Turfgrass Water Use Efficiency

Dr. Phillip Ford
Melbourne Polytechnic

Several different factors affect the efficient use of water on turf. This paper picks out three of the main factors for discussion. While seemingly unrelated, the combined effect of better efficiency in each of these three factors is greater than the sum of the parts.

1. C_3 vs C_4 photosynthesis

Cool season grasses (bentgrass, ryegrass, fescue and bluegrass) form a three-carbon intermediate in the first step of photosynthesis. Warm season grasses (bermudagrass, kikuyu, zoysia and paspalum) initially form a four-carbon intermediate, which demonstrates that their physiology is fundamentally different. Due to possible confusion with the cool season/warm season terminology, it's probably better to use the terms C_3 and C_4 for the two groups.

C_3 grasses have a daily evapotranspiration (ET) rate around 25% higher than C_4 grasses. In hot, dry conditions, C_3 species need to keep their stomata open to enable reasonably efficient photosynthesis, and to provide cooling and reduce Heat Stress. C_4 species have an add-on pathway to normal photosynthesis that operates efficiently with reduced stomatal opening, so their daily ET rate is lower, as shown in the table below:

Table 1: Mean crop coefficient of various C_3 and C_4 turfgrasses in a Melbourne summer (Ford, 2006)

Turfgrass species	Mean crop coefficient
Creeping Bent	0.90
Tall Fescue	0.89
Perennial Ryegrass	0.88
Kentucky Bluegrass	0.91
Creeping Red Fescue	0.89
Seashore Paspalum	0.75
Stenotaphrum secundatum	0.71
Kikuyu	0.70
Hybrid Bermudagrass	0.70
Zoysia japonica	0.72

However, this doesn't adequately explain the real difference in drought resistance between the two groups. In Melbourne, for example, a Turf Manager must budget around 8 Megalitres per hectare per summer to sustain a C_3 surface, while the budget for a C_4 surface is in the range 0 – 4 Ml/ha per summer, depending on the colour and activity required. In southern Australia, C_4 grasses will survive without any summer irrigation. This is due to a combination of factors:

a) C_4 grasses have a 25% lower ET rate than C_3 grasses, as shown in the table above.

b) C_4 grass roots improve over summer, whereas C_3 grass roots decline and become dysfunctional as summer goes on.

c) Summer moisture stress in C_3 grasses leads to Heat Stress, as evaporative cooling declines and foliage temperatures exceed 36^{o}C or so. This leads to inefficiency in photosynthesis, plus a number of summer pest and disease problems, and possibly to High Temperature Kill at temperatures over 42^{o}C. By comparison, C_4 grasses tolerate foliage temperatures of 60^{o}C, and high temperatures 'should not be a concern with warm season grasses' (Fry & Huang, 2004).

d) C_4 grasses revive rapidly from drought stress, immediately after rainfall or irrigation occurs. C_3 grasses, on the other hand, don't recover from summer drought dormancy until cooler temperatures return in the autumn.

e) Many C_4 grasses have rhizomes, a major factor in drought resistance, survival and recovery (Zhou, Lambrides & Fukai, 2014).

The true drought resistance of C_4 grasses can only be appreciated when they are pushed to their limit. In Melbourne, where the long running Millenium Drought had forced the issue, C_4 grasses on sportsgrounds and fairways performed extremely well for several summers without any irrigation at all. Turf Managers in that city now have the confidence to severely limit irrigation whenever they choose.

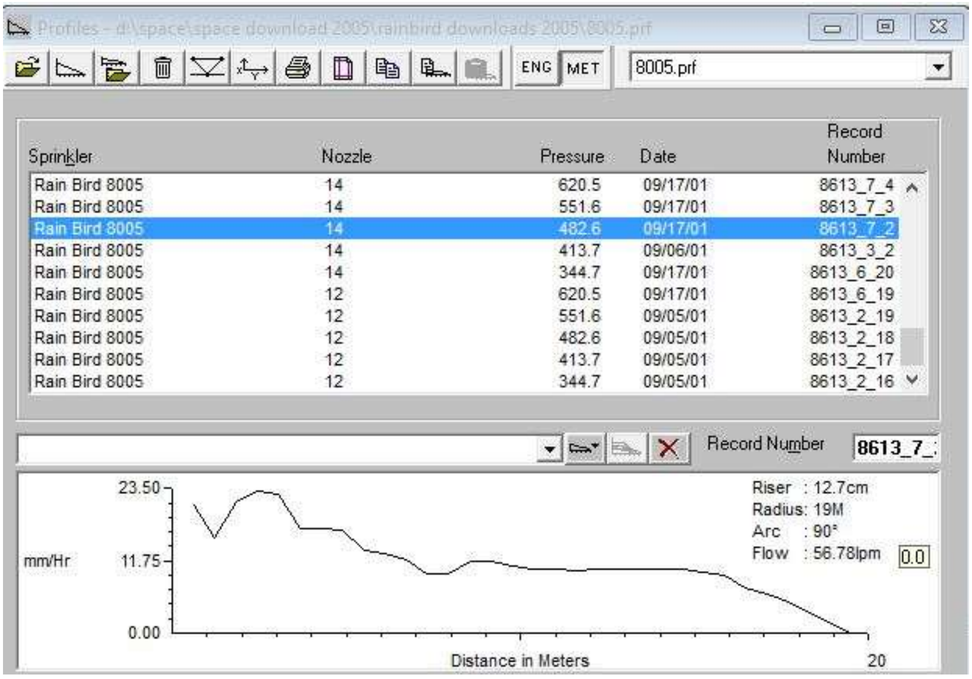
2. Irrigation Uniformity

An audit of ten golf course greens in Melbourne, including some high profile clubs, found an average coefficient of uniformity (CU) of only 78%. With good design and maintenance, a CU of over 90% is perfectly feasible. This author has tested several turf areas with CUs in the field over 90%, the highest being 94%. (Note: rainfall will have a CU of 100%).

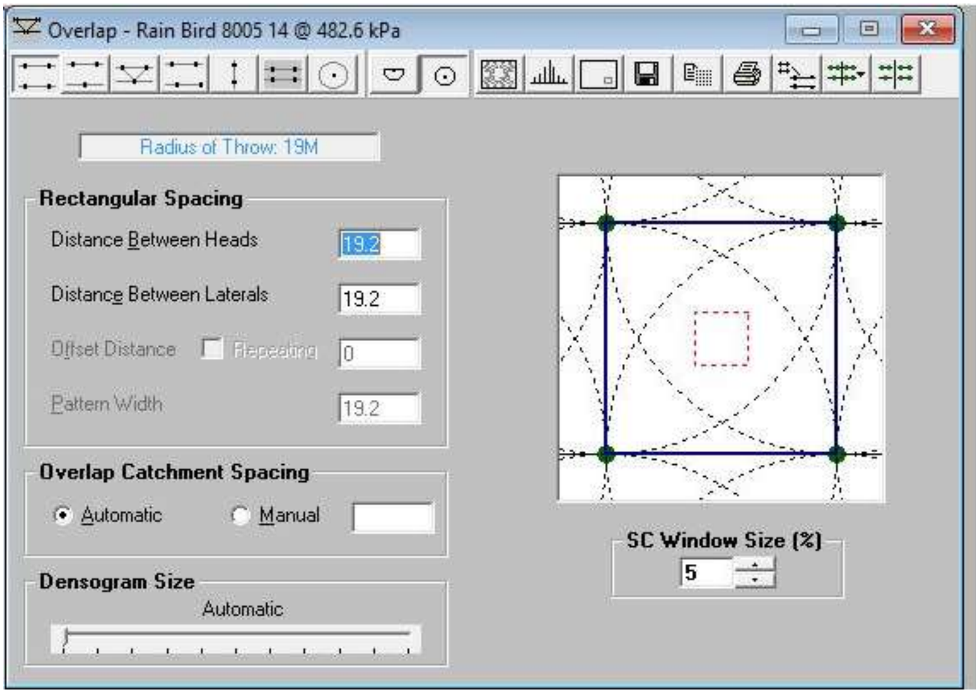
A poor CU means that some areas are receiving far too much water and other areas too little. In practice, the watering program needs to cater for the driest areas, unless a lot of hand watering is done. But poor CU doesn't just involve a waste of water and an excessive use of labour, it affects plant health. The drier areas, in particular, can suffer drought and heat stress and all the problems that follow. It might also lead to salt accumulation, if saline water is being used. For that reason a calculation of Distribution Uniformity should also be done, which gives greater emphasis to the driest areas. DU values over 85% are desirable.

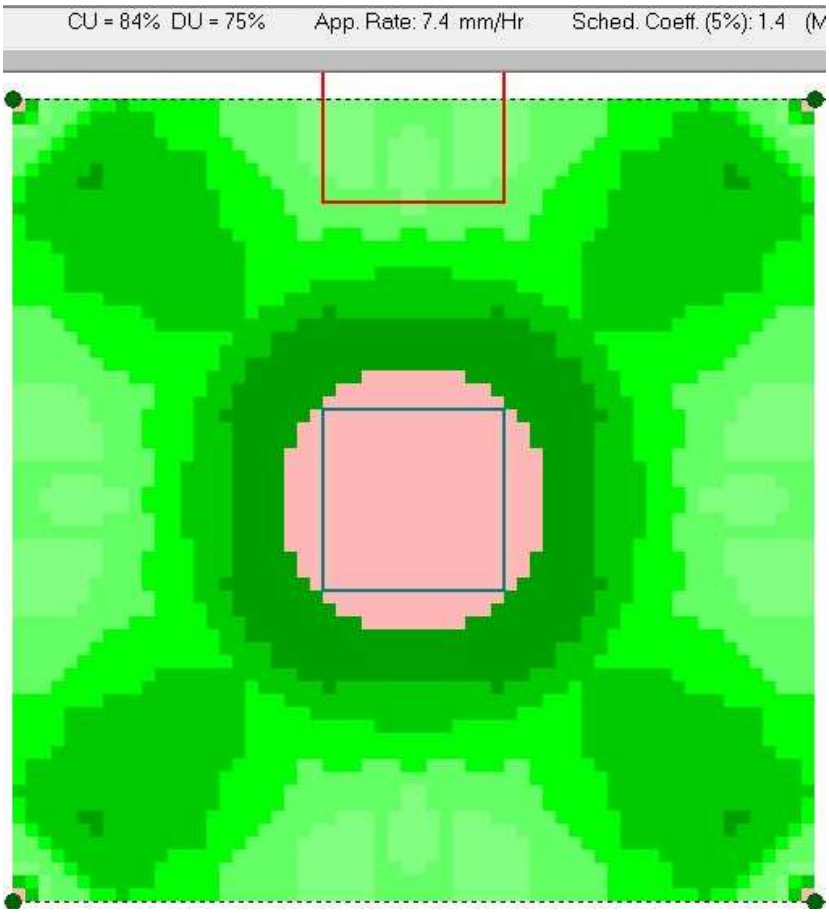
Designing an irrigation system with a high CU and DU requires careful application of the design principles, including sprinkler selection, stationing and pipe sizing, followed by competent, diligent installation and, afterwards, periodic testing and maintenance. Computer tools such as the SPACE program (Sprinkler Profile and Coverage Evaluation, from the

Centre of Irrigation Technology, Fresno, http://www.fresnostate.edu/jcast/cit/software/) make it relatively simple to design systems with high uniformity. The program has empirical data on the output (precipitation rate at distance from the head) of many types of turf sprinkler head, tested at a range of pressures and flow rates. An example is shown below. If we select a Rain Bird 8005, to operate at 480kPa, we can view its precipitation profile:

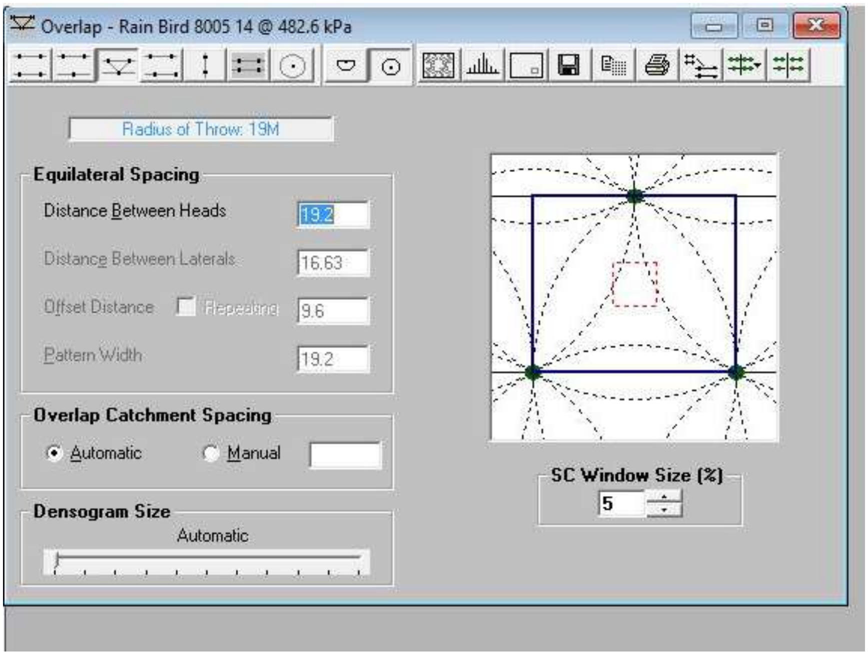


We could then set up the 8005 heads on a square design at head-to-head spacing, as below, and model the result as a Densogram (over the page):

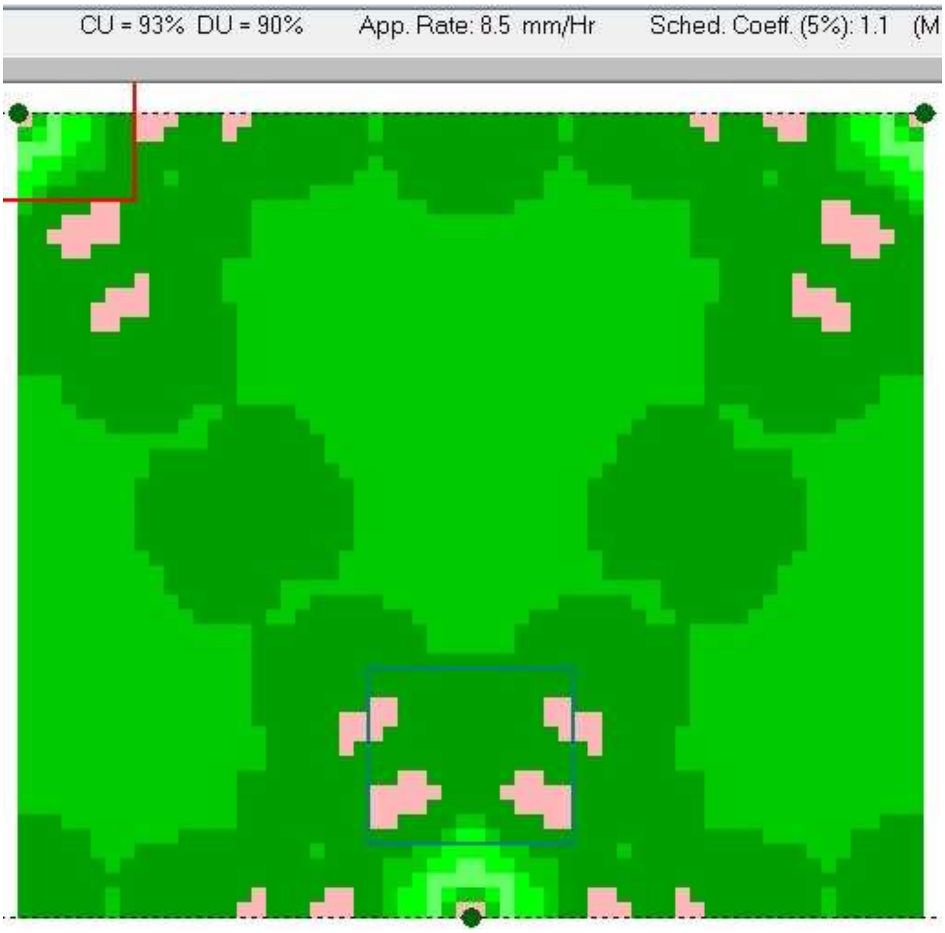




The square design at head-to-head spacing has a CU of only 84% and DU of 75%. We can do much better. The Scheduling Coefficient, by the way, of 1.4, indicates that the system would need to run 40% longer compared to if the CU was 100%; so there is a wastage factor of 40%. Using a triangular design with the laterals brought in 3m, as shown below, the Densogram on the next page looks a lot better:



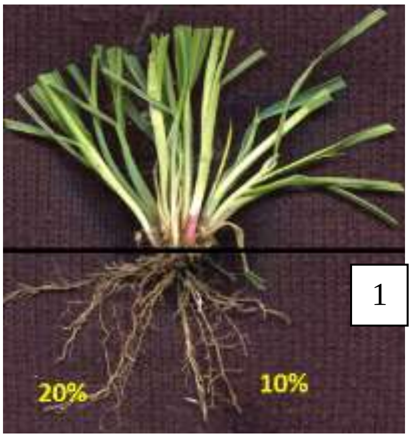
Densogram on a triangular design at 19.2 head spacing, 16.6m lateral spacing. Note the CU, DU and SC figures now. The figures can be improved even further, and the SPACE program lets you model several configurations. Putting the irrigation heads at 15m spacing, for example, results in very high CU values, but cost would become an issue.



These theoretical CU and DU values are achievable in the field, and should be used routinely to guide sprinkler selection and layout. Tender documents should specify a uniformity standard required by the designer and installer (e.g. minimum CU of 90% and DU of 85%) that can be audited on completion of the project. An irrigation audit (a catch-can test) is a relatively simple process, whether for newly-completed installations or for existing systems. Uniformity values in older systems can often be improved with a few simple modifications.

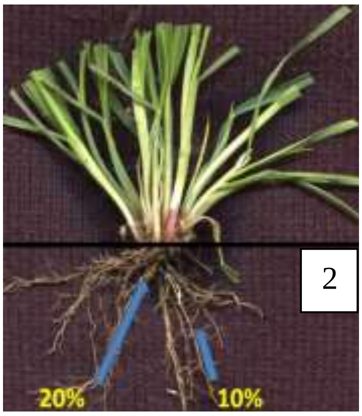
3. Root depth and function

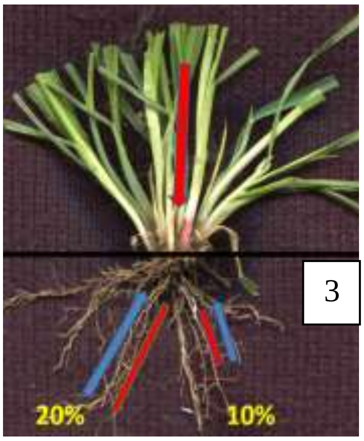
Root growth is constrained by soil temperature. But when conditions are right for growth, the main driver of root architecture is the chase for water. The mechanism is quite simple. The hormone auxin is largely produced in the shoots, and travels down in the phloem to activate mitosis, cell elongation and root hair development at the root tips. The role of auxin is complex in dicot plants, and not well understood. But its role seems simpler in grasses; a likely mode of action is as shown in the following concept diagrams:



1. Imagine a grass with roots on the left side growing into a moist zone (maybe a bit more organic or clayey) and the roots on the right side growing into a drier zone, maybe a bit sandy.

2. The amount of water delivered to the shoots by each side is indicated by the blue arrows.





3. Auxin is produced in the shoots and travels down to stimulate growth at the root tips. The amount of auxin delivered to each side (the red arrows) is proportional to the amount of water each side delivered.

4. Some days later, the root architecture will have responded as shown. The mechanism explains how roots chase water.

The implications of this mechanism are profound. Thatch has a volumetric moisture holding capacity of around 40% (Hurto, Turgeon & Spomer, 1980), which is much higher than any underlying rootzone. Once a thatch layer has formed, new roots that are initiated from the crown or nodes won't move deeper into the soil but will ramify within the thatch layer. One of the great benefits of frequent sand topdressing is that it dilutes the moisture holding capacity of the thatch, hopefully to somewhere near the moisture holding capacity of the underlying rootzone, to encourage roots to go there.

Another illustration of the auxin mechanism concerns moisture gradients through the profile. A USGA-type perched water table construction automatically sets up a moisture gradient, with the top 100mm or so of rootzone having a moisture holding capacity of, say, 18%, which increases to 28-30% at the interface with the gravel. This gradient provides an incentive for roots to grow deeper, as they will be finding more water. In non-perched water table profiles, another type of moisture gradient can be generated if irrigation is held off as long as possible. Root density is usually highest near the surface, and diminishes as you go deeper into the profile. So after several days without irrigation, water uptake by the plant will have dried the upper zone of the profile, meaning there is relatively more water down deeper. The deep roots accessing this will receive more auxin, encouraging them to probe even further. But this won't be achieved if irrigation is done every day or two, there needs to be a gap of several days to establish the moisture gradient.

A soil moisture sensor is an invaluable tool to quickly and accurately measure volumetric soil moisture. Several types are available, although not all are accurate across all soil types. I used a Theta Probe in my research, and validated it against the oven drying method on 56 different samples, from sand through to clay. The correlation between the Theta Probe measurements and the oven-dry values was 0.93 (Ford, 2013), so I have great confidence in the Theta Probe, which is also robust and easy to use.

Summary

Several factors affect water use efficiency in turfgrass. This paper has touched on three important ones. While each is important on their own, the combination of using a C_4 grass with a deep root system, maintained with severely restricted watering, and irrigated with a system with over 90% uniformity, will result in very efficient water use.

References

Ford, P.G. (2006): ET rates, Crop Factors and canopy temperatures of common turfgrasses during soil moisture depletion in summer conditions. Masters Thesis, University of Sydney.

Ford, P.G. (2006): An investigation into the agronomic factors affecting sustainability, surface hardness and rotational traction on community-level football grounds during drought conditions. Phd thesis, Federation University, Ballarat.

Fry, J. and Huang, B. (2004): Applied Turfgrass Science and Physiology. Wiley & Sons, N.J.

Hurto, K.A., Turgeon, A.J. and Spomer, L.A. (1980): Physical characteristics of thatch as a turfgrass growing medium. Agronomy Journal, 72(1), 165-167.

Zhou, Y., Lambrides, C.J. and Fukai, S. (2014): Drought resistance and soil water extraction of a perennial C_4 grass: contributions of root and rhizome traits. Functional Plant Biology 41(5) 505-519. http://dx.doi.org/10.1071/FP13249