Optimum golf course playing conditions with minimum inputs

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This is the handout for my presentations on this topic in Beijing and Bangkok as part of The R&A Seminar on Sustainable Golf Course Design, Renovation, and Maintenance in Asia. I'm the Chief Scientist at the Asian Turfgrass Center, `www.asianturfgrass.com`, and an Adjunct Assistant Professor in the Department of Plant Sciences at the University of Tennessee. Contact me at micah@asianturfgrass.com or find me on Twitter at @asianturfgrass.

A version of this text was published in the handout for The R&A Seminar on Sustainable Golf Course Design, Renovation, and Maintenance in Asia. I've reproduced the text here, with some emendations, and have included links to the slides for each presentation. All of these presentations are related to the overall topic of optimizing playing conditions with a minimum of inputs. Some of the topics discussed include soil, grass selection, and the calculation of water requirements.

Sustainability: what it is and why it matters

Sustainability is about managing the course in the right way.[1] I look at this from the point of view of golf course operations and the customer. As a customer, I want to play a well-conditioned golf course. As a golf course operator, I want to produce a well-conditioned golf course with a minimum of inputs.

[1] The slides to accompany this section are available at `https://speakerdeck.com/micahwoods/sustainability-what-it-is-an-why-it-matters`.

But as any golfer knows, and as any golf course operator knows, those desired conditions don't just happen by accident. If you are a golfer, you will have played courses that did not have the desired conditions. Maybe the ball doesn't bounce the way it should, or roll the way it should; maybe there are patches of ground with no grass on them. If you are involved with golf course operations, it goes without saying that a lot of work goes into producing the golf course that is presented to the customer every day.

I used to really dislike the word *sustainability*. The reason for my dislike? The word seemed too vague. How can one say what is sustainable? Some years ago, I came across this definition from the R&A: optimising the playing quality of the golf course in harmony with the conservation of its natural environment under economically sound and socially responsible management. That is pretty concrete. One can strive to optimise playing quality. One can conserve the natural environment. One can be economically sound. Once can be socially responsible. All of those can be measured to some degree, that measurement can be tracked, and one can evaluate performance over time. After I became aware of that definition, I warmed to the term sustainability, because I realized that it was definable, and in reality it is how one wants to manage a property anyway. Sustainability is not something exceptional; it is (or should be) the standard.[2]

[2] The R&A's golf course management site (`http://golfcoursemanagement.randa.org/`) has articles, case studies, and resources related to the sustainable management of golf courses.

The information here is all related in some way to that definition from the R&A. Some of it pertains to optimising the playing quality of the golf course. Some of it is about conservation of its natural environment. Related to conservation is economic soundness; that is, from a golf course maintenance perspective, don't waste money.

What are the right conditions for golf?

First of all, one needs customers. If there are not customers in the area, then one better produce an exceptional product that has a regional or global appeal.[3]

[3] Excellent resources about golf course development, construction, and management are available from The Golf Environment Organization (GEO), providing guidance for all types of projects, and through GEO On Course and the GEO Certified ecolabel. Details at `http://www.golfenvironment.org/`.

Soil

As far as the golf course goes, what is really needed?[4] There must be some type of soil suitable for growing plants. There must be enough water available for irrigation. And there must be sufficient drainage. That's what is needed for a site. If the site has those things naturally, then it is a much better site for golf. If it doesn't have those things, then they must be obtained or constructed.

[4] The slides to accompany this section are available at `https://speakerdeck.com/micahwoods/the-right-conditions-for-golf`.

Sandy soil is good, but not essential. The advantage of naturally sandy soils is that they tend to drain well. This makes it a lot easier to build the course, and the course will tend to play well after construction. Artificial sandcapping of golf courses is a common practice in Asia, but installing a sandcap over the existing soil does not transform a site into a sandy one. More specifically, I mean that installing a sandcap does not provide the same inherent benefits of free drainage and easy to work with soils that come with a naturally sandy site.

Because sandcapping is so common, I'll explain a little more about what a sandcap does and doesn't do. First, what it does do. On a naturally sandy site, water will move down freely through the soil profile, away from the surface. This is what I would call a "free-draining" soil. That's a good thing about sand, because for golf, we generally want to have a relatively dry surface to play from. Also, sands are resistant to compaction. If you look at sand under a microscope, magnifying it 20 or 30 times, the grains of sand look like big rocks. Now imagine what happens when you push big rocks against each other. The rocks can be pressed against each other as tight as possible, but there is a point beyond which the rocks can't be pressed any closer. Because the rocks have different shapes, as they are pressed together they do not fit together perfectly. Some corners and edges of the rocks will be pressed tightly against the adjacent rocks, and there will be air spaces as well. That's the same thing that happens with sand. Sand can be compressed up to a point, and because of irregular shapes there remain relatively large spaces that contain air in-between the sand particles.

These are the main benefits of sand for high-traffic areas. There tends to be a high infiltration rate, so that water can go into the soil and then go down through the soil, and the soil itself is resistant to compaction, allowing for plenty of traffic across the site while still retaining necessary pore space in the soil.

But there is a big difference between a naturally sandy site and one that is sandcapped. On a naturally sandy site, the sand is deep, and it is only in the natural low areas where supplemental drainage is required, if at all. An artificial sandcap is different. With a sandcap placed on top of a less free-draining soil, one still needs to install a subsurface drainage system. The sand at the top may make for a faster infiltration rate, but the sand itself does not make the water go away. On a site that isn't naturally sandy, one needs a really good drainage system whether there is a sandcap or not.

Now for some of the things a sandcap doesn't do. A sandcap doesn't make the grass grow better. In fact, grass grown on sand will require more fertilizer and more water than grass grown on soil, for the simple reason that sand doesn't hold very much water and doesn't retain many plant nutrients. Therefore, when growing grass on sand, more frequent fertilizer applications are required, and more frequent irrigation is required. When the fertilizer and irrigation are applied, that makes the grass grow more, and as the grass grows it produces a lot of roots and stems and leaves. All this organic matter produced by the growing grass starts to form a layer at the soil surface. When this organic matter is interspersed with sand or soil it is called a *mat* layer. When it is not mixed with soil, and is only a layer of living and dead plant material, it is called *thatch*.

A mat layer is desirable; thatch is not desirable. Whether it is mat or thatch, however, what happens at the surface of a sand rootzone as the grass grows is the development of a layer that is finer-textured than the underlying sand. This finer-textured layer holds more water than the sand beneath it. In soils, it is easier to manage this layer. Actually, in soils, nature does much of the work of managing this layer for you. Soils have more microbial activity and more earthworms. There is more rapid mixing of soil with the organic matter and more rapid breakdown of the organic matter. Also, in soils there is less frequent irrigation and less frequent fertilizer application. And in soil, the underlying material may not have a rapid infiltration rate, but the organic layer over it is often coarser than the underlying material, so water still moves down without having to saturate the upper layer first. On a sandcap with an organic layer over it, the water will not move down from the organic layer until the organic layer is saturated.

That's why so much maintenance work is done on putting greens to control the organic matter. The greens are core aerified, and topdressed, and scarified, and all these maintenance practices are done to keep the surface layer of organic matter from becoming too extensive. When there is too much organic matter at the surface of a sand, the benefits of the sand go away. At too many golf courses, the entire property is sandcapped, but then the work to control the organic matter is only done on the greens. When that happens, the benefits of the sand go away over time, and the playability of the course is not what it should be. On a sandcap, it is essential to manage the accumulation of organic matter. If the organic matter is not managed, the sandcap will fail.

My preference, unless the site does not have soil suitable for growing plants, is to work with the existing topsoil. The advantage of this is less cost at the time of construction because of no need to purchase sand, fewer water and nutrient inputs for the life of the golf course, and healthier grass from growing in soil rather than in sand. The disadvantages of this include possibly slower construction time, more need for decompaction work over time especially if golf carts are driven on fairways, and more extensive drainage system.

In terms of sustainability, not sandcapping is usually going to be preferable. One can optimise the playing conditions with fewer inputs by using the topsoil on site, rather than bringing in sand from somewhere else. There are two clear exceptions to this. One is for putting greens, where the desired consistency of the surface almost requires that all the greens be grown on the same underlying rootzone.[5]

[5] The R&A document *Build a greener green* (available at `http://golfcoursemanagement.randa.org/en/Features/2015/12/Build-a-greener-green.aspx`) is a good reference.

A second exception, a case where sandcapping the entire property is desirable, maybe even essential, is when the irrigation water source is known to have a high salinity and a high sodium adsorption ratio (SAR). Salt applied through irrigation water must be leached from the rootzone; if the salt accumulates in the rootzone, it will kill the grass. Water with a high SAR will cause problems in soils that contain clay, eventually creating sodic soil conditions if not treated. A sandcap in this case makes it easier to leach the salt from the rootzone and avoids the sodicity problem altogether.

Water

Then there is irrigation water. A golf course needs to have enough irrigation water availability to grow grass at the desired growth rate. This amount can be calculated using what is called a *water requirement* or a *water budget*. The amount of water grass is expected to use is the reference evapotranspiration multiplied by the crop coefficient. The reference evapotranspiration is function of the weather conditions at a location, and the crop coefficient is a function of the grass type and the desired growth rate. A crop coefficient of 0.8 is often used for golf course turfgrass.

To get the water requirement for a site, one adds up the reference evapotranspiration for the desired time period and multiples it by the crop coefficient, then subtracts the effective precipitation, and then multiplies by the area to be irrigated, and adjusts for the distribution uniformity of the irrigation system. For example, let's calculate a water requirement for 20 ha in Beijing in June and for 20 ha in Bangkok in June. Based on latitude and normal temperatures in those cities, and using a crop coefficient of 0.8 for both locations, Beijing has an average daily evapotranspiration of 4.6 mm in June;

Bangkok is 3.7 mm. With 30 days in June, that gives a monthly total evapotranspiration of 138 mm in Beijing and 111 mm in Bangkok. What about precipitation? In an average June in Beijing, there are 71 mm of rainfall. In Bangkok, the average June sees 149 mm. The effective precipitation[6] is an adjustment from the actual precipitation, to account for how much of the rainfall is expected to be available for plants to use. After making the adjustment, the effective precipitation at Beijing is 32 mm in June; in Bangkok the effective precipitation is 95 mm.

[6] For more about effective precipitation or effective rainfall, see chapter 3 in the FAO document on irrigation water needs (`http://www.fao.org/docrep/s2022e/s2022e03.htm`). In particular, see Table 6, which gives a standard effective precipitation for rainfall amounts of 0 to 250 mm per month.

In Beijing, then, the grass is expected to use 138 mm and the amount expected from effective precipitation is 32 mm, leaving a difference of 106 mm that must be supplied by irrigation. To account for the irregularity of water applied through an irrigation system, this number is adjusted by the distribution uniformity of the irrigation system. Let's say we have an irrigation system with a distribution uniformity of 0.84. To ensure that all the areas supplied with water by that system receive the necessary 106 mm, the amount of water that must be applied is 106 mm multiplied by 1/0.84. Thus, the total irrigation requirement is 126 mm. Conveniently, 1 mm spread over 1 square meter is 1 liter, so the 126 mm required are equivalent to 126 liters per square meter. For 20 ha of irrigated area, the water requirement in June in Beijing, with the assumptions made in the previous paragraphs, is 25,200,000 liters. If the irrigation water contains salt that much be leached, then the water requirement can be further adjusted by accounting for the water required for leaching.

In Bangkok, the grass is expected to use 111 mm and the effective precipitation is 95 mm. The different that must be supplied by irrigation is 16 mm. Assuming that we have an equivalent irrigation system as that in Beijing, with a distribution uniformity of 0.84, then the total irrigation requirement will be 19 mm. For 20 ha of irrigated area, this comes to 3,800,000 liters.

This procedure of calculating a water requirement or water budget for a site allows the amount of water that will be required as irrigation to be estimated.

Choosing the right grass

First, choose a grass that won't die. Second, choose a grass that requires minimal inputs to produce the desired playing conditions.[7]

[7] The slides to accompany this section are available at `https://speakerdeck.com/micahwoods/choosing-the-right-grass`.

More specifically, one should choose warm-season grasses whenever the temperatures are warm enough for them to grow, because warm-season grasses use water more efficiently, thrive in the hot weather that causes a lot of problems to cool-season grasses, and will generally require fewer inputs in a climate where both cool-season and warm-season grasses could grow. A good value to check is the average annual temperature. If the average annual temperature is more than 20°C, cool-season grasses are a bad choice. If the average annual temperature is in the range from 14 to 20°C, then it is likely a transition zone area, and one might be able to use cool-season or warm season grasses. If the average annual temperature is less than 14°C, it is unlikely that warm-season grasses can be used.

As an example, Beijing has an average annual temperature of about 12°C, so I expect almost all cool-season grasses in that area. In Shanghai, the average annual temperature is about 16°C; that puts Shanghai into a transition zone area. Cool-season grasses can be used there, but in most cases warm-season grasses will be preferable because they tend to require less water and fewer inputs. Moving further south, Guangzhou is clearly in a warm-season area, with an average annual temperature of 22°C; Hong Kong is 23°C; Bangkok is 28°C; Singapore is 27°C. Still moving south, by the time one gets to Sydney, the average temperature is about 18°C, and here is a transition zone area again, but warm-season grasses are generally preferred.

I wrote the following as a *My View* article on the R&A's golf course management site, about grass selection for greens and fairways in Asia. I reproduce the text of that article below.[8]

[8] Available online at `https://golfcoursemanagement.randa.org/en/My-view/2012/12/Grass-selection-in-Asia.aspx`

The work I do is focused on turfgrass information. I conduct research to obtain new information and I share turfgrass information through training programs and advisory work. This involves frequent travel. I am usually in about four countries each month and I consequently have a chance to see many grasses and how they perform as golfing surfaces in a wide range of environments.

What I write here must be prefaced with a note – Asia is a vast area with a wide range of climates, so one can find exceptions to just about everything I write here! But I can certainly provide a general overview of the grasses used on greens and fairways, with thoughts on what works well.

In locations where the average annual temperature is less than 20°C, it is customary to use creeping bentgrass (*Agrostis stolonifera*) on putting greens. This is usually the right choice in places such as Shanghai, Tokyo, Seoul, or Beijing. The summers in East Asia are too hot for annual bluegrass (*Poa annua*) or fine fescue (*Festuca* spp.) to have a place on putting greens here. It is not easy to manage creeping bentgrass during the hot summer months in most parts of Asia where this grass is used, the main reason being nighttime temperatures that often remain above 25°C during summer, but successful management during the two or three months of extreme heat allows for an excellent playing surface during the rest of the year.

When the average annual temperature is more than 20°C, putting greens will be one of four species: hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*), seashore paspalum (*Paspalum vaginatum*), manilagrass (*Zoysia matrella*), or serangoon grass (*Digitaria di-

dactyla). Most people would be familiar with bermudagrass greens, as that is the standard in warm-season areas around the world.

What about these other grasses? Why are they used? They can produce a better putting surface than bermudagrass in a low light environment, and a distinguishing characteristic of the climate across many parts of East, South, and Southeast Asia is the cloudiness. Clouds can block more than 50% of the light that grasses use for photosynthesis. This can really be a problem for grasses on putting greens, and in general, seashore paspalum, manilagrass, and serangoon grass tolerate such weather better than does bermudagrass.

But bermudagrass remains the most common grass on putting greens in these areas, and many courses have superb surfaces of this grass even with the low light environment. Putting greens cover about 10,000 m^2 (1 ha) on the average course, and no matter what grass we choose, the greens are always going to be intensively maintained. So it is possible to produce good surfaces with bermudagrass, although it can take more work than would be required for some other species.

Grass selection for fairways is more interesting. I'm convinced that it is best to use a grass that won't die. On the putting greens, I can plant a grass that will die without intensive maintenance, because I am always going to provide intensive maintenance to the greens. But fairways cover well over 10 ha on most courses, and it just is not possible to provide intensive maintenance over such a large area.

If I plant a grass that won't die, the surface can be maintained aggressively to create the desired playing surface. I can mow the fairways shorter, but the grass won't die. I can keep the fairways dry, even going without supplemental irrigation during the dry season, but the grass won't die. I can maintain the fairways with a slow growth rate, avoiding frequent applications of water and fertilizer, and still the grass won't die.

In northern China, parts of Korea, and Hokkaido and the northern prefectures on Honshu Island in Japan, these fairways will be cool-season grasses. But I soon find warm-season grasses, especially manilagrass and its more cold-tolerant relative, *Zoysia japonica*, as I move south through Japan and Korea, with thousands of courses using those grasses. Then in southern China, Southeast Asia, and South Asia, it is all warm-season grass – hybrid bermudagrass, seashore paspalum, manilagrass, or broadleaf carpetgrass (*Axonopus compressus*).

Manilagrass and broadleaf carpetgrass – and in some locations, bermudagrass – are the grasses that don't die on fairways in South and Southeast Asia. If I would try to manage seashore paspalum fairways without supplemental irrigation, they would die. If I managed bermudagrass fairways in most areas by cutting the grass short and keeping a slow growth rate by withholding fertilizer and water, the fairways would be overcome by weeds and the bermudagrass would die. But with just a little irrigation combined with close mowing and a minimum of fertilizer, manilagrass and broadleaf carpetgrass don't die. The implication of this is that I can manage these grasses to produce the desired playing surfaces with less effort and cost than if I were to plant a grass on fairways that dies with such management.

I expect to provide intensive management to putting greens, but I don't want to do that to the entire golf course. To do so requires extensive work and cost, and only in rare cases produces good playing conditions.

Practical solutions for keeping inputs to a minimum

THE DECISIONS MADE at the time of construction play a huge role in what the required inputs will be for the life of the course. How much area to plant as maintained grass? What kind of grass to use? Sandcap the entire property, or use topsoil from the site? What type of irrigation system to install? These are some of the most important questions to answer before the project even gets started, because once made, they can play a controlling role not only in the inputs required for construction, but more importantly in the sustainability of the golf course once it is operating.[9]

[9] The slides to accompany this section are available at `https://speakerdeck.com/micahwoods/practical-solutions-for-keeping-inputs-to-a-mini`

The easiest way to reduce inputs is to reduce the area of maintained turf. This directly reduces the quantity of irrigation water required, the amount of fertilizer and pesticides required, the amount of diesel or gasoline used by maintenance equipment, the amount of electricity used, and so on for every input. The area of maintained turf is directly proportional to the quantity of all those inputs. For example, I've calculated that 20 ha of maintained turf in Beijing would have an irrigation water requirement during an average June of 25,200,000 liters. If that 20 ha were reduced to 16 ha, the irrigation water requirement goes down to 20,160,000 liters. Want to save more than 5,000,000 liters in a month? Reducing the maintained turf area, while still keeping enough turf for the desired playability on the golf course, is the single most important way to minimize required inputs. Just as the amount of water required goes down, so does the fertilizer requirement, the fuel used for mowing, and any other input.

I'm a grass scientist, so I'm certainly biased to think that this is important, but if we talk about the subject of reducing inputs, the second most important way to reduce inputs is to choose the right grass. One needs to have the desired playing conditions, so for a particular climate and type of golf course, there will be a number of choices for grasses that can possibly be used. The reason why choosing the right grass is so important is because grasses have different growth rates, different fertilizer requirements, different susceptibilities to insects and diseases and to weed invasion, and different water requirements as well. And grasses also produce different types of surfaces. The first step is choosing a grass that won't die. Once one gets that out of the way, what's left is a list of grasses that won't die at that location. Then, one should choose the grass that will produce the desired playing surfaces with a minimum of inputs.

In general, it is native or naturalized grasses that perform the best with the fewest inputs, because these are the grasses that are the best-adapted to a particular area. East and Southeast Asia are too big, with too much diversity in climate, to have any hard and fast rules about just what grasses will be best. It is always good to do some on site testing, and to study the grasses and their performance and input requirements at nearby locations.

To make some general observations, starting with the cool-season areas, creeping bentgrass is almost always the best choice for greens, will often be the best choice for fairways and tees, and in the roughs tall fescue and fine fescue are good. Kentucky bluegrass is another species that can work well but it required more fertilizer inputs and may have more disease problems than do bentgrass and the fescues. This is not meant to be a prescription for which grasses to use, but to point out that there are significant differences between the grasses in the inputs required to produce the desired playing surfaces.

In transition zone areas, creeping bentgrass often works well on greens, and then the rest of the course can be planted to a warm-season grass. Of the warm-season grasses, the zoysiagrasses, which are native to Asia, tend to perform especially well. Centipedegrass, which is native to China, is a grass that requires few inputs and can be utilized in many rough areas.

In warm-season areas in Asia, hybrid bermudagrass is usually used on putting greens; other grasses that can produce an excellent putting surface include fine-bladed zoysiagrasses, seashore paspalum, and serangoon grass. If one has a lot of tree shade on the putting surfaces, or if the golf course location is particularly cloudy, then bermudagrass is less desirable, and zoysia or paspalum or serangoon grass will perform better with fewer inputs.

Putting greens are less important in terms of inputs than are the larger areas of the course. Putting greens make up 1 to 2 ha of the course. The putting greens are the most important areas for the play of golf, so these 1 to 2 ha are going to be intensively maintained no matter what grass is planted to them. For the inputs required, which include things like irrigation water, electricity to pump the water, fungicides and herbicides and insecticides, fertilizer, mowing and other machinery, and the associated diesel or gasoline or electricity to go with the operation of those machines, it is most important to look at the larger areas of turf. This is the fairways and rough. What grass is planted on those areas, and what inputs are required to produce the desired playing surfaces for that grass, compared to the inputs required for the alternative grasses?

In warm-season areas in East and Southeast Asia, bermudagrass is especially susceptible to weed invasion, and seashore paspalum is especially susceptible to drought, insects, diseases, and invasion by other grassy weeds. The grasses that perform the best in this region with the fewest inputs are manilagrass (*Zoysia matrella*) and in the tropical areas, tropical carpetgrass (*Axonopus compressus*) can be added to the list. These grasses, when supplied with irrigation water through the dry season and when mowed regularly, will tend to dominate in a stand of maintained turf. Therefore, these should be the default choices for most golf projects, and then the choice of other species such as bermudagrass or seashore paspalum should be based on particular site characteristics. For example, bermudagrass may be preferable to the default species at a location where there is going to be a chronic shortage of irrigation water; bermudagrass tends to have better drought tolerance than the default species. As another example, perhaps the irrigation water supply is ample, but the water has a high salinity. In that case, seashore paspalum may be a better choice than the default species, as it can tolerate high salinity and lots of water.

Moving on to another default choice, and that should be to use the soil on site. Not to sandcap. A site should only be sandcapped if there are good reasons for it, such as the lack of topsoil on site, or the use of irrigation water that will require leaching. Not sandcapping saves a lot of money up front and reduces water and fertilizer inputs for the life of the course. What may be required more often on a non-sandcapped site is cultivation, some type of decompaction of the soil. The sandcapping decision should be site specific, not a standard.

For irrigation, one generally wants to minimize the irrigated area, which goes along with minimizing the maintained turfgrass area. But one should also put in the best irrigation system possible, with a high distribution uniformity. This saves water in the long run because water is applied more uniformly to the turf, reducing the water requirement. Especially important for playability, and something that I've seen cause problems at many golf courses in Asia, is the poor design and control of irrigation around the putting greens. Individual sprinkler head control is essential in the approach area and around greens, because it allows the turfgrass manager to selectively apply water to areas that require water, while minimizing overthrow of water onto areas that don't require it.

Take this common situation as an example. Creeping bentgrass on the green with a certain type of sand used for the putting green rootzone. Hybrid bermudagrass on the fairway and surrounding the green, with a different sand or soil than that used for the putting green. Now we have two differences. One is the difference in grass species. Remember, warm-season grasses tend to use less water in high temperatures than do cool-season grasses. So the bentgrass on the greens is going to naturally have a higher water requirement than does the surrounding bermudagrass. Also, the root length of grass is related to the mowing height. With lower mowing heights, the entire plant becomes smaller, so the roots of the bentgrass on the green will be shorter than the roots of grass on fairway or rough height grass around the green. With a shorter root system, irrigation must be applied more frequently, because the roots don't explore such a large volume of soil to obtain water. Here we have two different grasses, with their different water requirements, two different mowing heights, which ensures there will be different root system depths, grown on two different soils with different water holding capacities.

It is essential that the irrigation in these areas be set up in such a way that the water can be applied as precisely as possible to the different grasses and to the different soil types. This is where individual head control, and part-circle irrigation heads for the different areas, are critically important. I can't count the number of times I've seen full-circle heads on a block system that supply water to both of these areas. That is, the green and the approach and surrounds are irrigated with the exact same sprinkler heads, despite these areas having vastly different water requirements. The result invariably is dry spots in one area or much more common, wet and muddy areas and even increased weed invasion in the area receiving too much water. Making sure there is control of the water that is applied to the different areas of the golf course is a key way to reduce inputs of water.

So minimize the maintained turf area, choose the right grass, don't sandcap unless absolutely necessary, and make sure that the irrigation system allows one to control the water that is applied to the course. Those are the most important things for sustainability in terms of being able to optimise the playing quality of the golf course while minimizing inputs.

Then, measure the inputs year to year, and track them.[10] Try to use less water from one year to the next. How much fertilizer did you use in 2015? Can you get the same or better conditions in 2016 with less fertilizer? How about pesticides? Can you use less? Or can you use safer products? How about fuel? Electricity? Tracking all these inputs year to year, working to optimize playing quality of the golf course while at the same time minimizing inputs, is the practical way to keep inputs to a minimum.

[10] In *Quantifying sustainability*, Gelernter, Stowell, and Woods explained what to measure and how to do this. Available in English at `http://files.asianturfgrass.com/201312_gelernter_et_al_gcm_sustainability.pdf` and in Chinese at `http://gcmchina.gcsaa.cn.com/i/250462-jan-feb-2014/20`.

Characteristics of the best playing surfaces

The focus of turfgrass management should be on the playing corridors. This goes along with reducing the maintained turfgrass, or at least, reducing the intensity of maintenance in some areas in order to focus maintenance on the areas that are most important. I'm not a huge fan of balance in golf course maintenance. I like to focus on having the best possible surfaces on the playing areas that receive the most play. That is, on the greens, and tees, and especially on the fairway landing areas and approaches to the greens. Sustainable management will find ways to optimize as much as possible the playing corridors and to reduce inputs as much as possible in some of the out of play areas.[11]

[11] The slides to accompany this section are available at https://speakerdeck.com/micahwoods/characteristics-of-the-best-playing-surfaces.

The best playing surfaces are consistent, one doesn't get mud on the ball, so they are dry, there is a predictable bounce, and the ball roll is smooth. This is all achieved by producing the slowest acceptable growth rate. At any site, the grass must grow fast enough to recover from traffic damage. That is the divots, and general foot or vehicle traffic, and ball marks, produced on the site by whatever amount of traffic occurs. A busy golf course has lots of traffic. An empty golf course has very little traffic. The optimum growth rate for a site will be the amount of growth necessary to recover from that traffic damage, but no faster.

Any extra growth beyond that which is required to recover from traffic damage is using water and fertilizer that otherwise would not have to be used, and is requiring mowing and organic matter management that would not otherwise be required. The overall goal should be to optimize the playing quality of each area of the golf course based on the amount of traffic the course receives. This usually involves trying to restrict the growth of the grass, by applying as little water as possible, and by applying as little fertilizer as possible.

One of the big differences between the best playing surfaces, and those that are just average, is how firm the surface is. On the best playing surfaces, the ball bounces and rolls, one never gets mud on the ball, and the bounce and the roll are consistent. On average playing surfaces, the ground is softer, sometimes one gets mud on the ball, and it is unpredictable how the ball will bounce (if at all) or roll.