Costs and Availabilities of Maintenance Resources

1. Water

1.1 Golf Course Irrigation

The estimated 15,386 golf facilities in the U.S.A. (Gelernter et al. 2015) represent 0.08 to 0.10% (1.7 to 2 million acres, respectively) of U.S.A. land use (Theobald, 2014; Merrill and Leatherby, 2018; Bigelow and Borchers, 2012). Although rainwater is the preferred irrigation source for golf facilities, it rarely falls in an amount and frequency that is ideal for management. As such, every golf course requires some form of supplemental irrigation (Hartwiger, 2013) for the estimated 80.2 irrigated acres per 18-hole facility on average in the U.S.A (Gelernter et al. 2015).

Some golf courses have only one source of water to fulfill supplemental needs, whereas others have access to multiple water sources. As of the latest estimate in 2013, golf courses in the U.S.A. used approximately 1.859 million acre-ft of irrigation water with diverse sources and strategies to meet annual supplemental needs (Gelernter et al., 2015). On average, 15% of golf courses in the U.S.A irrigate with municipal drinking water, 15.3% irrigate with recycled wastewater, 48% irrigate with groundwater from wells, and 75.5% irrigate with surface waters such as lakes and ponds (51.9%), canals (3.6%), or rivers, streams, and creeks (20%) (Gelernter et al. 2015). The use of recycled wastewater has increased 4.4% in the U.S.A. since 2005, mostly in the Southwest, Southeast, and Pacific regions. Use of water from all other sources has decreased since 2005. Water scarcity, cost, and regulations vary by water source and by region, so it is important to understand the origins of water used to irrigate golf courses.

1.2 Scarcity

According to the United Nations, global water use will continue to increase by approximately 1% annually until 2050 (Uhlenbrook and Connor, 2019). In 2012, the U.S. intelligence community projected that freshwater availability would not meet the demands for food and energy production in many countries by 2040, hindering global food markets and economic growth, especially in North Africa, the Middle East, and South Asia (Kojm et al., 2012). Although global agriculture will continue to be the highest consuming sector of water for decades to come, industrial and domestic sectors are expected to have greater relative increases in water use over the next 30 years, especially in developing regions of the world. It’s currently estimated that industry accounts for 19% of the world’s water use (Uhlenbrook and Connor, 2019), 75% of which is used for energy production (United Nations, n.d.).

As population growth increases global water use, other factors such as climate change will disproportionally strain water resources (Uhlenbrook and Connor, 2019). It’s expected that regions with high relative precipitation rates will receive even more precipitation, but regions with lower relative precipitation rates will receive less. Approximately the eastern third of the U.S.A. is expected to see a 0.1 to 0.5 mm increase in daily net precipitation from 2010 to 2050. A similar trend is expected in the western U.S.A., with some areas expected to receive more than a 0.5 mm per day increase in daily net precipitation. The central third of the country and most of Alaska, however, are projected to receive 0.1 fewer mm to 0.1 more mm of daily net precipitation over the same timeframe. South and eastern Texas appear to have the worst outlook relative to current precipitation in the U.S.A., with a projected decrease in net precipitation of 0.1 to 0.5 mm per day.

In Europe, most of the United Kingdom and Ireland are expected to see a 0.1 to 0.5 mm increase in daily net precipitation from 2010 to 2050, but the majority of western European countries are projected to receive 0.1 fewer mm to 0.1 more mm of daily net precipitation over the same timeframe (Uhlenbrook and Connor, 2019). Portugal, Spain, parts of Italy, and the majority of eastern Europe have a projected decrease in net precipitation of 0.1 to 0.5 mm per day. Most of Japan is expected to receive 0.1 fewer mm to 0.1 more mm of daily net precipitation. However, the southeastern portion of the country that includes Tokyo has a projected decrease in net precipitation of 0.1 to 0.5 mm per day. The majority of Australia and South Africa can expect similar changes in daily net precipitation as Tokyo, but an isolated area surrounding Brisbane, Australia is projected to receive at least 0.5 fewer mm of daily net precipitation from 2010 to 2050.

The collective strain on the world's water resources will necessitate innovations to store, transport, and use fresh water more efficiently, to source or produce freshwater in unconventional ways and with emerging technologies, and to continue to develop and adopt plant materials that can fulfill their utility with less or poorer-quality water than ever before in history. New technologies will contribute to the cost and supply of freshwater in the future, potentially replacing current water treatment strategies and even non-potable, recycled wastewater used to irrigate many golf courses. For example, zero-liquid discharge is increasingly being adopted by industries and municipalities. The Padre Dam Municipal Water District in Santee, CA is seeking $350 million of federal support for infrastructure to purify recycled water from east San Diego county and produce approximately 30% of the area's drinking water (Jennewein, 2019). The current high cost and energy requirements for zero-liquid discharge treatment preclude large-scale adoption and replacement of conventional wastewater treatment or disposal, but regulatory incentives and increasing strain on freshwater resources may eventually favor zero-liquid discharge (Tong and Elimelech, 2016) and other emerging technologies.

1.3 Cost

Droughts directly affect the cost and availability of water, and the United Nations estimates that drought causes $5.4 billion of economic damage annually (Uhlenbrook and Connor, 2019). Comparatively, this figure is nearly one-fifth the size of the annual economic damages from flooding ($31.4 billion) or earthquakes and other epidemics ($30 billion). The relatively low cost of water worldwide breeds consumers that perhaps are not highly motivated to adopt conservation strategies and technologies, leading to modest water prices in developed countries that range from $0.60 to more than $3.00 per cubic meter for industrial and domestic use and $0.10 per cubic meter for agricultural use (Kojm et al., 2012).

The future price of water is difficult to predict. No governmental organization projects these costs and, because infrastructure improvements and not commodity prices determine diverse price escalations among water providers, forecasts are best determined by local utilities (FEMP, 2017). Gasson (2017) explains that water utility services are funded by consumer tariffs, taxpayer subsidies, or by depreciating assets. Depreciating assets are a large contributor to the complexity of pricing water, but the process is necessary since most operational costs for a water utility are related to infrastructure maintenance.

Still, some have attempted to document water pricing trends in the golf course management industry. A survey reporting median costs of U.S.A. water sources in 2013 revealed that municipal drinking water was the most expensive water source available for golf course irrigation ($1,329.20 per acre-foot)

(Gelernter et al., 2015). The median cost of municipal water was followed by recycled wastewater ($320.70 per acre-foot), canal water ($78.80 per acre-foot), well water ($76.70 per acre-foot), water from lakes and ponds ($64.10 per acre-foot), and river water ($47.80 per acre-foot). Based on statistical analysis and comparison of these water pricing rates to rates reported in 2005, only municipal and wastewater rates increased from 2005 to 2013.

Averaged over sources, Gelernter et al. (2015) also reported median 2013 water costs per U.S.A. region. The Pacific region had the greatest median water costs ($1,340.30 per acre-foot), followed by the transition region ($689.80 per acre-foot), the Northeast ($666.80 per acre-foot), the Southwest ($424.80 per acre-foot), the Southeast ($225.90 per acre-foot), the Upper West/Mountain region ($199.40 per acre-foot), and the Northcentral region ($40.00 per acre-foot). Compared to rates reported in 2005, average water rates have increased for the U.S.A. and for all stratified regions except the Northcentral and Upper West/Mountain regions.

Gelernter et al. (2015) did not report median water costs for each source by region, but their municipal and wastewater costs are comparable to 2016 data from the U.S. Department of Energy's Federal Energy Management Program (FEMP, 2017). The FEMP analyzed eight years of data (2008-2016) from 60 water and 40 wastewater utilities to determine annual price escalation rates. The data, reported as 2016 U.S. dollars, show municipal water rates from $1.00 per 1,000 gallons ($325.85 per acre-foot) in Rochester, MN to $8.00 per 1,000 gallons ($2,606.81 per acre-foot) in Lubbock, TX and wastewater rates from less than $2.00 per 1,000 gallons ($651.70 per acre-foot) in Oakland, CA to $18.00 per 1,000 gallons ($5,865.33 per acre-foot) in Seattle, WA.

Averaged over water utilities, FEMP (2017) determined that municipal water rates increased 40% from $2.44 per 1,000 gallons ($795.08 per acre-foot) in 2008 to $3.38 per 1,000 gallons ($1,101.38 per acre-foot) in 2016, an average annual price escalation of 4.1%. Because factors such as annual precipitation and technological innovations will affect pricing in the future, extrapolating this annual price escalation to project future costs is inappropriate. Still, the estimate would at least provide a starting point for consideration. Therefore, assuming an average annual price escalation of 4.8% nationwide, municipal water rates would average $4.91 per 1,000 gallons ($1,599.11 per acre-foot) in 2029 and $7.26 per 1,000 gallons ($2,364.86 per acre-foot) in 2049 (in 2016 U.S. dollars) (Figure 1).

Averaged over wastewater utilities, wastewater rates increased 24% from $3.82 per 1,000 gallons ($1,244.75 per acre-foot) in 2008 to $4.73 per 1,000 gallons ($1,541.28 per acre-foot) in 2016, an average annual price escalation of 3.3%. Some cities had annual water and wastewater price escalations as high as 16.65 or 9.99%, respectively, whereas others experience slight annual decreases in water and wastewater prices. Assuming an average annual price escalation of 2.9% nationwide, wastewater rates would average $6.21 per 1,000 gallons ($2,023.13 per acre-foot) in 2029 and $8.48 per 1,000 gallons ($2,764.44 per acre-foot) in 2049 (in 2016 U.S. dollars) (Figure 1).

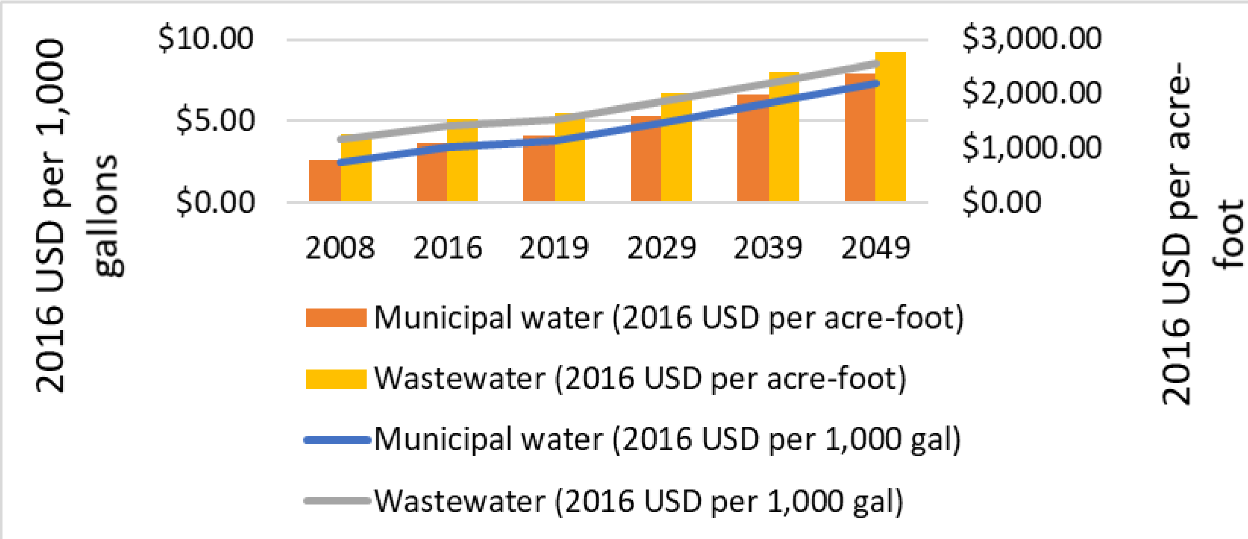

Figure 1 A scenario for the average price of municipal water and wastewater in the U.S. Projections out to 2049 assume a fixed annual price escalation of 4.8% for municipal water and 2.9% for wastewater (FEMP, 2017). This scenario is only a starting point, and does not account for numerous factors that will likely affect the future cost of water and wastewater (e.g. annual precipitation, innovation, etc.).

1.4 Regulatory and Humanitarian Concerns

In the U.S.A., state law allocates water resources (NALC, n.d.). Surface waters are allocated based on land ownership adjacent to the water resource (riparianism, generally in the Eastern U.S.A.), based on order of first use (prior appropriation, generally in the Western U.S.A.), or a combination of the systems. Groundwater is regulated differently based on land ownership. Some systems do not regulate a landowner's use of groundwater, whereas others follow prior appropriation or evenly allocate groundwater to all landowners over an aquifer. In general, groundwater allocations favor on-tract over off-tract water use. Golf facilities that use municipal water follow regulations and pricing from a municipal water district.

Water is increasingly regulated for golf facilities in the U.S.A. The previously cited work from Gelernter et al. (2015) reported that 55% of surveyed golf facilities were subject to water-use reporting requirements in 2013 – up 6.6% since 2005. Similarly, 30.3% of golf facilities reported recurring annual water allocations – up 8.6% since 2005.

The Environmental Protection Agency (EPA) enforces federal clean water and safe drinking laws in the United States (EPA, n.d.).

2. Labour

2.1 Scarcity

Affordable labour is a diminishing resource in advanced economies, which already is affecting golf courses. As unemployment rates fall, wages increase and it becomes more difficult for businesses to fulfill staffing needs (Kupelian, 2019). The U.S.A. unemployment rate is currently 3.6% (BLS, 2019b) and is expected to continue to decline as employment grows by a projected 0.5% annually to create 8.4 million new jobs by 2028 (BLS, 2019a). Further, studies have revealed that labour scarcity in agriculture in some regions of the world are due, in part, to the higher wages at other locally-available jobs, the seasonality of agriculture jobs, and a presumption of the low value of agriculture jobs relative to other opportunities (Prabakar et al., 2011). Careers in golf course maintenance are somewhat similar to agriculture jobs in these ways.

To meet labour demands, many golf courses rely on migrant seasonal workers through the U.S. Department of Labour H-2B Visa program (NGCOA, n.d.). The H-2B visa program issues 66,000 visas annually (USCIS, 2019), which was insufficient to meet labour demands for golf courses as recently as 2018 (Kaufmann, 2018). To help meet demand in recent years, 15,000 additional visas were added to the cap in May 2018 and 30,000 additional visas were added to the cap of 66,000 in March 2019 (Asimow, 2019).

2.2 Cost

According to the Organisation for Economic Cooperation and Development, the average annual wage in the U.S.A. was $63,093 in the U.S.A. in 2018, behind only Switzerland ($64,109), Luxembourg ($65,449), and Iceland ($66,504) for countries included (OECD, 2019). Mexico had the lowest average 2018 wage at $16,298.

In 2013, PricewaterhouseCoopers Global predicted the average annual wage in the U.S.A. would be $54,888 by 2030 from an average annual growth of real wages of 2% from 2011 to 2030 (PWC, 2013). This is less than that predicted by The *Economics Program Working Pager Series* from The Conference Board in 2016, which predicted that average annual wages would grow by 3.1% for the U.S.A. from 2015 to 2020 (Levanon et al., 2016). This estimate was less than that projected for Japan (0.5%), equal to that for the UK, and slightly less than the projections for Australia (3.8%) and Canada (3.4%) over the same timeframe. When considering annual wage growth regionally, the U.S.A. is projected to lead Southern Europe (2.0%), Western and Northern Europe (2.6%), and the rest of the world outside of these regions (1.6%).

2.3 Regulatory

The U.S. Department of Labour recently ruled that all employees earning less than $35,568 annually (or $684 per week for seasonal employees), will be eligible for time-and-one-half overtime pay beginning January 1, 2020 (Thomas, 2019). This will require employers to pay overtime to nonexempt employees earning less that this amount for any work past 40 hours or increase their pay to meet the new threshold.

As unemployment improves in the U.S.A., golf courses will likely continue to rely heavily on seasonal workers through congressional appropriations to the H-2B Visa program.

3. Energy

Turfgrass maintenance operations use an average of 2,405 million British thermal units (Btu) annually and account for approximately 47% of all energy use at the average 18-hole facility (Gelernter et al., 2017). Fifty-two percent of this total is estimated as electricity use, 23% is gasoline use, 21% is diesel fuel use, and less than 5% is from the use of propane, heating oil, or natural gas.

3.1 Scarcity

Future energy availability is not likely an issue based on recent projections. Because of increases in the production of crude oil, natural gas, and natural gas plant liquids, and slow growth in overall energy consumption from increased energy efficiency of end users, the U.S.A. is expected to be a net energy exporter from 2020 through 2049 (U.S. EIA, 2019). From 2011 to 2050, the share of electricity generation will increase from natural gas (34 to 39%) and renewable sources (18 to 31%) such as solar, wind, geothermal, and hydroelectric technologies, but shares decrease for nuclear (19 to 12%) and coal (28 to 17%) methods over the same timeframe (U.S. EIA, 2019). Interestingly, water availability and cost are not mentioned as drivers in the 2019 U.S. EIA report. Worldwide, the United Nations (n.d.) estimates that 75% of all industrial water withdrawals are used for energy production, so it's possible that water scarcity could confound these energy availability projections.

3.2 Cost

3.2.1 Fuel

Because of increasing crude oil prices, the "business-as-usual" (reference case) projections from the U.S. EIA (2019) predict that retail gasoline and diesel fuel prices will increase by $0.76 and $0.82 per gallon from 2018 through 2049. Scenarios where lower and higher expected crude oil prices bound this estimate in 2050, where retail gasoline prices are predicted to range from $2.51 to $5.57 per gallon and retail diesel fuel prices are estimated to range from $2.57 to $6.61 per gallon.

3.2.2 Natural Gas

Natural gas prices are expected to stay below $4.00 per million Btu through 2035 and less than $5.00 per million Btu through 2050 (U.S. EIA, 2019). Because of these modest increases, most end-use sectors, including that for electricity production, are expected to increase natural gas use through 2050.

3.2.3 Electricity

Electricity demand is expected to increase by an average of 1% annually through 2049 (U.S. EIA, 2019). In projections with lower or higher economic growth than the reference case, average annual electricity demand respectively increases or decreases by 0.2% compared to the reference case. The reference case projection estimates that average electricity costs will be $0.10 to 0.11 per kilowatt hour (kWh) in 2050 (in 2018 USD) – slightly cheaper than in 2018. However, alternate-case projections with different assumptions around oil and gas prices, resources, technologies, and economic growth from 2020 to 2049 estimate that electricity prices will range from $0.097 per kWh to $0.116 per kWh.

3.3 Regulatory

Various tax-credit and regulatory programs will influence the production costs, and therefore, market prices for energy sources. One example is the Clean Air Act Amendments of 1990 (U.S. EIA, 1990). Assuming no further regulation of carbon dioxide emissions in the U.S.A., emissions related to electricity production are not predicted to increase from 2018 to 2050.

4. Nutrients

Many elements are essential for normal plant growth. Hydrogen, carbon, and oxygen are required in the largest amounts and are acquired from water or from the atmosphere. Sixteen mineral elements are plant-essential and are applied as fertilizers. Of these, nitrogen, phosphorous, and potassium are required and applied in the greatest amounts (Taiz and Zeiger, 2010).

On golf courses, nitrogen, phosphorous (applied as P_2O_5), and potassium (applied as K_2O) fertilizer use decreased by 34%, 53%, and 42% from 2006 to 2014 because of lower application rates, fewer fertilized golf courses acres, and 618 golf course closures (approximately 10% of the overall reduction) (Gelernter et al., 2016). Although fertilizer use seems to be decreasing on average in the golf course management industry, fertilizer always will be an essential component of turfgrass management. Further, because commercial fertilizers are often attributed with approximately 40 to 60% of agricultural crop yields (Stewart et al., 2005), their use is critical to sustain food production for a growing population that will continue to drive worldwide fertilizer consumption.

4.1 Scarcity

The Organisation for Cooperation and Development estimates that global demand for minerals will double by 2034 (HCSS, 2009). Specific to agricultural fertilizers, the Food and Agriculture Organization (FAO) (2012) estimated in 2012 that worldwide aggregate consumption of nitrogen, phosphorous, and potassium fertilizers was 166 million tons (150.59 million tonnes) in 2007 and would be 263 million tons (238.59 million tonnes) by 2050. However, by 2017, the FAO (2017) predicted that the aggregate world demand for nitrogen, phosphorous, and potassium fertilizers would total 251.87 million tonnes by 2020 (including 50.21 tonnes of non-fertilizer use of nutrients), representing respective annual growths of 1.5%, 2.2%, and 2.4% for nitrogen, phosphorous, and potassium fertilizers from 2015 to 2020. Fertilizer production is precited to increase with demand and the total supply of nitrogen, phosphorous, and potassium fertilizers is expected to be 273.38 million tonnes by 2020, exceeding total demand worldwide.

Regionally, North America is expected by the FAO (2017) to have a surplus of phosphorous and potassium fertilizers, but nearly a three million tonnes deficit of nitrogen fertilizers in 2020. Western Europe is expected to have both nitrogen and phosphorous fertilizer deficits in 2020, but western Asia and a region containing eastern Europe and central Asia are expected to have surpluses of nitrogen, phosphorous, and potassium fertilizers in 2020.

4.2 Cost

Fertilizer prices are linked to several industries and directly affected by agricultural commodity prices, transportation costs, and the cost and availability of natural gas (TFI, 2019). According to the previously cited work by Gelernter et al. (2016), the average cost of nitrogen-, phosphorous-, and potassium-based fertilizers respectively increased by more than 60%, 100%, and 100% for golf courses from 2006 to 2013. Data from the World Bank (2019) shows that fertilizer prices generally decreased worldwide from 2015 to 2017, then generally increased for nitrogen and phosphorous until 2019. After an initial spike and correction in early 2017, the price of potassium fertilizer remained relatively constant until 2019 when demand drove prices up 23.2%. Overall, worldwide fertilizer prices dropped 0.6% in 2019 (and phosphorous prices reached a 10-year low) but prices are expected to rise 2.2% in 2020 (World Bank, 2019).

4.3 Regulatory

Fertilizer regulations reported by golf courses, most commonly for phosphorous-containing fertilizers, have increased from 2006 to 2014 (Gelernter et al., 2016). Another commonly introduced regulation was for date, location, or buffer-strip application restrictions that are designed to reduce runoff of nutrients into surface waters. These best management practices reduce the transport of nutrients and were developed with many years of USGA support (Nus and Kenna, 2011).

5. Pesticides

Pesticides include chemicals that are applied to control insects (insecticides), nematodes (nematicides), fungi (fungicides), and weeds (herbicides). Overall pesticide use decreased on U.S.A. golf courses from 2007 to 2015 (Gelernter et al., 2016). Golf course superintendents reportedly relied 4% more on fungicides and 2% more herbicides from 2007 to 2015, but 4% less on insecticides and 15% less on nematicides during the same timeframe. This trend should most appropriately be observed as a no-change scenario since nematicide use drove the overall trend and few were available during this time frame.

5.1 Scarcity

Because most pesticides are synthetic, their production is tied to the availabilities of raw materials and energy. Beyond production considerations, the two biggest factors likely to affect the future availability of pesticides are pesticide resistance and human health concerns.

Pesticide resistance is a phenomenon whereby a target pest (e.g., a specific insect, fungus, or weed) population loses sensitivity to a pesticide that previously provided effective control. When this happens, it may require a higher dose of the pesticide to control the resistant pest or the pesticide may become temporarily or permanently ineffective. In either scenario, the availability of effective pesticides has been reduced, even if there is a healthy supply of ineffective pesticides.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the U.S. Environmental Protection Agency (EPA) rigorously evaluates pesticides for human health risks during registration (EPA, n.d.; NPIC, 2017). Some effective pesticides are never registered or have been rightfully banned by the EPA because of human health concerns. In other cases, public concerns over the safety of pesticide exposure results in pesticide bans by local governments against the EPA's recommendations. Similar to pesticide resistance, either case reduces pesticide availability regardless of supply.

The increased regulation of pesticides under FIFRA increased pesticide development costs, caused mergers among manufacturers, reduced overall pesticide registrations, and limited the development of pesticides for minor commodities (Fuglie et al., 2017; Ollinger and Fernandez-Cornejo, 1995) such as turfgrass grown on golf courses. These trends are likely to continue, which further strains the supply of effective pesticides for golf course maintenance. Biologically based pesticide products, including transgenic crops, are likely to expand in use relative to traditional pesticides in the future (NRC, 2000).

5.2 Cost

The development costs of bringing a new pesticide to market now exceed $280 million (Fuglie et al., 2017). Approximately 3 billion kilograms of pesticides valued at $40 billion are applied worldwide each year (Pimentel, 2005). A previous estimate based on 1997 sales put the global pesticide market at $31 billion with annual growth of 1-2% (NRC, 2000). North America and western Europe represented $9.2 and $7.8 billion of the global market, respectively, and the market sector containing turfgrass was valued at $5.25 billion – a 17% market share.

Global or national projections of the future costs of pesticides are challenging to acquire. However, data from the University of Illinois shows the per-acre costs of fertilizers, seed, and pesticides for high-producing corn farms in central Illinois from 1990 to 2015 (Schnitkey and Sellars, 2016). The data show that pesticide costs increased by an annual rate of 3.5% on average from $22 per acre in 1990 to $40 per acre in 2006. The annual rate increase then averaged 5.7% from $40 per acre in 2006 to $66 per acre in 2015. It is likely that these costs will continue to increase, following the projections for fossil fuels and fertilizers.

5.3 Regulatory

In a 2016 survey, golf course superintendents reported low impacts of regulations on pest management programs and their use of pesticides (Gelernter et al., 2016). Record keeping, storage, and notification-of-application requirements were the most commonly reported regulations.

6. References

Asimow, N. 2019. Federal government to raise cap on H2B visas. Vineyard Gazette. 29 March 2019. https://vineyardgazette.com/news/2019/03/29/government-expands-cap-h2b-visas (accessed 27 November 2019).

Bigelow, D. and A. Borchers. 2012. Major Uses of Land in the United States, 2012. United States Department of Agriculture. https://www.ers.usda.gov/publications/pub-details/?pubid=84879 (accessed 22 October 2019).

BLS (Bureau of Labour Statistics). 2019a. Employment projections: 2018-2028. United States Department of Labour. 4 September 2019. https://www.bls.gov/news.release/ecopro.nr0.htm (accessed 27 November 2019).

BLS (Bureau of Labour Statistics). 2019b. Employment situation summary. United States Department of Labour. 1 November 2019. https://www.bls.gov/news.release/empsit.nr0.htm (accessed 27 November 2019).

EPA (U.S. Environmental Protection Agency). No date. Regulatory information by topic: Water. United States Environmental Protection Agency. https://www.epa.gov/regulatory-information-topic/regulatory-information-topic-water#ground (accessed 23 October 2019).

EPA (U.S. Environmental Protection Agency). No date. Slowing and combating pest resistance to pesticides. United States Environmental Protection Agency. https://www.epa.gov/pesticide-registration/slowing-and-combating-pest-resistance-pesticides (accessed 27 November 2019).

FAO (Food and Agriculture Organization of the United Nations). 2012. World agriculture towards 2030/2050: The 2012 revision. ESA working paper no. 12-03. The United Nations. www.fao.org/3/ap106e/ap106e.pdf

FAO (Food and Agriculture Organization of the United Nations). 2017. World fertilizer trends and outlook to 2020. The United Nations. http://www.fao.org/3/a-i6895e.pdf

FEMP (U.S. Department of Energy Federal Energy Management Program). 2017. Water and wastewater annual price escalation rates for selected cities across the United States. U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2017/10/f38/water_wastewater_escalation_rate_study.pdf (accessed 21 October 2019.

Fuglie, K., M. Clancy, P. Heisey, and J. MacDonald. 2017. Research, productivity, and output growth in U.S. agriculture. Journal of Agricultural and Applied Economics. 49(4):514-554. doi: https://doi.org/10.1017/aae.2017.13. https://www.cambridge.org/core/journals/journal-of-agricultural-and-applied-economics/article/research-productivity-and-output-growth-in-us-agriculture/75A079865598B5C6BC11C85321E7FBAF/core-reader.

Gasson, C. 2017. A new model for water access. The Global Water Leaders Group. http://www.globalwaterleaders.org/water_leaders.pdf (accessed 21 October 2019).

Gelernter, W. D., L. J. Stowell, M. E. Johnson, C. D. Brown, and J. F. Beditz. 2015. Crop, Forage, & Turfgrass Management DOI: 10.2134/cftm2015.0149. https://dl.sciencesocieties.org/publications/cftm/pdfs/1/1/cftm2015.0149.

Gelernter, W. D., L. J. Stowell, M. E. Johnson, and C. D. Brown. 2016. Documenting trends in nutrient use and conservation practices on US golf courses. Crop Forage and Turfgrass Management. Volume 2. doi:10.2134/cftm2015.0225. https://dl.sciencesocieties.org/publications/cftm/pdfs/2/1/cftm2015.0225.

Gelernter, W. D., L. J. Stowell, M. E. Johnson, and C. D. Brown. 2016. Documenting trends in pest management practices on US golf courses. Crop Forage and Turfgrass Management. Volume 2. doi:10.2134/cftm2016.04.0032. https://dl.sciencesocieties.org/publications/cftm/pdfs/2/1/cftm2016.04.0032.

Gelernter, W. D., L. J. Stowell, M. E. Johnson, and C. D. Brown. 2017. Documenting trends in energy use and environmental practices on US golf courses. Crop Forage and Turfgrass Management. Volume 3. doi:10.2134/cftm2017.07.0044. https://dl.sciencesocieties.org/publications/cftm/articles/3/1/cftm2017.07.0044.

Hartwiger, C. 2013. Golf course irrigation – Where does it come from? USGA Green Section Record 51(16):1-4. http://gsrpdf.lib.msu.edu/ticpdf.py?file=/article/hartwiger-golf-8-9-13.pdf.

HCSS (The Hauge Centre for Strategic Studies). 2009. Scarcity of minerals: A strategic security issue. The Hauge Centre. No. 2-01-10. https://www.hcss.nl/sites/default/files/files/reports/HCSS_Scarcity_of_Minerals.pdf

Jennewein, C. 2019. Padre Dam's Ambitious Drinking Water Recycling Project to Get Federal Funding. Times of San Diego. 29 October 2019. https://timesofsandiego.com/tech/2019/10/29/padre-dams-ambitious-drinking-water-recycling-project-to-get-federal-funding/ (accessed 31 October 2019).

Kaufman, M. 2018. Insufficient numbers of seasonal workers under H-2B visa program an issue for course operators. Golfweek|Digital Edition. 3 June 2018. https://golfweek.com/2018/06/03/golf-immigration-h2b-visa-work-shortage/ (accessed 27 November 2019).

Kupelian, B. 2019. Predictions for 2019: Coming off the boil. PWC Global. https://www.pwc.com/gx/en/issues/economy/global-economy-watch/predictions-2019.html (accessed 1 November 2019).

Kojm, C., J. Gartin, M. J. Burrows, M. Roth, C. Yost, and C. Manning, eds. 2012. Global water security. Intelligence Community Assessment no. ICA 2012-08. https://www.dni.gov/files/documents/Special%20Report_ICA%20Global%20Water%20Security.pdf (accessed 21 October 2019).

Levanon, G., B. Colijin, M. Paterra, F. Steemers, and E. Rust. 2016. International Labour Cost Projections. The Conference Board Economics Program. EPWP #16-03. https://www.conference-board.org/pdfdownload.cfm?masterProductID=10241.

Merrill, D. and L. Leatherby. 2018. Here's how America uses its land. Bloomberg. https://www.bloomberg.com/graphics/2018-us-land-use/ (accessed 22 October 2019).

NALC (National Agriculture Law Center). No date. Water law: An overview. The University of Arkansas National Agricultural Law Center. https://nationalaglawcenter.org/overview/water-law/ (accessed 23 October 2019).

NGCOA (National Golf Course Owners Association). No date. Seasonal workers: Immigration/H2-B Visa. National Golf Course Owners Association. http://www.ngcoa.org/pageview.asp?doc=2544 (accessed 27 November 2019).

NPIC (National Pesticide Information Center). 2017. Regulating pesticide through risk assessment. National Pesticide Information Center. http://npic.orst.edu/reg/risk.html (accessed 27 November 2019).

NRC (National Research Council). 2000. Chapter 4: Technological and biological changes and the future of pest management. In: The future role of pesticides in US agriculture. The National Academies Press. Washington, DC. https://doi.org/10.17226/9598. https://www.nap.edu/read/9598/chapter/6.

Nus, J. and M. Kenna. 2011. Reviewing USGA-funded research: Nutrient fate and transport. USGA Turfgrass and Environmental Research Online 10(21): 1-8. http://usgatero.msu.edu/v10/n21.pdf

OECD (Organisation for Economic Cooperation and Development). 2019. Average wages. OECD Library. https://www.oecd-ilibrary.org/employment/average-wages/indicator/english_cc3e1387-en (accessed November 1 2019).

Ollinger, M. and J. Fernandez-Cornejo. 1995. Regulation, innovation, and market structure in the U.S. pesticide industry. U.S. Department of Agriculture, Economic Research Service, Agricultural Economics Report No. 719, 1995. https://naldc.nal.usda.gov/download/CAT11121165/PDF.

Pimentel, D. 2005. Environmental and economic costs of the application of pesticides primarily in the United States. Environment, Development, and Sustainability. 7:229-252. doi: 10.1007/s10668-005-7314-2.
https://www.beyondpesticides.org/assets/media/documents/documents/pimentel.pesticides.2005update.pdf

Prabakar, C., K. Sita Devi, and S. Selvam. 2011. Labour scarcity – Its immensity and impact on agriculture. Agricultural Economics Research Review. 24:373-380.
http://ageconsearch.umn.edu/bitstream/119387/2/2-C-Prabakar.pdf

PWC (PricewaterhouseCoopers Global). 2013. Global wage projections to 2030.
https://www.pwc.co.uk/assets/pdf/global-wage-projections-sept2013.pdf.

Schnitkey, G. and S. Sellars. 2016. Growth rates of fertilizer, pesticide, and seed costs over time. farmdoc daily (6):130. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign. 12 July 2016. https://farmdocdaily.illinois.edu/2016/07/growth-rates-of-fertilizer-pesticide-seed-costs.html.

Stewart, W. M., D. W. Dibb, A. E. Johnston, and T. J. Smyth. The contribution of commercial fertilizer nutrients to food production. Agronomy Journal. 97:1-6.
https://dl.sciencesocieties.org/publications/aj/pdfs/97/1/0001?q=publications/aj/pdfs/97/1/0001

Taiz, L. and E. Zeiger. 2010. Plant physiology, 5th ed. Sinauer Associates, Inc. Sunderland, MA.

TFI (The Fertilizer Institute). 2019. The global economics of fertilizer: The facets of a fluctuating market. The Fertilizer Institute. https://www.tfi.org/our-industry/intro-to-fertilizer/global-economics (accessed 26 November 2019).

Theobald, D. M. 2014. Development and applications of a comprehensive land use classification and map for the US. PLOS ONE 9(4): e94628. https://doi.org/10.1371/journal.pone.0094628.

Thomas, R. 2019. New rule extends overtime pay to 1.3 M Americans. Club and Resort Business. https://clubandresortbusiness.com/overtime-pay-extended-to-1-3m-americans-with-new-rule/ (accessed 1 November 2019).

Tong, T. and M. Elimelech. 2016. The global rise of zero liquid discharge for wastewater management: Drivers, technologies, and future directions. Environmental Science and Technology 50:6846-6855.DOI:10.1021/acs.est.6b01000. https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b01000.

Uhlenbrook, S. and R. Connor, eds. 2019. The United Nations world water development report 2019: Leaving no one behind. The United Nations Educational, Scientific, and Cultural Organization. Paris, France. https://unesdoc.unesco.org/ark:/48223/pf0000367306 (accessed 22 October 2019).

United Nations. No date. Water. United Nations: Shaping Our Future Together. https://www.un.org/en/sections/issues-depth/water/ (accessed 21 October 2019).

USCIS (U.S. Citizenship and Immigration Services). 2019. Cap count for H-2B Nonimmigrants. U.S Citizenship and Immigration services. https://www.uscis.gov/working-united-states/temporary-workers/h-2b-non-agricultural-workers/cap-count-h-2b-nonimmigrants (accessed 27 November 2019).

U.S. EIA (U.S. Energy Information Administration). 2019. Annual energy outlook 2019: With projections to 2050. U.S. Department of Energy. https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf

World Bank. 2019. Commodity markets outlook. International Bank for Reconstructions and Development / World Bank. October 2019. https://www.worldbank.org/en/research/commodity-markets

Appendix A - Table of Figures