applied Ecology, John Wiley & Sons, Ltd (10.1111), 11 July 2011. <https://doi.org/10.1111/j.1365-2664.2011.02021.x>

²⁴ Braun, R. C., & Bremer, D. J. (2019). Carbon sequestration in zoysiagrass turf under different irrigation and fertilization management regimes. *Agrosystems, Geosciences & Environment*, 2, 180060. <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/age2018.12.0060>

²⁵ Alejandra A. Acuña E., Claudio Pastenes V., Luis Villalobos G., March 2017 Carbon Sequestration and Photosynthesis in Newly Established Turfgrass Cover in Central Chile, *Agronomy Journal*. <https://access.onlinelibrary.wiley.com/doi/full/10.2134/agronj2016.05.0257>

industry-standard best management recommendation practices (BMPs), had a net SOC sequestration rate of 51.7 to 204.3 g C/m²/year.” “Lawns can be a net sink for atmospheric CO₂ under all three evaluated levels of management practices with a national technical potential ranging from 25.4 to 204.3 g C/m²/year.”²⁶

- “Turfgrasses in the U.S. alone result in 20 million tons of carbon being removed from the atmosphere each year... the greatest carbon sequestration rates occur during the first 25 to 30 years after establishment of turfgrass, after which sequestration rates level off. This is because soils eventually reach a saturation point for storing carbon.”²⁷
- The turfgrass on golf courses serves as sinks for CO₂ - “A rapid increase in carbon sequestration occurs the first 25 to 30 years after the turfgrass is established. The study found that greens and fairways each store nearly a ton of carbon per acre per year.”²⁸
- “Total C sequestration continued for up to about 31 years in fairways and 45 years in putting greens. However, the most rapid increase occurred during the first 25 to 30 years after turfgrass establishment, at average rates approaching 0.9 and 1.0 t ha⁻¹ yr⁻¹ for fairways and putting greens, respectively.”²⁹
- “Carbon sequestration rates were 0.74, and 0.78 Mg ha⁻¹ yr⁻¹ for irrigated fine fescue and creeping bentgrass, respectively, which are higher than those of unirrigated fine fescue and irrigated Kentucky bluegrass.” “In summary, our experiment demonstrates that urban turfgrass systems provide a significant sink for SOC (soil organic C) sequestration.”³⁰
- Mulched garden areas provide greatest C sequestration potential in soil and vegetation.” “reducing the irrigation and fertilizer application to lawns can help mitigate GHG emissions from urban garden systems, and increasing the area of mulched perennial garden beds can also provide net GHG benefits.”³¹
- “Large healthy trees sequester about 93 kg C/yr as compared to 1 kg C/yr for small trees.”³²
- A tree with a 16-inch diameter can sequester about 34.6 pounds of carbon per year and can remove about 0.58 pounds of pollutants per year.³³

²⁶ Zirkle, Gina; L. Rattan, B. Augustin. May 2011. Modeling Carbon Sequestration in Home Lawns, American Society for Horticultural Science. <https://journals.ashs.org/hortsci/view/journals/hortsci/46/5/article-p808.xml>

²⁷ Bremer, Dale. “Carbon Sequestration in Turfgrass: An Eco-Friendly Benefit of Your Lawn.” Kansas Turfgrass Foundation Newsletter, Oct. 2007 www.walterreeves.com/uploads/pdf/turfsequestration.pdf

²⁸ Elstein, David June 2003. Are Golf Courses Holding the Carbon? Turfgrass as a “Sink” for CO₂. Agricultural Research. Ronald F. Follett is with the USDAARS Soil, Plant, and Nutrient Research Laboratory <https://agresearchmag.ars.usda.gov/ar/archive/2003/jun/golf0603.pdf>

²⁹ Qian, Y. and R.F. Follett. 2002. Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. Agron. J. 94:930-935. <https://access.onlinelibrary.wiley.com/doi/full/10.2134/agronj2002.9300>

³⁰ Qian, Y.L., R Follett, and J Kimble. Estimating Soil Carbon Sequestration in Turfgrass Systems From Natural Carbon Isotopic Signatures. Department of Horticulture and Landscape Architecture, Colorado State University. (2002) https://www.researchgate.net/publication/237613871_Assessing_Soil_Carbon_Sequestration_in_Turfgrass_Systems_Using_Long-Term_Soil_Testing_Data/link/55ef66bc08aef559dc44cc61/download

³¹ Livesley, S.J., Dougherty, B.J., Smith, A.J. et al. Soil-atmosphere exchange of carbon dioxide, methane and nitrous oxide in urban garden systems: impact of irrigation, fertiliser and mulch Urban Ecosyst (2010) 13: 273. <https://doi.org/10.1007/s11252-009-0119-6>

³² Dixon, K. K., and K. L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, WA). Washington D.C.: Transportation Research Board of the National Academies of Science. http://www.naturewithin.info/Roadside/TRB_UrbnStsTrees.pdf

³³ Nowak, et al. “Houston’s Urban Forest, 2015.” Resour. Bull. SRS–211. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station., 2017 www.srs.fs.usda.gov/pubs/54109.

APPENDIX 5—RELATIVE TREE EFFECTS

The urban forest in Houston provides benefits that include carbon storage, carbon sequestration, and air pollutant removal. These benefits vary across diameter classes (table 28). The relative value of tree benefits is calculated to show how carbon storage and sequestration, and air pollutant removal vary by tree size and equates to municipal carbon emissions, passenger automobile emissions, and household emissions.

Table 28—Average tree effects by tree diameter class, Houston, 2015

Diameter ^a inches	Carbon storage		Carbon sequestration		Pollution removal	
	Lbs.	\$ ^b million ^c	Boys ^d	Boys ^d miles	Boys ^d	Boys ^d
2	4	0.29	17	1.2	0.12	7
4	25	1.69	101	3.5	0.23	14
6	53	3.52	212	7.3	0.48	29
8	114	7.59	457	11.5	0.77	46
10	197	13.09	788	19.2	1.28	77
12	341	22.71	1,367	33.8	1.58	95
14	470	31.27	1,883	29.9	1.99	120
16	593	39.46	2,376	34.8	2.30	139
18	635	42.22	2,541	39.5	2.62	158
20	1,045	69.53	4,186	64.3	4.28	257
22	1,145	75.97	4,578	62.2	4.01	241
24	1,253	83.38	5,019	64.8	4.31	260
26	2,054	136.07	8,227	97.8	6.51	392
28	2,431	161.72	9,735	191.9	6.30	469
30 ^e	2,986	198.66	11,959	119.5	7.95	479
					1.32	5.57

^aDiameter classes are designated by their midpoint (e.g., 2" is actually 1" to 3" diameter). Diameter measurements were taken at breast height (4.5 ft) for most trees (or 6 ft) for woody vines.

^bValues = number of automobile miles driven that produces emissions equivalent to tree effect.

Oxygen Generation

- 58 square meters of lawn provides enough oxygen for one person for an entire day.³⁴
- The average adult consumes oxygen at a rate of 1.85 pounds per day.³⁵
- A 2500 square foot lawn produces enough oxygen for a family of four for a year. The grass and trees along the US interstate system produce enough oxygen to support 22 million people.³⁶
- One acre of grass produces more oxygen per year than one acre of rainforest.³⁷
- One acre of turfgrass produces enough oxygen for 64 people a day.³⁸
- American urban forests produce about 61 million metric tons of oxygen each year, enough for two thirds of the United States population.³⁹
- In some cities, like Moorestown, New Jersey, urban forests offset greater than 100% of human oxygen consumption. On average, a hectare of trees (100% tree canopy) provides oxygen for 19 people each year. On average, a hectare of trees (100% tree canopy) provides oxygen for 19 people each year.⁴⁰
- “Urban forests in the coterminous United States are estimated to produce ≈61 million metric tons (67 million tons) of oxygen annually, enough oxygen to offset the annual oxygen consumption of approximately two-thirds of the U.S. population.” An acre of trees (100% tree canopy) can provide enough oxygen for 8 people. “Oxygen production per acre of tree cover will vary based on tree density, diameter distribution, and tree health and growth.”⁴¹
- The following graph depicts data of trees from Minneapolis, Minnesota regarding how much average oxygen trees produce based on size.⁴²

³⁴ SUMMER / FALL 2004 NEWSLETTER. CMS Landscaping Corporation. <https://www.cmslandscaping.com/>

³⁵ Perry, J., and M.D. LeVan. C. 2003. Air Purification in Closed Environments: Overview of Spacecraft Systems. U.S. <https://ntrs.nasa.gov/citations/20030000981>

³⁶ 1996 Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

³⁷ “Oxygen Production by Urban Trees in the United States”, International Society of Arboriculture, Arboriculture & Urban Forestry 2007. 33(3):220-226, David J. Nowak, Robert Hoehn, and Daniel E. Crane https://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf

³⁸ The Lawn Institute, from data collected by Maryland Agricultural Statistics Services https://www.nass.usda.gov/Statistics_by_State/Maryland/index.php

³⁹ Nilsson, Kjell. Forests, Trees, and Human Health. Springer Verlag, 2011. <https://link.springer.com/book/10.1007/978-90-481-9806-1>

⁴⁰ Nowak, David, et al. “Oxygen Production by Urban Trees in the United States.” Northern Research Station, 2007, www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf.

⁴¹ “Oxygen Production by Urban Trees in the United States”, International Society of Arboriculture, Arboriculture & Urban Forestry 2007. 33(3):220-226, David J. Nowak, Robert Hoehn, and Daniel E. Crane https://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf

⁴² Nowak, David, et al. “Oxygen Production by Urban Trees in the United States.” Northern Research Station, 2007, www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf.

Size (inches)	Oxygen production (O ₂ /year)
1-3	6.4 lbs
9-12	49.9 lbs
18-21	100.5 lbs
27-30	200.8 lbs
Greater than 30	243.2 lbs

Temperature Modification

- Urban Green spaces have significant cooling effects in all seasons except winter.⁴³
- Urban parks are more effective at cooling air temperature in an urban heat island than bodies of water, such as urban ponds. Urban green spaces are also less expensive than so-called “urban blue spaces” and provide other benefits such as noise cancellation, aesthetic appeal, and recreational spaces.⁴⁴
- Green roofs act as natural insulation and provide a cooling effect by slowing the travel of sunlight and heat. A study by CSIRO found that green roofs can reduce the energy used to cool a home by 48%.⁴⁵
- Urban vegetation plays an especially important role in creating comfortable living environments in arid and semi-arid cities. Urban trees can help mitigate some of the warming effects of built environments. A 2018 study by Wang et al. found that the effects of urban shade trees were responsible for a 3.06 degrees celsius decrease in near-surface air temperature in urban areas in the contiguous US due to their shading effect. The shade cools off surface temperatures and diminishes the amount of energy that is stored and reradiated later.⁴⁶
- Rooftop lawn garden soil thickness has important effects on building temperature regulation. In a 2012 study, a rooftop lawn garden with a soil thickness of .20 m was found to decrease building energy usage by 37.11% compared to a building with a bare roof, while soil thickness of .10 m contributed to a decrease in energy usage of 31.07%.⁴⁷
- Large urban parks can extend their cooling effects to up to 480 m from park boundaries during summer months.⁴⁸

⁴³ Xingyuan He, Lingxue Yu, Kun Bu, Jiuchun Yang, Liping Chang, Shuwen Zhang, Chaobin Yang, Fengqin Yan, and Ranghu Wang. 2017. “The Effect of Urban Green Spaces on the Urban Thermal Environment and Its Seasonal Variations.” *Forests* (19994907) 8 (5): 153. <https://www.mdpi.com/1999-4907/8/5/153>

⁴⁴ Targino, Admir Créso, Guilherme Conon Coraiola, and Patricia Krecl. 2019. “Green or Blue Spaces? Assessment of the Effectiveness and Costs to Mitigate the Urban Heat Island in a Latin American City.” *Theoretical & Applied Climatology* 136 (3/4): 971–84. <https://link.springer.com/article/10.1007/s00704-018-2534-1>

⁴⁵ Tufvesson, Angela. “Green Roofs.” *Sanctuary: Modern Green Homes*, no. 21 (2012): 68-71. <http://www.istor.org/stable/sanctuary.21.68>.

⁴⁶ Wang, Zhi-Hua, Xiaoxi Zhao, Jiachuan Yang, and Jiyun Song. 2016. “Cooling and Energy Saving Potentials of Shade Trees and Urban Lawns in a Desert City.” *Applied Energy* 161 (January): 437–44. <https://www.sciencedirect.com/science/article/abs/pii/S030626191501274X>

⁴⁷ Permpituck, Sittipong, and Pichai Namprakai. 2012. “The Energy Consumption Performance of Roof Lawn Gardens in Thailand.” *Renewable Energy: An International Journal* 40 (1): 98–103. https://www.researchgate.net/publication/257414848_The_energy_consumption_performance_of_roof_lawn_gardens_in_Thailand

⁴⁸ Chaobin Yang, Xingyuan He, Lingxue Yu, Jiuchun Yang, Fengqin Yan, Kun Bu, Liping Chang, and Shuwen Zhang. 2017. “The Cooling Effect of Urban Parks and Its Monthly Variations in a Snow Climate City.” *Remote Sensing* 9 (10): 1066. <https://www.mdpi.com/2072-4292/9/10/1066>

- A well-maintained lawn and landscape keeps homes cooler on hot days, reducing surface temperatures by 30° to 40° compared with bare soil, and 50° to 70° cooler than streets and driveways.⁴⁹
- Eight healthy front lawns have the cooling effect of 70 tons of air conditioning, which is enough for 16 average homes. Temperatures over turfed surfaces on a sunny summer day will be 10-14° cooler than over concrete or asphalt. Each blade of grass acts as an evaporative cooler. An acre of turf on a summer day will lose about 2,400 gallons of water through evaporation and transpiration to the atmosphere. About 50% of the sun’s heat striking the turf may be eliminated through this transpiration cooling process.⁵⁰
- Because healthy lawns have been so beneficial in decreasing energy consumption, cities are beginning to implicate the “green roofing strategy” where grass is grown on the top of buildings. In Chicago, roof top temperatures during summer months are reduced by up to 78°. This is necessary, because cities with little trees and turf become “heat islands” where temperatures are 10° to 30° F hotter than outlying rural areas.⁵¹
- Temperature comparisons of four types of surfaces on August 20 in College Station TX:⁵²

Type of Surface	Maximum Daytime Surface Temperature	Minimum Nocturnal Surface Temperature
Green growing Cynodon turf	87.8° F	75.2° F
Dry bare soil	102.2° F	78.8° F
Brown summer-dormant Cynodon turf	125.6° F	80.6° F
Dry synthetic turf	158° F	84.2° F

- A 10% increase of green space in Manchester, England reduced surface temperatures in the urban areas by 4°C, which in the researchers’ opinions would overcome temperature rises caused by global warming over the next 75 years, effectively climate proofing the city.⁵³

⁴⁹ “How The Environment Benefits From a Well-Maintained Lawn”. Better Lawn and Turf Institute. <https://lawnnation.com/how-the-environment-benefits-from-a-well-maintained-lawn/>

⁵⁰ 1996 Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

⁵¹ Climate Change Literature Review. Department of Urban and Regional Planning. University of Wisconsin, Madison.

⁵² Beard, J.B., and D. Johns. 1985. The comparative heat dissipation from three typical urban surfaces: Asphalt, concrete, and a Bermuda grass turf. P. 125-133 .In Texas turfgrass res.-1985. Texas Agric. Exp. Stn. PR-4329. College Station. <https://agris.fao.org/agris-search/search.do?recordID=US874814188>

⁵³ Ennos, R., J. Handley, and S. Gill. 2007. Build parks to climate proof our cities, Urban green spaces could offset global warming until 2080s. School of Environment and Development. University of Manchester. <https://www.sciencedaily.com/releases/2007/05/070514101534.htm>

- Roughly 50 percent of the heat striking a turf area is eliminated by transpiration. When the temperature of the sidewalk is 100 °F, the temperature of the adjacent turf remains near 75 °F. This cooling may last into the night, with studies showing a 13° cooling at 9 p.m.⁵⁴
- The transpiration cooling effect of green turfs and landscapes can save energy by reductions in the energy input required for interior mechanical cooling of adjacent homes and buildings⁵⁵
- Lawn areas around homes can reduce air temperatures from 7° to 14° F through the effects of shading and evapotranspiration. This can directly result in curbing summer air conditioning costs. One estimate suggests that strategic planting of lawns and other landscape plants could reduce total U.S. air conditioning energy requirements by 25 percent.^{56 57}
- Turfgrasses and other landscape plantings dissipate radiant heat through the cooling process of evapotranspiration, which saves energy by reducing the interior mechanical cooling needed for nearby homes and commercial buildings.⁵⁸
- Because of the temperature modification effects of trees, a computer program predicted that three trees for every other one family home could reduce heating and air conditioning energy consumption by 30 billion kWh, which equals about two billion dollars' worth of energy.⁵⁹
- In an analysis of tree planting in Tuscan, Arizona, it was determined that due to trees' ability to cool temperatures, the average benefit of each tree is \$25.09 per year, with yard trees providing the highest rate of return. The biggest benefit from planting trees in this analysis was determined to be the money saved in cooling measures.⁶⁰
- "The temperature within the park was always lower than over the lake, confirming that urban forestry is a more effective mechanism to combat the UHI. Introducing a park would be about sevenfold cheaper than building a city pond. Hence, green spaces are not only more efficient to combat the UHI but it is also a cheaper strategy compared to blue spaces. Moreover, vegetation delivers other benefits, such as removal of air pollutants, attenuation of urban noise, improvement of city aesthetic and their use as recreational spaces."⁶¹
- "Results show that on average the mean near-surface air temperature in urban areas decreases by 3.06 °C over the entire contiguous United States with the shading effect. Analysis of pedestrian thermal comfort shows that shade trees improve the thermal comfort level in summers." "Trees have multiple biophysical functions in the urban ecosystem (Erell et al., 2011), among which the radiative shading and evapotranspiration (ET) are predominant in regulating the thermal environment. The presence of crowns can reduce the penetration of shortwave solar radiation, and lower the surface and air temperatures in shade (Roy et al., 2012). In

⁵⁴ Mississippi State University Extension. Establish and Manage Your Home Lawn, Publication 1322.

<http://extension.msstate.edu/publications/publications/establish-and-manage-your-home-lawn>

⁵⁵ Johns, D., and J.B. Beard. 1985. A quantitative assessment of the benefits from irrigated turf on environmental cooling and energy saving in urban areas. P. 134-142. In Texas Turfgrass Research – 1985. Texas Agric. Exp. Stn. PR-4330. College Station. <https://agris.fao.org/agris-search/search.do?recordID=US874814288>

⁵⁶ Hull, R. J., Alm, S. R., and Jackson, N.1994.Toward Sustainable Lawn Turf, in Handbook of Integrated Pest Management for Turf and Ornamentals. <https://www.routledge.com/Handbook-of-Integrated-Pest-Management-for-Turf-and-Ornamentals/Lealie/p/book/9780873713504>

⁵⁷ Roberts, E. C. and Roberts, B. C. 1987. Lawn and Sports Turf Benefits, The Lawn Institute. <https://www.thelawninstitute.org/>

⁵⁸ UCRTRAC Newsletter. 2002. Better Turf Thru Agronomics.University of California, Riverside Turfgrass Research Program.

<https://turfgrass.ucr.edu/reports/btta/03-BTTA%20March%201997.pdf>

⁵⁹ F. Dwyer, John & McPherson, E & Schroeder, Herbert & A. Rowntree, Rowan. (1992). Assessing the benefits and costs of the urban forest. J. Arbor. https://www.fs.fed.us/psw/publications/mcpherson/psw_1992_mcpherson002.pdf

⁶⁰ McPherson, E. Gregory. 1994. Cooling urban heat islands with sustainable landscapes. In: Platt, Rutherford H.; Rowntree, Rowan A.; Muick, Pamela C.; eds. The ecological city: preserving and restoring urban biodiversity. Amherst, MA: University of Massachusetts Press: 151-171. <https://www.fs.usda.gov/treearch/pubs/42252>

⁶¹ Targino, Admir Créso, Guilherme Conon Coraiola, and Patricia Krecl. 2019. "Green or Blue Spaces? Assessment of the Effectiveness and Costs to Mitigate the Urban Heat Island in a Latin American City." Theoretical & Applied Climatology 136 (3/4): 971–84. <https://link.springer.com/article/10.1007/s00704-018-2534-1>

addition, trees can provide cooling by transpiration, especially during nighttime (Konarska et al., 2016).⁶²

- “Shade trees have more prominent energy saving potential than urban lawns.” “The presence of trees in street canyons can effectively reduce environmental temperature via radiative shading.” “It is found that the cooling effect by shading from trees is more significant than that by evapotranspiration from lawns, leading to a considerable saving of cooling load.”⁶³
- “Trees that shade pavement can reduce asphalt temperatures by as much as 36°F, and fuel tank temperatures by nearly 7°F.” “Tree planting is one of the most cost-effective means of mitigating urban heat islands. Air temperature differences of approximately 2 to 4°C have been observed across urban areas having variable tree cover, with approximately 1°C of temperature difference being associated with 10% canopy cover difference. Studies in Sacramento CA suggest that 50% shading of paved areas would reduce hydrocarbon emissions citywide by 1 to 2%.”⁶⁴
- “On a block of eight houses, the front lawns have the cooling effect of 70 tons of air-conditioning. The plants, in transpiring water to cool themselves, also cool the surrounding area. Roughly 50 percent of the heat striking a turf area is eliminated by transpiration. When the temperature of the sidewalk is 100 °F, the temperature of the adjacent turf remains near 75 °F. This cooling may last into the night, with studies showing a 13-degree cooling at 9 p.m.”⁶⁵
- “Urban green spaces did have significant cooling effects in all seasons, except for winter, but the effects varied considerably across the different seasons and green types, and seemed to depend on the NDVI and size of urban green spaces.” “The difference of LST between the urban green spaces and urban areas was large in the summer and small in the winter. The maximum value of the differences was 1.27 °C on 31 July.” “We found that every 10% increase in urban green spaces explained a 0.34 °C decrease in LST in summer at the 0.5 km × 0.5 km scale.” “Rather than increasing the area of green patches, increasing the NDVI (more woodland area and denser vegetation) is a better and more practicable approach for urban green planning.”⁶⁶
- “Urban parks have been shown to form park cool islands (PCIs), which can effectively alleviate the negative influences of urban heat islands (UHI).” “For parks larger than 30 ha, the cooling effects extended approximately 480 m from the park edge between June and August.”⁶⁷
- “With evaporative cooling by the Roof Lawn Gardens, it was found that the consumption of energy in a building with a RLG with 0.20 m of soil was 37.11% less than in a building with a bare roof surface (without evaporative cooling). Moreover, a building with 0.10 m of soil in the RLG consumed 31.07% less energy than a building with a bare roof surface. The results show that an increase in the thickness of the soil layer reduces the building energy consumption.”⁶⁸

⁶² Wang, Chenghao, Zhi-Hua Wang, and Jiachuan Yang. 2018. “Cooling Effect of Urban Trees on the Built Environment of Contiguous United States.” *Earth’s Future* 6 (8): 1066–81. <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018EF000891>

⁶³ Wang, Zhi-Hua, Xiaoxi Zhao, Jiachuan Yang, and Jiyun Song. 2016. “Cooling and Energy Saving Potentials of Shade Trees and Urban Lawns in a Desert City.” *Applied Energy* 161 (January): 437–44. <https://www.sciencedirect.com/science/article/pii/S030626191501274X>

⁶⁴ Dixon, K. K., and K. L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, WA). Washington D.C.: Transportation Research Board of the National Academies of Science. http://www.naturewithin.info/Roadside/TRB_UrbnStsTrees.pdf

⁶⁵ Mississippi State University Extension. Establish and Manage Your Home Lawn, Publication 1322. Published 2015 http://extension.msstate.edu/sites/default/files/publications/publications/p1322_1.pdf

⁶⁶ Xingyuan He, Lingxue Yu, Kun Bu, Jiuchun Yang, Liping Chang, Shuwen Zhang, Chaobin Yang, Fengqin Yan, and Ranghu Wang. 2017. “The Effect of Urban Green Spaces on the Urban Thermal Environment and Its Seasonal Variations.” *Forests* (19994907) 8 (5): 153. <https://www.mdpi.com/1999-4907/8/5/153/htm>

⁶⁷ Chaobin Yang, Xingyuan He, Lingxue Yu, Jiuchun Yang, Fengqin Yan, Kun Bu, Liping Chang, and Shuwen Zhang. 2017. “The Cooling Effect of Urban Parks and Its Monthly Variations in a Snow Climate City.” *Remote Sensing* 9 (10): 1066. <https://www.mdpi.com/2072-4292/9/10/1066>

⁶⁸ Permpituck, Sittipong, and Pichai Namprakai. 2012. “The Energy Consumption Performance of Roof Lawn Gardens in Thailand.” *Renewable Energy: An International Journal* 40 (1): 98–103. <https://www.sciencedirect.com/science/article/pii/S0960148111005416>

- “Research by the CSIRO found green roofs can reduce the amount of energy used to cool a room by 48 percent in summer.”⁶⁹
- “The University of Manchester study has calculated that a mere 10% increase in the amount of green space in built-up centres would reduce urban surface temperatures by as much as 4°C. This 4°C drop in temperature, which is equivalent to the average predicted rise through global warming by the 2080s, is caused by the cooling effect of water as it evaporates into the air from leaves and vegetation through a process called transpiration.”⁷⁰

Water Purification

- High density turfgrass has lower loss of phosphorous to surface water than other types of land use -- particularly untouched wooded areas where the ground is uncovered.⁷¹
- Even low-density turfgrass has lower runoff and sediment loss (both of which pollute water sources) than bare-soil landscapes.⁷²
- Sodding a landscape can reduce runoff volume by 25% and sediment loss by over 99%.⁷³
- In an experimental study, Erickson et al. (2000) found that turfgrass was more effective than a mixed-species landscape at preventing nitrogen leaching into groundwater after fertilization. This means that even when fertilized, turfgrass landscapes allow significantly lower levels of nitrogen to contaminate groundwater than mixed-species landscapes.⁷⁴
- Lawns are incredibly important in rainwater drainage. In vegetation-free cities, roughly 60% of rainwater becomes surface runoff which can contribute to erosion and pollute water. In cities with lawns, only 5-15% of rainwater becomes surface runoff with the rest evaporating or being absorbed into the ground to be used by vegetation.⁷⁵
- Turfgrass is effective in halting the pollution from landfill leakage.⁷⁶
- Groundwater found under turfgrass soil has lower nitrate levels (indicative of less pollution) than water found under soil in agricultural lands. The same was found for iron levels.⁷⁷
- Turfgrasses can be used in the restoration of soil contaminated by lead.⁷⁸

⁶⁹ Tufvesson, Angela. "Green Roofs." *Sanctuary: Modern Green Homes*, no. 21 (2012): 68-71. <http://www.jstor.org/stable/sanctuary.21.68>.

⁷⁰ Ennos, R., J. Handley, and S. Gill. 2007. Build parks to climate proof our cities, Urban green spaces could offset global warming until 2080s. School of Environment and Development. University of Manchester <https://www.sciencedaily.com/releases/2007/05/070514101534.htm>

⁷¹ Petrovic, A.M. & Easton, Z.M. 2005. "The Role of Turfgrass Management in the Water Quality of Urban Environments." *International Turfgrass Society*, 10, pp. 55-69

https://www.researchgate.net/publication/267817326_The_Role_of_Turfgrass_Management_in_the_Water_Quality_of_Urban_Environment

⁷² Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from turfgrass. *J. Environ. Qual.* 19: 663-668 <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1990.00472425001900040006x>

⁷³ Krenitsky, E.C., M.J. Carroll, R.L. Hill, and J.M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. *Crop Sci.* 38:1042- 1046. <https://access.onlinelibrary.wiley.com/doi/abs/10.2135/cropsci1998.0011183X003800040026x>

⁷⁴ Erickson, J. E., J. L. Cisar, J. C. Volin, and G. H. Snyder. 2001. Comparing Nitrogen Runoff and Leaching between Newly Established St. Augustinegrass Turf and an Alternative Residential Landscape *Journal Series no. R-08216 of the Florida Agricultural Experiment Station.. Crop Sci.* 41:1889-1895.

https://www.researchgate.net/publication/238073168_Comparing_Nitrogen_Runoff_and_Leaching_Between_Newly_Established_St_Augustine_Grass_Turf_and_an_Alternative_Residential_Landscape

⁷⁵ P. Bolund, S. Hunhamma. *Ecosystem Services in Urban Areas.* *Ecol. Econ.*, 29 (1999), pp. 293-301

[https://www.scirp.org/\(S\(i43dyn45teexjx455qlt3d2q\)\)/reference/ReferencesPapers.aspx?ReferenceID=1768763](https://www.scirp.org/(S(i43dyn45teexjx455qlt3d2q))/reference/ReferencesPapers.aspx?ReferenceID=1768763)

⁷⁶ Gabka, Daria. "Use of Turfgrasses in Landfill Leachate Treatment," *Polish Journal of Environmental Studies*, no. 20(5) (2011), pp. 1161-1165. <http://www.pjoes.com/Use-of-Turfgrasses-in-Landfill-Leachate-Treatment,88663,0,2.html>

⁷⁷ Kasper, Joshua W., Judith M. Denver, and Joanna K. York. 2015. "Suburban Groundwater Quality as Influenced by Turfgrass and Septic Sources, Delmarva Peninsula, USA." *Journal of Environmental Quality* 44 (2): 642–54. <https://pubmed.ncbi.nlm.nih.gov/26023982/>

⁷⁸ Li, Xi, Huameng Cen, Youxiang Chen, Siying Xu, Lingli Peng, Hanmingyue Zhu, and Yiqiao Li. 2016. "Physiological Analyses Indicate Superoxide Dismutase, Catalase, and Phytochelatins Play Important Roles in Pb Tolerance in *Eremochloa Ophiuroides*." *International Journal of Phytoremediation* 18 (3): 251–60. <https://pubmed.ncbi.nlm.nih.gov/26368658/>

- Turfgrass acts as a natural vegetative filter, preventing sediment from being transported to streams and rivers. This protects the soil nutrients and stops pollutants from entering water sources.⁷⁹
- A healthy turf will filter ground water and reduce sedimentation and runoff. The average suburban lot, which is about 10,000 square feet, can absorb more than 6,000 gallons of rainwater without noticeable runoff. This runoff typically consists of at least 50% nutrients and pesticides, 60% of certain pathogens, and 75% of sediment, in which radioactive materials may be present.⁸⁰
- In urban areas runoff is likely to include metals such as Pb, Cd, Cu and Zn, hydrocarbon compounds such as those from oil, grease and fuels, and household and industrial hazardous wastes such as oils, paint thinners, and organic preservatives.⁸¹
- A healthy sodded landscape absorbs rainfall six times more effectively than a wheat field and four times more than a hay field. Soil microbes help break down chemicals such as turf pesticides into harmless materials. This filtration system is so effective that rainfall is often as much as 10 times more acidic than the same water filtered through a healthy lawn.⁸²
- Turf's high growth density nearly eliminates runoff in favor of infiltration, which then increases the amount of water entering the soil.⁸³
- Turfgrass ecosystems support abundant earthworm populations, which contribute to increased macropore space in soil, resulting in higher soil water infiltration rates, higher water-holding capacity, and improved soil structure.⁸⁴
- The reduction in runoff volume linked to turf can lead to a decrease in storm water management expenses.⁸⁵
- A reduction in surface runoff water is a benefit of turfgrass and is a key component to protecting water quality. An average golf course, for example, can absorb 4 million gallons of water during a 1-inch rainstorm. A golf course or turf area can absorb far more than one inch of rain water without runoff, assuming it's not coming down too fast. This is because a dense turf area can reduce runoff to virtually nothing. When compared to a non-turf area (like a garden or agricultural field), grass areas can reduce runoff-induced soil erosion by up to 600 times.⁸⁶
- When soil is planted to turf, more water infiltrates and filters through the soil-turfgrass ecosystem, enhancing groundwater recharge, rather than increasing surface runoff.⁸⁷
- The turfgrass system can efficiently reduce groundwater and surface water contamination from fertilizers and pesticides applied by capturing, retaining and using them. Turf also protects water

⁷⁹ Maryland Professional Lawn Care Manual, 2013 https://mda.maryland.gov/SiteAssets/Pages/fertilizer/MDAProLawnCareManual_10.3.18.pdf

⁸⁰ Hoffman, H. and M. Dozier. 2000. Use of Grass Buffer Strips in Reducing Non-point Source Herbicide Runoff on the Texas Blackland Prairie. Texas Agricultural Experiment Station and Texas Agricultural Extension Service. Texas A&M University System.

⁸¹ Schuyler, T. 1987. Controlling urban runoff: A practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments, Washington, DC. <https://www.mwcog.org/documents/1987/07/01/controlling-urban-runoff-bmp-stormwater/>

⁸² 1996 Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

⁸³ Beard, J.B., and R.L. Green. 1994. The role of turfgrass in environmental protection and their benefits to humans. *J. Environ. Qual.* 23:452-460.

<https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x#:~:text=Specific%20functional%20benefits%20include%3A%20excellent,improvement%20that%20includes%20CO2>

⁸⁴ Potter, D.A. 1993. Pesticide and fertilizer effects on beneficial invertebrates and consequences for thatch degradation and pest outbreaks in turfgrass. P. 331-343. In K.D. Racke and A.R. Leslie (ed.) Pesticides in urban environments: Fate and significance. *Am. Chem. Soc.*, Washington, DC. <https://pubs.acs.org/doi/abs/10.1021/bk-1993-0522.ch028>

⁸⁵ Schuyler, T. 1987. Controlling urban runoff: A practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments, Washington, DC. <https://www.mwcog.org/documents/1987/07/01/controlling-urban-runoff-bmp-stormwater/>

⁸⁶ Whiting, D., R. Tolan, B. Mecham, and M. Bauer. 2005. Water-wise gardening: creating practical turf areas. Colorado State University Cooperative Extension. https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/Resources/HG_Turf_2006-01.pdf

⁸⁷ UCRTRAC Newsletter. 2002. Better Turf Thru Agronomics. University of California, Riverside Turfgrass Research Program. <https://turfgrass.ucr.edu/reports/btta/03-BTTA%20March%201997.pdf>

sources when excessive applications are inadvertently applied. Fertilizers or pesticides that are applied to bare soil are more likely to contaminate water sources than those applied to turf.⁸⁸

- Proper landscaping reduces nitrate leaching from the soil into the water supply and reduces surface water runoff, keeping phosphorus and other pollutants out of our waterways and preventing septic system overload.⁸⁹
- Trees in urban forests aid in water purification by absorbing some of the rainfall in their leaves and branches, reducing the amount of runoff that could overwhelm drainage systems, and softening the power of raindrops falling from the sky, meaning that when they land on the ground the raindrops will have less power to erode soil and pick up pollution.⁹⁰
- An urban forest in Dayton, Ohio was found to reduce runoff by 7% when unchanged, 12% when the canopy was modestly increased in size. It is also explained that if runoff is guided through further landscaping once it is through the canopy, it will be reduced even more.⁹¹
- Hard surfaces lead to two to six times more runoff than soft, natural surfaces.⁹²
- In two year study it was found that by covering soil with wood mulch, soil nitrates decreased by 74%. Nitrates can seep into groundwater and contaminate drinking water supplies.⁹³
- Proper application of fertilizer that has no excess application makes chances for pollution due to leaching low.⁹⁴
- In a study that compared surface-water runoff losses of perennial turfgrass and tobacco plants, runoff loss from turfgrass was only 0.0096 inches per acre per month, while the tobacco plant (in growing season) lost 0.11 inches of runoff per acre per month.⁹⁵

Erosion Control

- Based on a review of existing literature, Jose Montiero concluded that turf seems to have a higher potential than other types of vegetation for reducing runoff, increasing infiltration, purifying water from sediments and pollutants, controlling erosion, improving soil quality and reducing fire hazards.⁹⁶
- Grass cover reduced soil erosion by 63.9% to 92.75% and sediment transport rate by 80.59% to 96.17% depending on slope gradient, rainfall levels, and turf coverage. Rates of erosion protection increased when turf coverage percentage increased.⁹⁷
- One of the effects of climate change is increased rainfall, which can cause extensive soil erosion. A 2013 study by Ahn and Choi found that a plot of land covered in turfgrass resulted in “minimal”

⁸⁸ Streich, A., Rodie, S. and Gausson, R. 2003. Turf in the Landscape. University of Nebraska – Lincoln Extension, Institute of Agriculture and Natural Resources. <https://digitalcommons.unl.edu/extensionhist/1720/>

⁸⁹ Virginia Cooperative Extension: The Value of Landscaping, <https://vtechworks.lib.vt.edu/bitstream/handle/10919/78531/426-721.pdf?sequence=1&isAllowed=y>

⁹⁰ Nilsson, Kjell. Forests, Trees, and Human Health. Springer Verlag, 2011. <https://link.springer.com/book/10.1007/978-90-481-9806-1>

⁹¹ F. Dwyer, John & Mcpherson, E & Schroeder, Herbert & A. Rowntree, Rowan. (1992). Assessing the benefits and costs of the urban forest. J. Arbor https://www.fs.fed.us/psw/publications/mcpherson/psw_1992_mcpherson002.pdf

⁹² Dixon, K. K., and K. L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, WA). Washington D.C.: Transportation Research Board of the National Academies of Science. https://nacto.org/docs/usdg/benefits_and_risks_of_an_urban_roadside_landscape_dixon.pdf

⁹³ University of British Columbia. “Wood Mulch Can Help in Climate Change Fight.” Phys.org, Phys.org, 14 June 2016, <https://phys.org/news/2016-06-wood-mulch-climate.html>.

⁹⁴ “Fertilisers and the Environment.” NSW Department of Primary Industries, 1 Jan. 1970, <https://www.dpi.nsw.gov.au/agriculture/chemicals/fertilisers>

⁹⁵ Beard, James B. The Environmental Protection and Beneficial Contribution of Golf Course Turfs. International Sports Turf Institute, 1994. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.529.8868&rep=rep1&type=pdf>

⁹⁶ Monteiro, José A. 2017. “Ecosystem Services from Turfgrass Landscapes.” Urban Forestry & Urban Greening 26 (August): 151–57. <https://www.sciencedirect.com/science/article/abs/pii/S161886671630139X>

⁹⁷ Dong, Yuequen et al. (2015). “Effects of rye grass coverage on soil loss from loess slopes.” International Soil and Water Conservation Research, 3(3), p. 170-182. <https://www.sciencedirect.com/science/article/pii/S2095633915300915>

soil erosion, while plots pepper cultivation, rice and beans cultivation, and bare soil all resulted in significant loss of surface soil due to erosion.⁹⁸

- Surface soil is kept stabilized due to turf's high shoot density and extensive root mass.⁹⁹
- A single grass plant grown under ideal conditions has over 300 miles of roots.¹⁰⁰
- Perennial turfgrasses offer one of the most cost-effective methods to control water and wind erosion of soil, reducing dust and mud problems around homes, schools, factories, and businesses.¹⁰¹
- Quality turfgrass stands modify the overland flow process so that runoff is insignificant in all but the most intense rainfall events.^{102 103 104 105}
- Low growing, dense perennial turf grass sod in urban areas and communities can aid in reducing carbon dioxide emissions, mitigating the heat island effect, and reducing energy consumption, thus contributing to efforts to reduce global-warming trends.¹⁰⁶
- Perennial turfgrasses offer one of the most cost-efficient methods to control water and wind erosion of soil. Such control is very important in eliminating dust and mud problems around homes, factories, schools, and businesses. When this major erosion control benefit is combined with the groundwater recharge organic chemical decomposition, and soil improvement benefits, the resultant relatively stable turfgrass ecosystem is quite effective in soil and water preservation.¹⁰⁷
- The dense leaves, thatch, mat and roots of the turfgrass system provides an excellent groundcover that significantly reduces soil erosion and water runoff when compared to other landscape plants or bare soil. Bare soil losses from wind and water can be several tons per acre per year.¹⁰⁸
- With up to 90% of the weight of a grass plant in its roots, grass makes a very efficient erosion prevention device.¹⁰⁹
- It takes a minimum of 500 years to regenerate 25 millimeters of fertile soil.¹¹⁰
- Having plants covering the ground protects against erosion. In Utah and Montana, ground coverage plummeted from 100% to less than 1%, and erosion rates increase 200 times.¹¹¹

⁹⁸ Ahn, Byung-Goo & Choi, Joon-Soo. (2013). Effect of Turfgrasses to Prevent Soil Erosion. Weed & Turfgrass Science.

https://www.researchgate.net/publication/264178100_Effect_of_Turfgrasses_to_Prevent_Soil_Erosion

⁹⁹ Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs, NJ.

https://books.google.com/books/about/Turfgrass_Science_and_Culture.html?id=LG8IAQAAMAAJ

¹⁰⁰ 1996 Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

¹⁰¹ Beard, J.B., and R.L. Green. 1994. The role of turfgrass in environmental protection and their benefits to humans.

<https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x#:text=Specific%20functional%20benefits%20include%3A%20excellent%20improvement%20that%20includes%20CO2>

¹⁰² Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual.

20:604-607. <https://www.semanticscholar.org/paper/Runoff-and-sediment-losses-from-tall-fescue-under-Gross-Angle/40aec09ad557ffd4d3bbb9d226476e74bb66811b>

¹⁰³ Morton, J.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of over-watering and fertilization on nitrogen losses from home lawns. J. Environ.

Qual. 17:124-130. http://cels.uri.edu/docslink/whl/Journals/Morton_1988_JEQ.pdf

¹⁰⁴ Watschke, T.L., and R.O. Mumma. 1989. The effect of nutrients and pesticides applied to turf on the quality of runoff and percolating water.

Pennsylvania State Univ. Environmental Resources Res. Inst. ER-8904, University Park.

<https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB89236756.xhtml>

¹⁰⁵ Watson, J.R. 1985. Water resources in the United States. P. 19-36. In V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation.

Univ. of California, Div. of Agric. And Natural Resources, Publ. No. 21405, Riverside.

¹⁰⁶ 1990 Farm Bill

¹⁰⁷ Beard, J.B. and R.L. Green. 1994. The Role of Turfgrasses in Environmental Protection and Their Benefits to Humans. Journal of

Environmental Quality. 23:3. <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x>

¹⁰⁸ Streich, A., Rodie, S. and Gaussion, R. 2003. Turf in the Landscape. University of Nebraska – Lincoln Extension, Institute of Agriculture and

Natural Resources. <https://digitalcommons.unl.edu/extensionhist/1720/>

¹⁰⁹ New England Turf, Inc. <http://www.newenglandturf.com/>

¹¹⁰ Pimental, D. (1998). Population Growth and The Environment: Planetary Stewardship. Electronic Green Journal, 1(9). Retrieved from

<https://escholarship.org/uc/item/8g67g6ng>

¹¹¹ Pimentel, David. "Soil Erosion: a Food and Environmental Threat." Save Our Soils, College of Agriculture and Life Sciences, Cornell University, 2006, <http://saveoursoils.com/userfiles/downloads/1368007451-Soil%20Erosion-David%20Pimentel.pdf>

- It is estimated that turfgrass turns over 6,035 pounds of root biomass annually per acre. This high turnover rate helps speed up the process of soil restoration in areas where soil may have been eroded or damaged.¹¹²

Fire Retardation

- Ignited lawns have lower risk of damaging fire than non-irrigated landscapes.¹¹³
- A healthy turf serves as a firebreak that significantly lowers fire hazard.¹¹⁴
- Landscaping techniques can be utilized to protect the home from fires. Examples include creating a defensible space around the home where an individual removes vegetation and dry material from the direct vicinity of the home and plants leaving vertical and horizontal spaces between shrubs, flowers, trees, etc.¹¹⁵
- In some areas, lawn care to create a defensible space around the home is the law.¹¹⁶
- Hardscaping is less flammable than plants and can be used strategically around the house or through grass patches to break up a fire's path. Year-round care is crucial to ensure that a lawn resists fires to the best of its ability.¹¹⁷

Climate Change

- Global warming is caused by greenhouse gasses, most prominently carbon dioxide and methane, being released into the atmosphere, which can trap radiation and warm the atmosphere. Plants feed off of carbon dioxide and can decrease the amounts in the atmosphere by storing it in their stems, leaves, roots, flowers, and trunks. When summer gets to its hottest point, air conditioning usage accounts for half of the United State's electricity usage. Air conditioning usage is responsible for 100 million tons of carbon dioxide released into the atmosphere by power plants. Strategically planting trees to shade and cool off buildings can reduce air conditioning related energy use by up to 70% and strategically planting trees to block wind can reduce up to 30% of heating related energy use.¹¹⁸
- Tree trunks are made largely of carbon, increase in size each year, and remain in place for years, rather than regenerate annually. Because of this, trees are a great storage space for the air's carbon dioxide that they feed off of, and rarely re-release it due to their year-round lifespan. A single shade tree can store between 10 and 24 pounds of carbon each year.^{119 120}

¹¹² Beard, James B. The Environmental Protection and Beneficial Contribution of Golf Course Turfs. International Sports Turf Institute, 1994. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.529.8868&rep=rep1&type=pdf>

¹¹³ Monteiro, José A. "Ecosystem Services from Turfgrass Landscapes." Urban Forestry & Urban Greening 26 (August 2017): 151–57. <https://www.sciencedirect.com/science/article/abs/pii/S161886671630139X>

¹¹⁴ Younger, V.B. 1970. Landscaping to protect homes from wildfires. California Turfgrass Culture. 20(4):28-32.

¹¹⁵ "Maintain Defensible Space." Cal Fire. www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/.

¹¹⁶ "Know the Law for Defensible Space and Hardening your Home." Cal Fire. <https://www.readyforwildfire.org/more/fire-safety-laws/>

¹¹⁷ "Fire Wise and Water Wise Landscaping." SantaBarbaraCa, City of Santa Barbara, www.santabarbaraca.gov/civicax/filebank/blobdload.aspx?BlobID=34108.

¹¹⁸ Kuhns, Michael. "Landscape Trees and Climate Change." Utah State University Forestry Extension, Utah State University, <https://forestry.usu.edu/trees-cities-towns/urban-forestry/landscape-trees-climate>

¹¹⁹ Kuhns, Michael. "Landscape Trees and Climate Change." Utah State University Forestry Extension, Utah State University, <https://forestry.usu.edu/trees-cities-towns/urban-forestry/landscape-trees-climate>

¹²⁰ Union of Concerned Scientists. The Climate Friendly Gardener. Cornell University, 2010, <http://monroe.cce.cornell.edu/resources/climate-friendly-gardener>

- There are 85 million gardening households in the United States and if each one were to plant a small shade tree, those trees would take away more than 2 million tons of CO₂ from the atmosphere.¹²¹
- Plants and foliage not only cool off surrounding air by giving off shade, they also use a process called evapotranspiration, where plants release small traces of water into the space around it, cooling both itself and the air off. A leaf transpires much more water than its own weight in growing season, a tree can transpire ten gallons of water a day, and a large oak as much as 40,000 gallons a year.^{122 123}
- In a study on bark mulch application, it was found that when applying bark mulch to the surface over a two-year period, the average nitrous oxide emissions decrease was 28%. Mulching areas also resulted in a 74% decrease in soil nitrate, which helps form N₂O. Increasing the area of mulch application can decrease greenhouse gas emissions.^{124 125 126}
- Planting cover crops in a garden can take in carbon, while also improving soil, which holds carbon for years. Cover crops in a garden can also take up excess nitrogen, preventing it from turning into nitrous oxide. American urban trees are estimated to absorb 711,000 tons of air pollutants each year. This includes sulfur dioxide, smog, and ground-level ozone.¹²⁷
- Proper, waste-avoiding use of fertilizer avoids leaching which leads to a very low chance of pollution or contribution to greenhouse gasses.¹²⁸
- “Models have been developed to estimate these effects and show that in the United States, urban forests remove 651,000 metric tons of air pollution in 2010, store 643 million tons of carbon, annually sequester 25.6 million tons of carbon and annually produce 61 million tons of oxygen.” “In the United States, it is estimated that the annual values of urban forests is 4.7 billion USD from energy conservation and 2.3 billion USD from avoided pollutant emissions (Nowak et al., in review), 4.7 billion USD from air pollution removal (Nowak et al., 2014), 2 billion USD from carbon sequestration (Nowak et al., 2013a) and is negligible for oxygen production (Nowak et al., 2007).”¹²⁹

Other Environmental Factors

- Many decks are now being made out of Wood Plastic Composites, which are made from recycled wood and plastic, reducing waste.¹³⁰

¹²¹ “Gardening for Climate Change.” National Wildlife Federation, www.nwf.org/Our-Work/Environmental-Threats/Climate-Change/Greenhouse-Gases/Gardening-for-Climate-Change.

¹²² “Evapotranspiration and the Water Cycle.” USGS Science for a Changing World, Water Science School. https://www.usgs.gov/special-topic/water-science-school/science/evapotranspiration-and-water-cycle?qt-science_center_objects=0#qt-science_center_objects

¹²³ Cho, Renee. “How Plants Could Impact Global Warming.” State of the Planet, Columbia University Earth Institute, 12 Feb. 2011, <https://news.climate.columbia.edu/2011/02/12/how-plants-could-impact-global-warming/>

¹²⁴ Mesfin M. Fentabil, Craig F. Nichol, Gerry H. Neilsen, Kirsten D. Hannam, Denise Neilsen, Tom A. Forge, Melanie D. Jones, Effect of micro-irrigation type, N-source and mulching on nitrous oxide emissions in a semi-arid climate: An assessment across two years in a Merlot grape vineyard, *Agricultural Water Management*, Volume 171, 2016, Pages 49-62, ISSN 0378-3774. <https://www.sciencedirect.com/science/article/pii/S0378377416300592>

¹²⁵ Livesley, S.J., Dougherty, B.J., Smith, A.J. et al. Soil-atmosphere exchange of carbon dioxide, methane and nitrous oxide in urban garden systems: impact of irrigation, fertiliser and mulch. *Urban Ecosyst* (2010) 13: 273. <https://doi.org/10.1007/s11252-009-0119-6>

¹²⁶ University of British Columbia. “Wood Mulch Can Help in Climate Change Fight.” *Phys.org*, Phys.org, 14 June 2016, <https://phys.org/news/2016-06-wood-mulch-climate.html>

¹²⁷ Union of Concerned Scientists. *The Climate Friendly Gardener*. Cornell University, 2010, <http://monroe.cce.cornell.edu/resources/climate-friendly-gardener>

¹²⁸ “Fertilisers and the Environment.” NSW Department of Primary Industries, 1 Jan. 1970, www.dpi.nsw.gov.au/agriculture/soils/improvement/environment.

¹²⁹ Ferrini, Francesco; van den Bosch, Cecil C.K.; Fini, Alessio, eds. *Routledge handbook of urban forestry*. New York, NY: Routledge: 152-163. Chapter 11. 2017 <https://www.routledge.com/Routledge-Handbook-of-Urban-Forestry/Ferrini-Bosch-Fini/p/book/9780367352387>

¹³⁰ Sidharta, Andre. *Wood Plastic Composites (WPCs) as an Alternative to Solid Lumber*. Thesis of the University of British Columbia, 2011. <https://open.library.ubc.ca/soa/cIRcle/collections/undergraduateresearch/52966/items/1.0103128>

- The larger the area of the yard, the more dogs will walk, run, carry objects, and interact with humans. Having more than 1% foliage in the yard is positively associated with activity time of dogs.¹³¹
- Turfgrass ecosystems provides support for the earthworm species, containing 18.6 to 28 worms per square foot. A turfgrass in New Jersey was found to support 83 different taxa of invertebrates.¹³²

Quality of Life

Place for Recreation

- A study in China found that people derive the most satisfaction from urban green spaces when they consist of open, grassy space and tree patches on the edges -- this allows for both active recreation and passive enjoyment of nature.¹³³
- A plush and healthy lawn offers a great place for family and friends to spend time together. Without weed control the turf is gradually destroyed by invasive species such as dandelion and ragweed, a common allergen.¹³⁴
- Pests are much less likely to breed in well-maintained lawns. Mowing the lawn reduces the presence of pests such as snakes, mosquitoes, rodents, ticks, and chiggers.^{135 136}
- In regard to sports and the playing field, 90% of National Football League players prefer natural turf, because it is softer and thus reduces injuries by cushioning falls.¹³⁷
- According to the National Turfgrass Research Initiative 25% of injuries in high school sports are related to the playing surface.¹³⁸
- In a study of 12 Pennsylvania high school football programs 21% of injuries were classified as either definitely or possibly field related.¹³⁹
- Soils in natural grass fields contain helpful bacteria which naturally sanitize the surface by decomposing human body fluids, algae and animal excretions.¹⁴⁰
- In a Chinese study, it was determined that cohesion among the different landscape aspects was the most important factor in determining recreational suitability of park green spaces. There is a

¹³¹ Amanda Jane Kobelt, Paul H. Hemsworth, John L. Barnett, Grahame J. Coleman, Kym L. Butler, The behaviour of Labrador retrievers in suburban backyards: The relationships between the backyard environment and dog behaviour, Applied Animal Behaviour Science, Volume 106, Issues 1–3, 2007, Pages 70-84, ISSN 0168-1591. <https://www.sciencedirect.com/science/article/abs/pii/S0168159106002681>

¹³² Beard, James B. The Environmental Protection and Beneficial Contribution of Golf Course Turfs. International Sports Turf Institute, 1994. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.529.8868&rep=rep1&type=pdf>

¹³³ LI, Z., C. XIE, H. LU, and S. CHE. 2019. "Rational Planning of Public Open Space by Exploring the Effects of Environmental Factors on Human Recreation - a Case Study in Shanghai, China." Applied Ecology & Environmental Research 17 (1): 1247–60. <https://www.semanticscholar.org/paper/RATIONAL-PLANNING-OF-PUBLIC-OPEN-SPACE-BY-EXPLORING-Li-Xie/ce8c9d756356495d55a5368c2f02e63455c73170>

¹³⁴ Beard, J.B and R. Green. The Role of Turfgrasses in Environmental Protection and Their Benefits to Humans. <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x>

¹³⁵ Clopton, R.E., and R.E. Gold. 1993. Distribution, seasonal and diurnal activity patterns of Eutrombicula alfreddugesi in a forest edge ecosystem. J. Med. Entomol. 30:47-53. <https://pubmed.ncbi.nlm.nih.gov/8433345/>

¹³⁶ Beard, James B. The Environmental Protection and Beneficial Contribution of Golf Course Turfs. International Sports Turf Institute, 1994. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.529.8868&rep=rep1&type=pdf>

¹³⁷ The Turf Resource Center

¹³⁸ Gramckow, J. 1968. Athletic field quality studies. Cal-Turf Inc., Camarillo, CA.

¹³⁹ Harper, J.C., C.A. Morehouse, D.V. Waddington, and W.E. Buckley. 1984. Turf management, athletic field conditions, and injuries in high school football. Pennsylvania Agric. Exp. Stn. Prog. Rep. 384. University Park. <https://extension.psu.edu/turf-management-athletic-field-conditions-and-injuries-in-high-school-football>

¹⁴⁰ Synthetic Turf Playing Fields Present Unique Dangers, Applied Turfgrass Science, November 3, 2005. <http://safesportsfields.cals.cornell.edu/book/export/html/162>

positive correlation between leisure activities like walking and the attractiveness of the surrounding area.¹⁴¹

- In inner-cities, community members are more likely to take use of common areas if there are grass and trees present. This promotes social interactions and community ties.¹⁴²
- Community members are more likely to recreationally walk on streets that are aesthetically pleasing and in order. Lawn disorder such as dying grass, weeds, or rusted fences dissuades recreational walkers, especially among children.¹⁴³
- In a study about schoolyards, young students identified large lawns and trees as important in their satisfaction of play.¹⁴⁴

Noise Abatement

- Turf planted on the banks of a lowered expressway reduces traffic noise twice as much as paving on the same bank.¹⁴⁵
- Turf planted beside lowered expressways reduce noise by 8-10 decibels.¹⁴⁶
- A healthy turf absorbs sound, thus reducing noise levels by 30 to 40 percent.^{147 148}
- Using turf instead of concrete on road embankments can reduce traffic noise by nearly 200 percent.¹⁴⁹
- A study in Seoul, South Korea demonstrated that trees planted along a road made it easier to hear conversations, and as the trees grew, the ease to communicate increased.¹⁵⁰
- Plants like hedges that line a road can redirect wind that carries sound waves, making road noise appear quieter.¹⁵¹
- Through the process of 'psychological noise reduction,' an individual emotionally believes that landscape plants reduce noise along roads, therefore their minds actually make them perceive a lesser noise volume when in the presence of landscape plants along a road. The simple visual of landscape plants along a road can serve as noise abatement.¹⁵²

¹⁴¹ Hua Zhang, Bo Chen, Zhi Sun, Zhiyi Bao, Landscape perception and recreation needs in urban green space in Fuyang, Hangzhou, China, *Urban Forestry & Urban Greening*, Volume 12, Issue 1, 2013, Pages 44-52, ISSN 1618-8667.

<https://www.sciencedirect.com/science/article/abs/pii/S161886671200115X>

¹⁴² Angelia Sia, Ee Heok Kua and Roger Ho, Building Social Resilience Through Parks and Common Recreational Spaces, *Building Resilient Neighbourhoods in Singapore*, 10.1007/978-981-13-7048-9_4, (51-62), (2019). https://link.springer.com/chapter/10.1007/978-981-13-7048-9_4

¹⁴³ Jack L. Nasar, Christopher Holloman, Dina Abdulkarim, Street characteristics to encourage children to walk, *Transportation Research Part A: Policy and Practice*, Volume 72, 2015, Pages 62-70, ISSN 0965-8564. <https://ideas.repec.org/a/eee/transa/v72y2015icp62-70.html>

¹⁴⁴ Aydin Ozdemir, Oguz Yilmaz, Assessment of outdoor school environments and physical activity in Ankara's primary schools, *Journal of Environmental Psychology*, Volume 28, Issue 3, 2008, Pages 287-300, ISSN 0272-4944.

https://www.researchgate.net/publication/223309618_Assessment_of_outdoor_school_environments_and_physical_activity_in_Ankara's_primary_schools

¹⁴⁵ 1996. Maryland Turfgrass Survey. An Economic Value Study. Institute of Applied Agriculture. University of Maryland, College Park.

¹⁴⁶ Professional Lawn Care Association and American Honda Motor Co., Inc.

¹⁴⁷ Robinette, G.O. 1972. Plants, people, and environmental quality. U.S. Dep. Interior, National Park Service, and Am. Soc.

¹⁴⁸ Cook, D.I., and D.F. Van Haverbeke. 1971. Trees and shrubs for noise abatement. Nebraska Agric. Exp. Stn. Res. Bull. 246, Lincoln.

¹⁴⁹ Streich, A., Rodie, S. and Gaussion, R. 2003. Turf in the Landscape. University of Nebraska – Lincoln Extension, Institute of Agriculture and Natural Resources. <https://digitalcommons.unl.edu/extensionhist/1720/>

¹⁵⁰ Kim, Yong Hee, et al. "Effects of Vegetation on Soundscape of an Urban Religious Precinct: Case Study of Myeong-Dong Cathedral in Seoul." *Building and Environment*, vol. 155, May 2019, pp. 389–398. EBSCOhost, doi:10.1016/j.buildenv.2019.03.046.

<https://www.semanticscholar.org/paper/Effects-of-vegetation-on-soundscape-of-an-urban-of-Kim-Hwang/8a010b47469a90d6d4b10930a497eba49e095d33>

¹⁵¹ Van Renterghem, Timothy, et al. "Measured Light Vehicle Noise Reduction by Hedges." *Applied Acoustics*, vol. 78, Apr. 2014, pp. 19–27. EBSCOhost, doi:10.1016/j.apacoust.2013.10.011. <https://core.ac.uk/download/pdf/30271161.pdf>

¹⁵² Yang, F.; Bao, Z.Y.; Zhu, Z.J. An Assessment of Psychological Noise Reduction by Landscape Plants. *Int. J. Environ. Res. Public Health* 2011, 8, 1032-1048. [https://pubmed.ncbi.nlm.nih.gov/21695027/#:~:text=Two%20videos%20\(showing%20a%20traffic,40%20participants%20on%20video%20glass.es.&text=These%20findings%20indicate%20that%20landscape,term%20'psychological%20noise%20reduction'](https://pubmed.ncbi.nlm.nih.gov/21695027/#:~:text=Two%20videos%20(showing%20a%20traffic,40%20participants%20on%20video%20glass.es.&text=These%20findings%20indicate%20that%20landscape,term%20'psychological%20noise%20reduction')

- By using a wall of trees along a road, noise levels can be reduced by half, and are more effective when paired with soft materials like grass as opposed to pavement.¹⁵³
- Plants reduce noise in through three different methods: bouncing lesser sound waves off itself (diffusion), absorption into the plant, and allowing lesser sound waves to pass through the plant (reduction).¹⁵⁴
- Gathering of tall, dense trees can, when paired with soft ground coverings, reduce noise by 50% or more.¹⁵⁵

Crime Reduction/Safety

- A number of studies have found that greenery is associated with a greater sense of safety, fewer incivilities, and less aggressive and violent behavior. Greenery helps to abate irritability, impulsivity, and cognitive deficits associated with mental fatigue, thus preventing minor conflicts from spiraling out of control and becoming violent. In turn, crime is reduced. In a large public housing development in Chicago buildings with high levels of vegetation had 52% fewer total crimes, 48% fewer property crimes and 56% fewer violent crimes.¹⁵⁶
- Residential greenery is associated with a greater sense of safety.¹⁵⁷
- Landscaping can be used as a defense mechanism to keep homes safe from burglary and break-ins. For example, “barrier plants” that are sharp can be placed under windows to deter unwelcome entrance. Rocks can be used to line a house instead of wood chips or mulch so anybody walking around can be heard.¹⁵⁸
- According to a study, aspects of landscaping such as having a garden hose, a tree in the yard, shrubs, and lawns had a negative correlation with nearby crime. However, aspects of lawn care neglect such as trash in the yard, dying grass, or a lack of mowing had a positive correlation with nearby crime. Well-landscaped neighborhoods increase the number of community members outside, increasing potential eye-witnesses to crime, thus reducing the likelihood of crime committed.¹⁵⁹
- Well kept landscaping in public areas gives community members a greater sense of security and reduced fear of crime because it clearly portrays a message that the area is well-looked after and cared for. Additionally, maintaining visibility (not too many trees or tall weeds) promotes feelings of safety in public areas.¹⁶⁰
- Tree density is positively associated with a sense of safety in inner-city communities.¹⁶¹
- A study in Canada found that landscape enhancements on roads decreased the number of crashes by 5%-20%. A study in Texas looked at crash rates before landscaping efforts on roads and

¹⁵³ Cook, David I. and Van Haverbeke, David F. (1971) Trees and shrubs for noise abatement (Research Bulletin No. 246)

¹⁵⁴ Veisten, K.; Smyrnova, Y.; Klæboe, R.; Hornikx, M.; Mosslemi, M.; Kang, J. Valuation of Green Walls and Green Roofs as Soundscape Measures: Including Monetised Amenity Values Together with Noise-attenuation Values in a Cost-benefit Analysis of a Green Wall Affecting Courtyards. *Int. J. Environ. Res. Public Health* 2012, 9, 3770-3788. <https://pubmed.ncbi.nlm.nih.gov/23202816/>

¹⁵⁵ F. Dwyer, John & Mcpherson, E & Schroeder, Herbert & A. Rowntree, Rowan. (1992). Assessing the benefits and costs of the urban forest. *J. Arbor.* https://www.fs.fed.us/psw/publications/mcpherson/psw_1992_mcpherson002.pdf

¹⁵⁶ Kuo, F.E. and W. Sullivan. Environment and Crime in the Inner City: Does Vegetation Reduce Crime?. University of Illinois Human-Environment Research Laboratory. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.644.9399&rep=rep1&type=pdf#:~:text=Although%20buildings%20with%20high%20levels,differences%20were%20not%20statistically%20significant.>

¹⁵⁷ Brower, S., Dockett, >, & Taylor, R.B. 1983. Residents’ perceptions of territorial features and perceived local threat. *Environment and Behavior*, 15, 419-437. <https://journals.sagepub.com/doi/10.1177/0013916583154002>

¹⁵⁸ “Landscaping & Crime Prevention.” Landscaping & Crime Prevention | Springfield, MO - Official Website.

¹⁵⁹ Troy, Austin, et al. “The Relationship between Residential Yard Management and Neighborhood Crime: An Analysis from Baltimore City and County.” Elsevier, 2015. <https://www.fs.usda.gov/treearch/pubs/50236>

¹⁶⁰ Wolf, Kathleen. “Crime & Public Safety.” *Crime and Public Safety :: Green Cities: Good Health*, 2010. https://depts.washington.edu/hhwb/Thm_Crime.html

¹⁶¹ Kuo, F. E., Bacaicoa, M., & Sullivan, W. C. (1998). Transforming Inner-City Landscapes: Trees, Sense of Safety, and Preference. *Environment and Behavior*, 30(1), 28–59. <https://journals.sagepub.com/doi/10.1177/0013916598301002>

afterwards over three to five years. They found that there were fewer crashes after the roadside landscape was improved.¹⁶²

Psychological and Physiological Benefits

- Dense lawns typically are void of the many weedy species that often produce allergy-related pollens. Most turfgrasses that are mowed regularly at a low height tend to remain vegetative with minimal floral development, and thus have reduced pollen production.¹⁶³
- Studies have shown that hospital patients with a view of natural green space recover faster.¹⁶⁴
- Lawn care offers individuals a source of exercise and a healthy mental diversion from the stresses of life. Weeding burns 300 calories per hour and mowing the lawn with a manual push mower burns 500 calories per hour.^{165 166 167 168}
- Children function better than usual after activities in green settings that the greener a child's play area, the less severe his or her attention deficit symptoms.¹⁶⁹
- Attention Restoration Theory suggests that natural environments assist in recovery from directed attention fatigue in part because they draw on involuntary attention rather than directed attention.¹⁷⁰
- Exposure to greenery aids in lowering blood pressure, reducing muscle tension related to stress, and improving attention.¹⁷¹
- Contact with nature is systematically linked with enhanced cognitive functioning as measured by self-report and performance on objective tests.¹⁷²
- In a study conducted in a Chicago public housing development, girls who lived in apartments with greener, more natural views scored better on tests of self-discipline than those living in more barren but otherwise identical housing.¹⁷³
- In general girls exposed to greenery are better able to handle peer and sexual pressure and tend to perform better in school.¹⁷⁴

¹⁶² Dixon, K. K., and K. L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, WA). Washington D.C.: Transportation Research Board of the National Academies of Science. https://nacto.org/docs/usdg/benefits_and_risks_of_an_urban_roadside_landscape_dixon.pdf

¹⁶³ Beard, J.B., and R.L. Green. 1994. The role of turfgrass in environmental protection and their benefits to humans. *J. Environ. Qual.* 23:452-460.

<https://access.onlinelibrary.wiley.com/doi/abs/10.2134/ieq1994.00472425002300030007x#:~:text=Specific%20functional%20benefits%20include%3A%20excellent,improvement%20that%20includes%20CO2>

¹⁶⁴ Ulrich, R.S. 1984. View through a window may influence recovery from surgery. *Science*. (Washington, DC) 224:420-421.

<https://pubmed.ncbi.nlm.nih.gov/6143402/>

¹⁶⁵ Pest Facts News, Summer 2005. Rise.

¹⁶⁶ Kaplan, R. and S. Kaplan. 1989. *The experience of nature*. Cambridge Univ. Press, New York.

[https://www.hse.ru/data/2019/03/04/1196348207/%5BRachel_Kaplan,_Stephen_Kaplan%5D_The_Experience_of_\(b-ok.xyz\).pdf](https://www.hse.ru/data/2019/03/04/1196348207/%5BRachel_Kaplan,_Stephen_Kaplan%5D_The_Experience_of_(b-ok.xyz).pdf)

¹⁶⁷ Soldier in Iraq

¹⁶⁸ Simson, Sharon Pastor. *Horticulture as Therapy: Principles and Practice*. Food Products Press, 2007.

<https://www.routledge.com/Horticulture-as-Therapy-Principles-and-Practice/Simson-Straus/p/book/9781560222798>

¹⁶⁹ "Coping with ADD: The Surprising Connection to Green Play Settings", Andrea Faber Taylor, Frances E. Kuo and William C. Sullivan, University of Illinois Human-Environment Research Laboratory. <https://journals.sagepub.com/doi/10.1177/00139160121972864>

¹⁷⁰ Kaplan, S. 1995. The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, 15, 169-182.

<https://www.sciencedirect.com/science/article/abs/pii/S0272494495900012>

¹⁷¹ Grower Talks. <http://growertalks.com/archive/articles/1384.asp>

¹⁷² Canin, L. H. 1991. Psychological restoration among AIDS caregivers: Maintaining self-care. Unpublished doctoral dissertation, University of Michigan. <https://deepblue.lib.umich.edu/handle/2027.42/128799>

¹⁷³ Faber Taylor, A., Kuo, F.E., & Sullivan, W.C. (2002). "Views of Nature and Self-Discipline: Evidence from Inner City Children." *Journal of Environmental Psychology*, 22, 49-63. <https://www.sciencedirect.com/science/article/abs/pii/S0272494401902415>

¹⁷⁴ Consumer and Environmental Sciences: Girls and Greenery. College of Agriculture. University of Illinois at Urbana-Champaign. http://lhlh.illinois.edu/ppt_girls.htm

- Exposure to nature in the workplace can improve productivity, efficiency, and creativity. Exposure to landscaping such as gardening can improve symptoms among dementia and alzheimers patients. Additionally, outdoor spaces can lower stress and also provide a space for exercise, both of which reduce symptoms of mental disorders like depression. Outdoor areas even improve cognitive ability of those who have recently been diagnosed with breast cancer.¹⁷⁵
- There is a correlation between green spaces and both muscle strengthening and prevention of bodily aches and pains. It has been found that stress has less of an effect on individuals who have their own gardens.¹⁷⁶
- Horticulture therapy is a type of therapy that can strengthen body and mind through garden work. In one study, after viewing nature, individuals recovered from stress in four to six minutes. Prisoners who had a view of nature from their cells reported sick calls less frequently and also exhibited fewer signs of stress.¹⁷⁷
- The ability to see green spaces from the home is associated with a decrease in severity and frequency for cravings of addictive substances such as alcohol, cigarettes, and some foods.¹⁷⁸
- A well-mowed lawn provides a less desirable environment for ticks that carry Lyme disease, which prefer longer, uncut grass.¹⁷⁹

Economic Opportunities

- Homes with appealing lawns and landscaping can increase property value by 15 to 20%.¹⁸⁰
- According to a study of three neighborhoods in Boulder, Colorado, property values decrease by \$4.20 for each foot that properties sits away from a “greenbelt”.¹⁸¹
- Turfgrass provides economic opportunities for the millions of people it employs at lawn care companies, athletic and park facilities, golf courses, highway departments, sod and seed producers, turf maintenance equipment manufacturers, and fertilizer suppliers.¹⁸²
- It is estimated that more than 500,000 people make their living directly from the care and maintenance of turf.¹⁸³
- In Michigan alone business regarding turfgrass contributes at least \$1.86 billion dollars to the economy.¹⁸⁴
- In New York State the turfgrass industry contributes \$5 billion dollars to the economy in turf maintenance expenses.¹⁸⁵

¹⁷⁵ Wolf, Kathleen. “Mental Health & Function.” *Mental Health :: Green Cities: Good Health*, University of Washington, 2010, https://depts.washington.edu/hhw/Thm_Mental.html

¹⁷⁶ Nilsson, Kjell. *Forests, Trees, and Human Health*. Springer Verlag, 2011. <https://link.springer.com/book/10.1007/978-90-481-9806-1>

¹⁷⁷ Simson, Sharon Pastor. *Horticulture as Therapy: Principles and Practice*. Food Products Press, 2007.

<https://www.routledge.com/Horticulture-as-Therapy-Principles-and-Practice/Simson-Straus/p/book/9781560222798>

¹⁷⁸ Martin, Leanne. “Using Natural Environments to Reduce Craving: Affective and Cognitive Mechanisms.” *UK Research and Innovation, University of Plymouth*, 2019, <https://gtr.ukri.org/projects?ref=studentship-1946248>

¹⁷⁹ Beard, James B. *The Environmental Protection and Beneficial Contribution of Golf Course Turfs*. International Sports Turf Institute, 1994. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.529.8868&rep=rep1&type=pdf>

¹⁸⁰ “April is the Month to Celebrate Lawns and Landscapes”. *Lawn and Landscape Magazine*.

¹⁸¹ The Urban Institute: *The Public Value of Urban Parks* <https://www.urban.org/research/publication/public-value-urban-parks>

¹⁸² Beard, J.B., and R.L. Green. 1994. The role of turfgrass in environmental protection and its benefits to humans. *Journal of Environmental Quality* 23(3):452-460.

<https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x#:~:text=Specific%20functional%20benefits%20includ%2e%3A%20excellent,improvement%20that%20includes%20CO2>

¹⁸³ 1996 Maryland Turfgrass Survey. *An Economic Value Study*. Institute of Applied Agriculture. University of Maryland, College Park.

¹⁸⁴ 2002 Michigan Agricultural Statistics Service survey, Michigan Department of Agriculture

https://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/Annual_Statistical_Bulletin/stats03/agstat03.pdf

¹⁸⁵ 2005. The New York Turfgrass Survey. New York State Turfgrass Association, Inc. <http://www.nysta.org/>

- A green environment improves worker productivity.¹⁸⁶
- By creating and properly caring for a quality lawn area, a homeowner can possibly realize a 10% to 15% increase in property value from a well-maintained lawn and landscape.¹⁸⁷
- A study by Clemson University and the University of Michigan found that consumers value a landscaped home up to 11.3% higher than its base price. A Quebec survey found that hedges raised property values by 3.6%, a landscaped curb by 4.4%, and a landscaped patio by 12.4%.¹⁸⁸
- Real estate professionals credit 7% of a home's value to having a beautiful landscape. According to a study taking place at Opryland Hotel, a location with 12 acres of indoor area and 18,000 plants, rooms that overlook the gardens sell for an additional thirty dollars per night and are booked more frequently. This higher room fee is responsible for an extra seven million dollars in revenue for the hotel each year.¹⁸⁹
- Office rentals are positively impacted by landscaping with trees that give shade, benefitting rates by about 7%.¹⁹⁰
- Strategically planted trees on a property can save a homeowner money from heating and air conditioning costs. A study in Wisconsin revealed that strategic, energy efficient planting around a home had annual heating and air conditioning costs of \$671, while no trees increased this to cost to \$700, and tree planting that blocked winter sunlight and offered little shade increased costs to \$769.¹⁹¹
- Landscaping and groundskeeping employed 912,360 workers as of 2017. The average hourly wage for landscapers and groundskeepers in 2017 was \$14.28, which is close to double the federal minimum wage.¹⁹²
- Landscaping is a \$53 billion dollar industry, supporting close to 300,000 businesses. It creates more than \$19 billion in wages.¹⁹³
- Gardeners estimate that replacing leaf blowers with rakes and brooms would make leaf removal two to three times longer. Landscaping companies could hire more workers to remain efficient, but this would heavily increase the cost of hiring a company. In order to keep company costs low, a gardener estimated that he would lose \$250 of his salary each month if leaf blowers were to be banned.¹⁹⁴

¹⁸⁶ Beard, J.B., and R.L. Green. 1994. The role of turfgrass in environmental protection and their benefits to humans. <https://access.onlinelibrary.wiley.com/doi/abs/10.2134/jeq1994.00472425002300030007x#:~:text=Specific%20functional%20benefits%20include%3A%20excellent,improvement%20that%20includes%20CO2>

¹⁸⁷ The Lawn Institute <https://www.thelawninstitute.org/>

¹⁸⁸ National Gardening Association, 1998- 1999. National Gardening Survey. <https://garden.org/>

¹⁸⁹ Simson, Sharon Pastor. Horticulture as Therapy: Principles and Practice. Food Products Press, 2007. <https://www.routledge.com/Horticulture-as-Therapy-Principles-and-Practice/Simson-Straus/p/book/9781560222798>

¹⁹⁰ Roberts, Laverne J, and Kimberly Winson-Geideman. "The Influence of Trees and Landscaping on Rental Rates at Office Buildings." Actrees, Journal of Arboriculture, Sept. 2003, http://www.actrees.org/files/Research/laverne_trees_and_rent.pdf

¹⁹¹ F. Dwyer, John & Mcpherson, E & Schroeder, Herbert & A. Rowntree, Rowan. (1992). Assessing the benefits and costs of the urban forest. J. Arbor. https://www.fs.fed.us/psw/publications/mcpherson/psw_1992_mcpherson002.pdf

¹⁹² "37-3011 Landscaping and Groundskeeping Workers." U.S. Bureau of Labor Statistics, U.S. Bureau of Labor Statistics, 30 Mar. 2018, <https://www.bls.gov/oes/current/oes373011.htm>

¹⁹³ Cafaro, Philip. How Many Is Too Many?: the Progressive Argument for Reducing Immigration into the United States. University of Chicago Press, 2015. <https://press.uchicago.edu/ucp/books/book/chicago/H/bo19211770.html>

¹⁹⁴ Cameron, Christopher David Ruiz. "The Rakes of Wrath: Urban Agricultural Workers and the Struggle against Los Angeles's Ban on Gas-Powered Leaf Blowers." U.C. Davis Law Review, vol. 33, no. 4, Summer 2000, pp. 1087-1104. HeinOnline, <https://heinonline.org/HOL/LandingPage?handle=hein.journals/davlr33&div=39&id=&page=>

Child Development

- Greenness of a neighborhood is associated with lower BMI scores in children. Additionally, the greener a neighborhood is, the less likely a child's BMI is to rise over a two year period.¹⁹⁵
- A study of an inner-city community in Texas found that landscape design and number of tree patches were negatively associated with BMI scores among Hispanic children.¹⁹⁶
- Well-designed landscape in schoolyards can contribute to the development of self-esteem among children. The landscaping and size of school yards is negatively associated with the BMI of students, and students are more satisfied by school yards with vegetation and well-maintained landscapes. *The Journal of Environmental Psychology* suggests that size of school yards and landscaping can play a role in schoolyard bullying.¹⁹⁷
- Children making use of outdoor play areas can help develop gross motor skills. Playing in nature can also help with cognitive and affective development and shape attitudes towards the environment later in life.¹⁹⁸

¹⁹⁵ Janice F. Bell, Jeffrey S. Wilson, Gilbert C. Liu, Neighborhood Greenness and 2-Year Changes in Body Mass Index of Children and Youth, *American Journal of Preventive Medicine*, Volume 35, Issue 6, 2008, Pages 547-553, ISSN 0749-3797.

<https://pubmed.ncbi.nlm.nih.gov/19000844/>

¹⁹⁶ Jun-Hyun Kim, Chanam Lee, Norma E. Olvera, and Christopher D. Ellis, The Role of Landscape Spatial Patterns on Obesity in Hispanic Children Residing in Inner-City Neighborhoods, *Journal of Physical Activity and Health* 2014 11:8, 1449-1457

<https://pubmed.ncbi.nlm.nih.gov/24384497/>

¹⁹⁷ Aydin Ozdemir, Oguz Yilmaz, Assessment of outdoor school environments and physical activity in Ankara's primary schools, *Journal of Environmental Psychology*, Volume 28, Issue 3, 2008, Pages 287-300, ISSN 0272-4944.

https://www.researchgate.net/publication/223309618_Assessment_of_outdoor_school_environments_and_physical_activity_in_Ankara's_primary_schools

¹⁹⁸ Acar, Habibe. "Landscape Design for Children and Their Environments in Urban Context." InTech, 2013,

https://cdn.intechopen.com/pdfs/45427/InTechLandscape_design_for_children_and_their_environments_in_urban_context.pdf.