

A blue golf ball is positioned behind the word "Sensors" in the main title. The background is a lush green lawn with a subtle white arc in the top-left and bottom-right corners.

To the Green: Audits, Sensors, and Tools for Next-Level Efficiency

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Water Quality: Why does it matter?

- **Affects soil structure and permeability (SAR, RSC)**
- **Influences infiltration rates**
- **Determines leaching requirement**
- **Impacts long-term rootzone stability (especially sand systems)**

Know your Water Quality



Salinity Hazard/Total Salts: Total content of soluble salts

Sodium Hazard/Sodium Adsorption Ratio: Relative proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions.

Bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) anions concentration, as it relates to Ca^{2+} plus Mg^{2+} ions

Specific ions that can be harmful: Boron, chloride, sulfate, and nitrate.

pH. Significance in relation to turfgrass health will depend on water use frequency and soil characteristics. pH can have major implications for tank mixtures.



Water Quality: Salinity

EC (dS/m)	Classification	Golf Implication
<0.5	Excellent	No salinity concern
0.5–1.5	Good	Monitor, rainfall often sufficient
1.5–3.0	Fair	Leaching required periodically
3.0–5.0	Poor	Routine leaching required
>5.0	Severe	Specialized management needed

***Salinity improves infiltration but increases plant stress.
You must balance both.***



Water Quality: Sodium Adsorption Ratio (SAR)

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{1}{2} (\text{Ca}^{2+} + \text{Mg}^{2+})}}$$

SAR	Risk Level	Golf Management Implication
<2	Low	Minimal concern
2-4	Moderate	Monitor structure; consider Ca inputs
4-8	High	Increased aerification + gypsum likely
>8	Severe	Structural decline likely; aggressive management

SAR alone is insufficient without EC context.

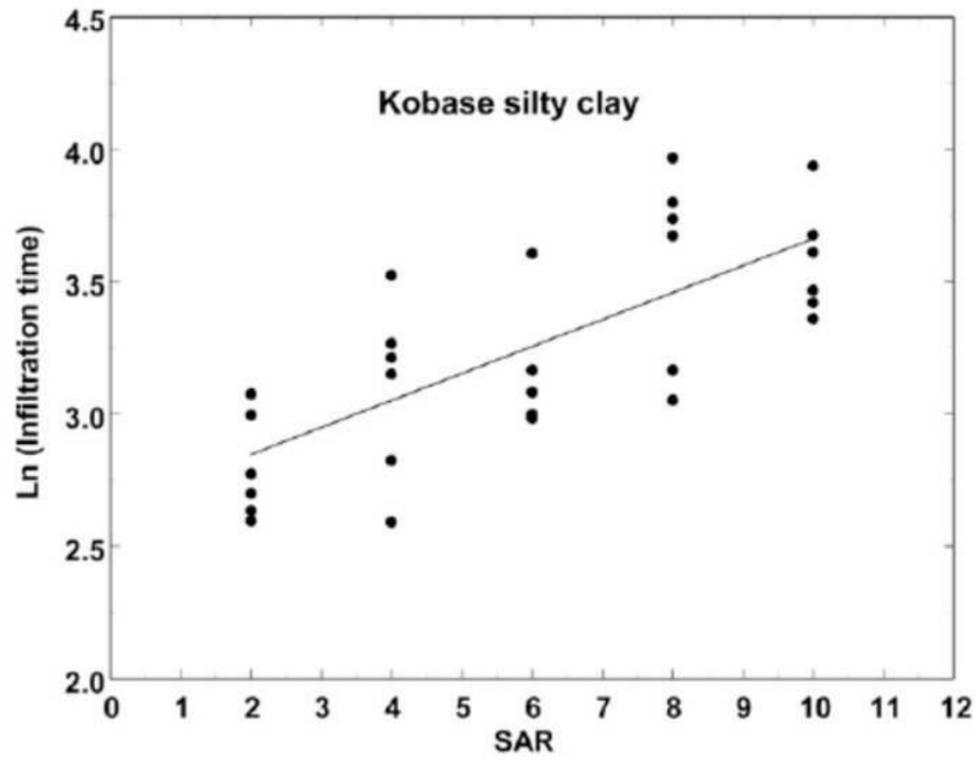
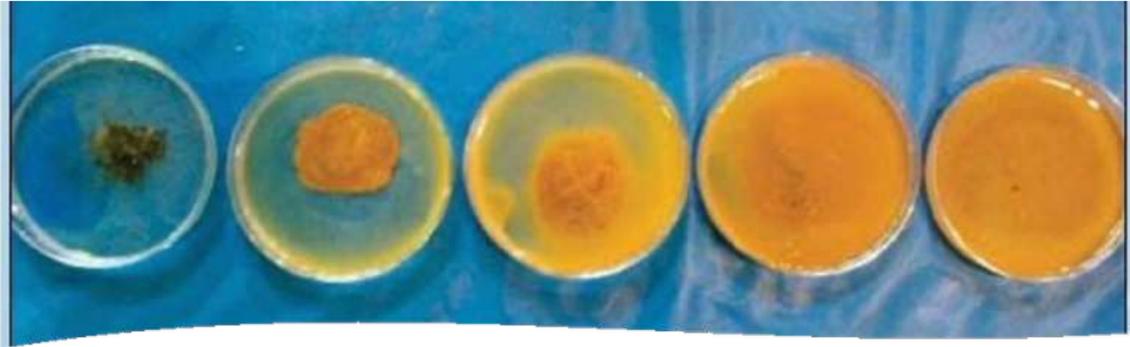
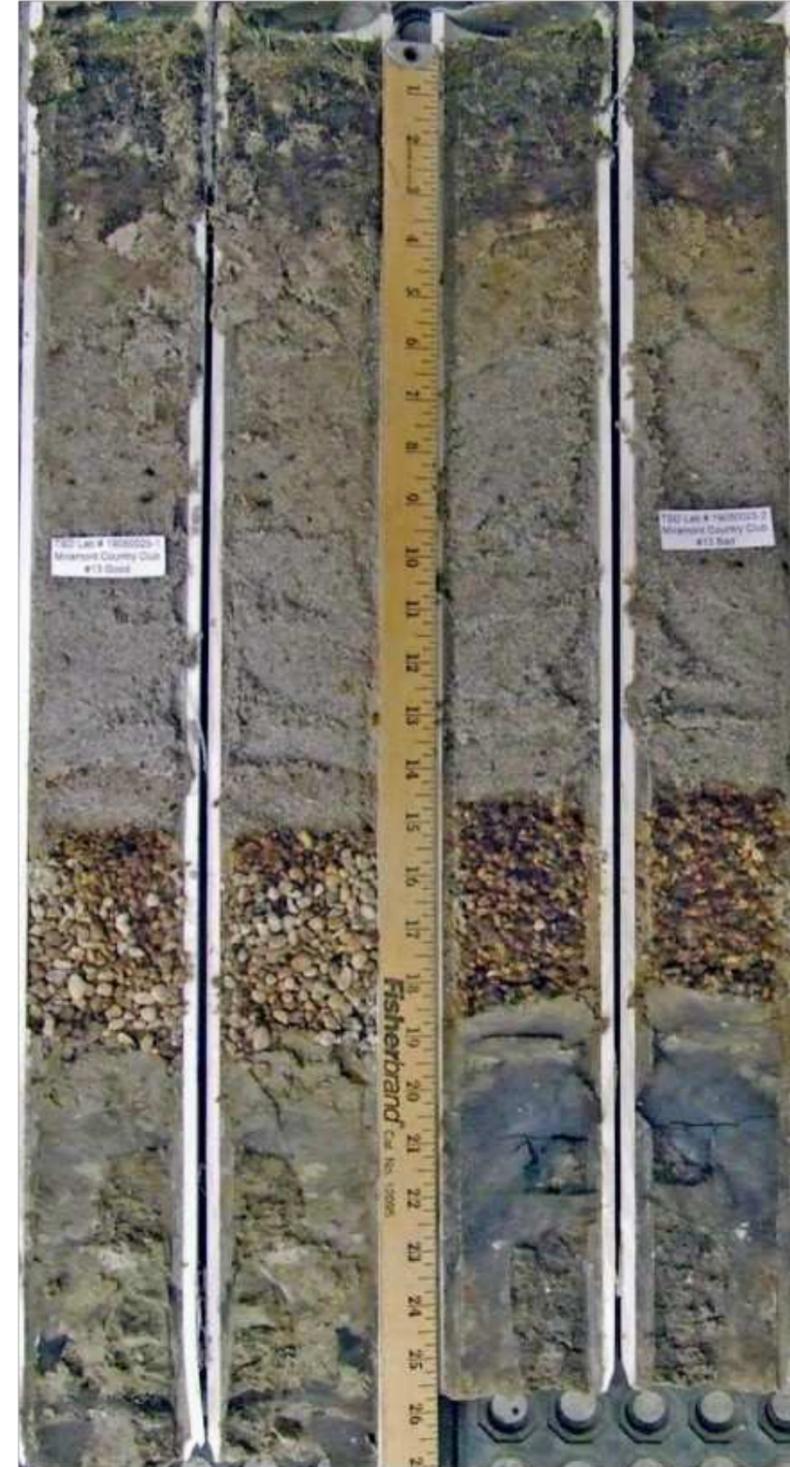


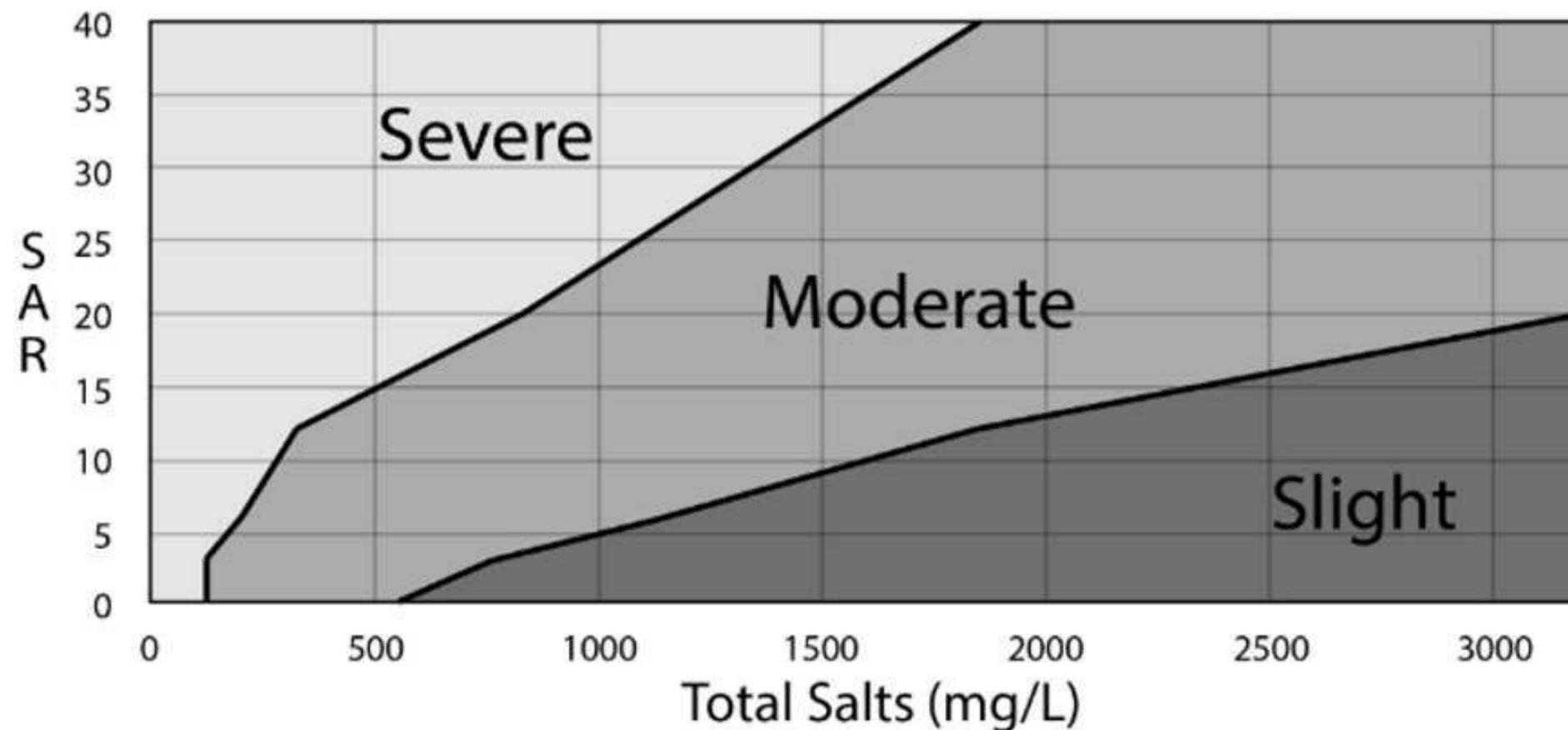
Fig. 4. Relationship between sodium adsorption ratio (SAR; $\text{mmol}^{1/2} \text{L}^{-1/2}$) and \ln infiltration time for clay soil, with data averaged across sampling periods.





Water Quality: SAR x EC

Expected Infiltration Problems



- High EC + high SAR → structural risk if salts are leached
- High SAR + low EC → highest dispersion risk
- High EC alone → infiltration improved but osmotic stress increases



Water Quality: Carbonates and Bicarbonates

- $\text{HCO}_3^- > 120 \text{ mg/L}$: **concern**
- $\text{CO}_3^{2-} > 15 \text{ mg/L}$: **concern**
- $\text{RSC} > 2.5 \text{ meq/L}$: **permeability hazard**

Carbonates remove Ca from solution → SAR increases over time → infiltration declines.

Parameter analyzed	Results	Units	Method	V. Limiting	Limiting	Acceptable
Calcium (Ca)	4	ppm	ICP			*****
Magnesium (Mg)	< 1	ppm	ICP			*****
Sodium (Na)	167	ppm	ICP			*****
Potassium (K)	1	ppm	ICP			*****
Boron (B)	1.39	ppm	ICP		*****	
Carbonate (CO ₃)	0	ppm	Titr.			*****
Bicarbonate (HCO ₃)	401	ppm	Titr.			*****
Sulfate (SO ₄ ⁻ calculated from total S)	19	ppm	ICP			*****
Chloride (Cl ⁻)	14	ppm	Titr.			*****
Nitrate-N (NO ₃ -N)	0.48	ppm	Cd-red.			*****
Phosphorus (P)	1.05	ppm	ICP			*****
pH	7.88		ISE			*****
Conductivity	732	umhos/cm	Cond.			*****
Hardness	1	grains CaCO ₃ /gallon	Calc.			*****
Hardness	15	ppm CaCO ₃	Calc.			*****
Alkalinity	329	ppm CaCO ₃	Calc.		*****	
Total Dissolved Salts (TDS)	611	ppm	Calc.		*****	
SAR	18.8		Calc.	*****		

Parameter analyzed	Results	Units	Method	V. Limiting	Limiting	Acceptable
Calcium (Ca)	2	ppm	ICP			*****
Magnesium (Mg)	< 1	ppm	ICP			*****
Sodium (Na)	372	ppm	ICP		*****	
Potassium (K)	2	ppm	ICP			*****
Boron (B)	1.52	ppm	ICP		*****	
Carbonate (CO ₃)	2	ppm	Titr.			*****
Bicarbonate (HCO ₃)	849	ppm	Titr.		*****	
Sulfate (SO ₄ ⁻ -calculated from total S)	3	ppm	ICP			*****
Chloride (Cl ⁻)	44	ppm	Titr.			*****
Nitrate-N (NO ₃ -N)	0.03	ppm	Cd-red.			*****
Phosphorus (P)	0.79	ppm	ICP			*****
pH	8.03		ISE			*****
Conductivity	1508	umhos/cm	Cond.		*****	
Hardness	1	grains CaCO3/gallon	Calc.			*****
Hardness	9	ppm CaCO3	Calc.			*****
Alkalinity	699	ppm CaCO3	Calc.		*****	
Total Dissolved Salts (TDS)	1277	ppm	Calc.		*****	
SAR	54.2		Calc.	*****		



Water Quality

- Test water and soil when there are concerns.
- Consult with an expert
- Develop a site-specific mitigation plan

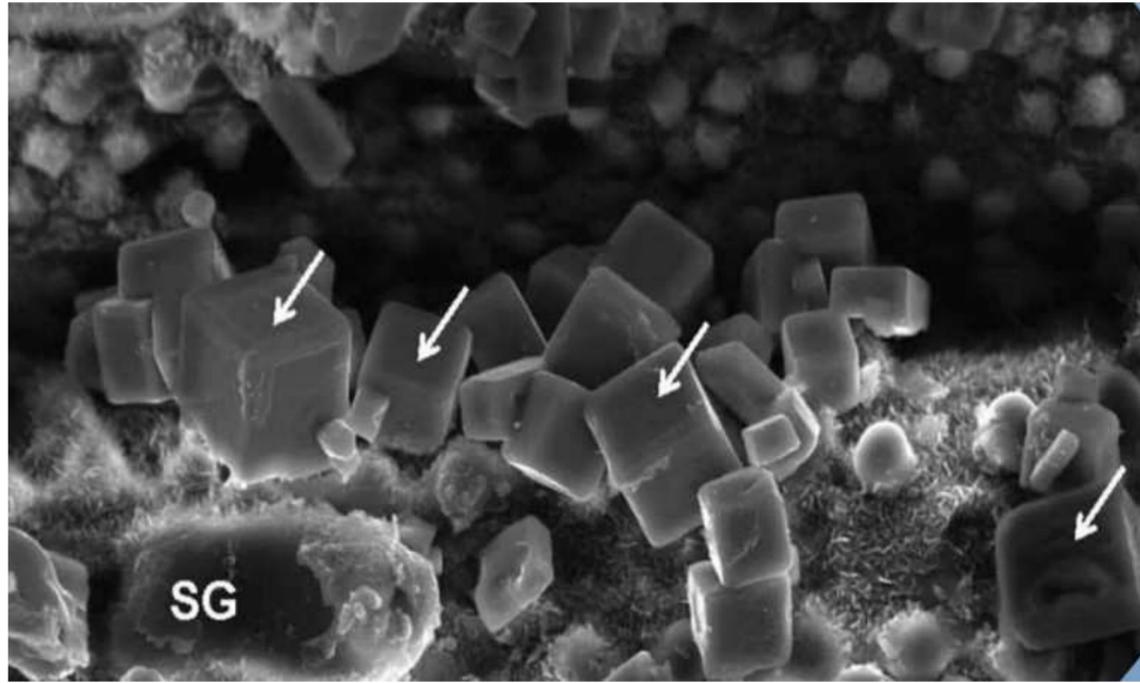


Water Quality: Mitigation through Selection



Species	Relative Salinity Tolerance	Average EC Threshold (dS/m)	Practical Notes
Seashore Paspalum	Very High	8.6	Best choice for saline irrigation; tolerates brackish water
St. Augustinegrass	High	6.5	Moderate-high tolerance; suitable for roughs
Common Bermudagrass	Moderate	4.3	Widely adapted; fair salinity tolerance
Hybrid Bermudagrass	Moderate	3.7	High performance but less salt tolerant than paspalum
Zoysiagrass	Variable	2.4	Tolerance varies significantly by cultivar

Adapted from Carrow, Waddington, Reike (2001)



Dynasty DALZ (0501) 2010 Salinity Test -



Advanced lines & commercial varieties after 8 weeks of 300 mM NaCl (\approx 40 % seawater)

Courtesy Dr. Milt Englke, Professor Emeritus, TX A&M



Water Quality: Mitigation

- 1. Turf Selection:** Choose species with EC thresholds aligned to irrigation source.
- 2. Leaching Fraction:** Plan periodic salt flushing based on EC of irrigation water.
- 3. Cultivation:** Aerification and topdressing maintain permeability under sodium pressure.
- 4. Soil Amendments:** Calcium inputs, acidification, and organic matter management to counter SAR and bicarbonates.

A close-up photograph of a cornfield. In the foreground, a black cylindrical container with a green lid sits on the ground, partially obscured by green corn stalks. The corn plants are vibrant green and appear to be covered in water droplets. The background is a vast field of similar corn plants, slightly out of focus, with a misty or foggy atmosphere. The word "AUDITING" is overlaid in large, white, bold, sans-serif capital letters across the center of the image.

AUDITING



WHY DO WE AUDIT?

- Determines actual precipitation rate (PR)
- Quantifies distribution uniformity (DU)
- Identifies hydraulic and mechanical inefficiencies
- Directly affects runtime calculations and water budget accuracy

YOU CANNOT SCHEDULE IRRIGATION ACCURATELY IF YOU DO NOT KNOW YOUR PRECIPITATION RATE AND UNIFORMITY.

AUDITING

WHAT AN AUDIT TELLS YOU



Precipitation Rate (PR)

- Inches/hour or mm/hour
- Converts ET demand into runtime

Distribution Uniformity (DU)

- Evenness of application
- Determines runtime multiplier
- Driest 25% controls schedule

System Condition

- Pressure imbalance
- Nozzle mismatch
- Arc coverage gaps
- Head-to-head spacing issues

AUDITING

Key Steps to Conduct an Audit:

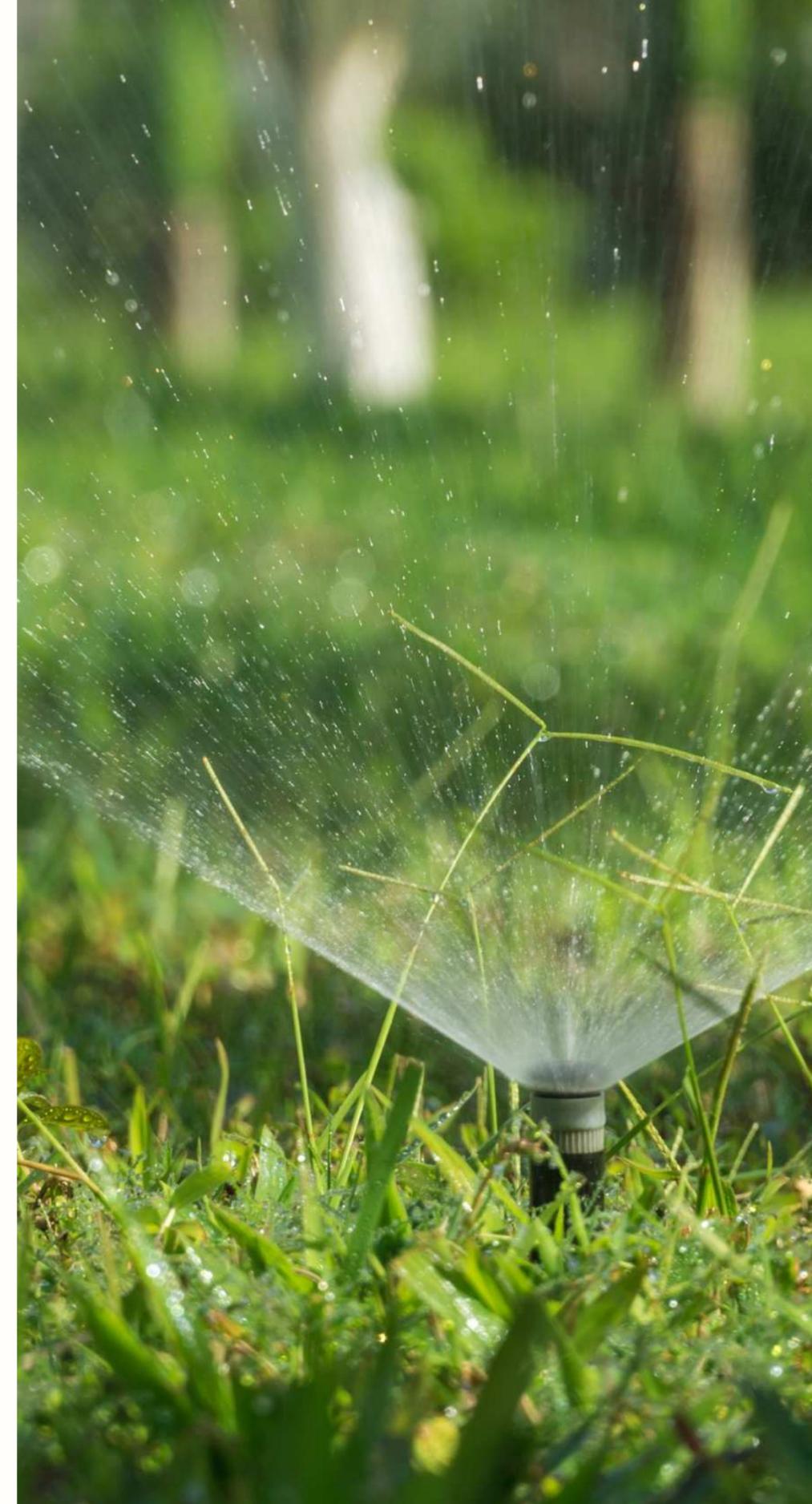
1. Site inspection and system tune-up
2. Place 24+ catch cans uniformly in test area
3. Run irrigation zone under calm conditions
4. Record water depth in each can (inches or mm)
5. Calculate metrics → adjust scheduling or maintenance



AUDITING: PRECIPITATION RATE

$$PR = \frac{\text{Average Catch Can Depth}}{\text{Testing Run Time}}$$

- The rate at which an irrigation system applies water.
- Typically expressed in: mm/hour
- PR determines how long a zone must run to deliver a target depth.



AUDITING: PRECIPITATION RATE

Irrigation Type	Typical PR (mm/hr)	Example Where Used
Spray heads	30–50 mm/hr	Tee surrounds, small turf areas
Traditional rotors	10–20 mm/hr	Fairways, rough
Multi-stream rotors (MPR)	10–15 mm/hr	Modern fairways
Valve-in-head golf systems	8–15 mm/hr	Greens, fairways

If PR > soil infiltration rate:
Runoff occurs

Example:

- Spray head PR = 40 mm/hr
- Soil infiltration = 15 mm/hr

Requires cycle-and-soak

AUDITING: DISTRIBUTION UNIFORMITY

Distribution Uniformity (DU, Lower Quartile):

- $DU = (\text{Avg. of lowest 25\% catch cans}) \div (\text{Avg. of all catch cans})$
- Expressed as a percentage (%)
- Higher DU = more efficient and uniform water coverage

AUDITING: DISTRIBUTION UNIFORMITY

Irrigation Technology	Typical DU _q Range (decimal)	Example Where Used / Notes
Matched Precipitation Rotors (MPR / Multi-stream rotary)	0.75 – 0.85+	Modern golf fairway & rough systems with matched precipitation heads; generally higher and more consistent DU due to engineered multi-stream flow.
Gear-Driven Rotor Heads (well-designed & spaced)	0.70 – 0.80	Traditional rotor systems on turf (fairways and large turf zones) when pressure and spacing are optimized. Often observed as “good” in practice.
Standard Spray Heads (fixed pattern)	0.55 – 0.75	Common in landscape but also found on tee surrounds and small turf pods. These heads tend to have lower DU than rotors and are pressure-sensitive.
Unoptimized / Poorly spaced Spray or Rotor Systems	≤ 0.60	Aging equipment, mixed nozzle types, pressure issues, or poor spacing can yield low DU; flagged for system improvement

AUDITING: SYSTEM PERFORMANCE

Common Issues...

- Pressure variation across long fairway runs
- Worn or mismatched nozzles
- Partial arc rotation errors
- Sunken or tilted heads
- Valve flow restrictions
- Pump station variability





KEY ADVANCEMENTS AND TRENDS IN IRRIGATION TECHNOLOGY

SMART CONTROLLERS



- Advanced devices that automate irrigation schedules.
- Adjust water delivery based on weather, soil moisture, and/or ET rates.
- Optimize water use, improve efficiency, and reduce waste.
- Ideal for golf courses, sports fields, and residential lawns.



SOIL MOISTURE SENSOR (SMS) SYSTEMS

Sensors monitor soil moisture levels and adjust irrigation schedules to prevent overwatering.

- Capacitance-based, time domain reflectometry (TDR), time domain transmission (TDT), impedance and resistive sensors, gypsum block, frequency domain sensors, etc.

SMS SYSTEMS

PRO

- **Reduces water use** without compromising turfgrass quality.
- **Improves precision and efficiency** compared to traditional systems.
- Newer systems are **user-friendly and cost-effective** (Muñoz-Carpena et al., 2005, Dukes 2012)

CON

- Requires careful calibration and proper placement of sensors.
- Soil variability can affect accuracy and performance, clay soils can present challenges

SAVING

- Reduced water usage by **59-82%** during rainy periods and **83% during dry weather** compared to constant schedules (Cardenas & Dukes, 2010; Haley & Dukes, 2011).
- Estimated water savings **up to 66%** in humid environments (Sandor et al., 2022).

EVAPOTRANSPIRATION (ET)-BASED CONTROLLERS



Uses weather data to estimate water loss through evapotranspiration and schedules irrigation accordingly.

ET-BASED CONTROLLERS

PRO

- Effectively matches water application to plant needs, minimizing waste.
- Ideal for large turfgrass areas, such as golf courses

(Serba et al., 2022; Serena et al., 2020)

CON

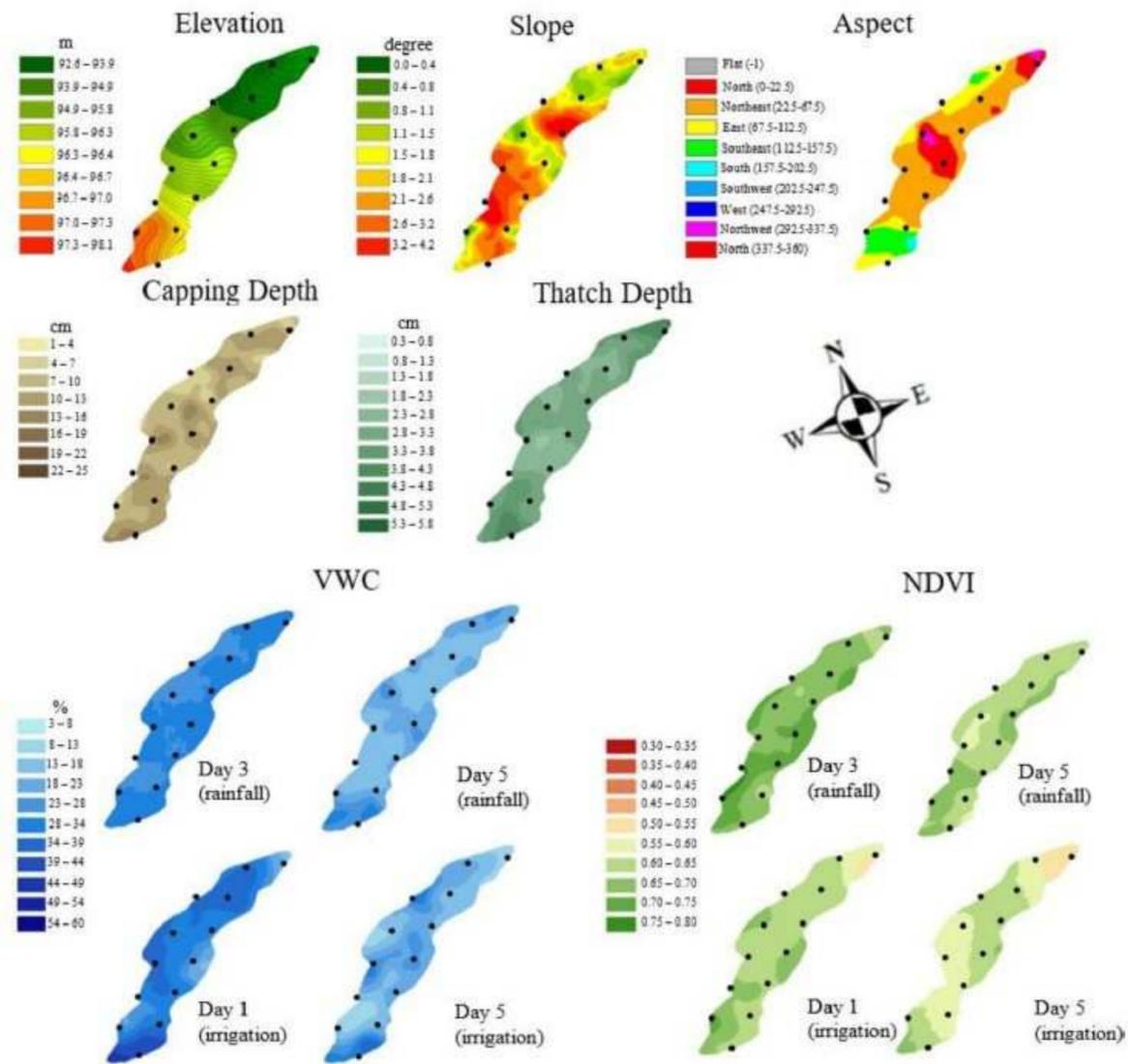
- Performance depends on the availability and accuracy of weather data.
- Initial setup costs can be high

SAVING

Reductions of **20-43%** in irrigation water use, depending on environmental conditions (McCready et al., 2009, Serena et al, 2020)

Can save **\$5-\$100** per month on water bills for an average-sized lawn (Blonquist et al., 2006)

PRECISION IRRIGATION TECHNOLOGY



Precision irrigation refers to the application of water based on specific site needs, using advanced tools and techniques to optimize water use and maintain turfgrass quality. In addition to SMS and ET-based technology, precision irrigation systems may utilize:

- **Valve-in-Head Sprinkler Systems:** Allow site-specific water application by controlling individual sprinkler heads (Hejl et al., 2022).
- **Drone and Remote Sensing Technologies:** Provide spatial data on soil moisture and turfgrass health for targeted irrigation management (Kerry et al., 2023).

(Hejl et al.,
2022).

PRECISION IRRIGATION TECHNOLOGY

PRO

- Reduces water waste by focusing irrigation on high-priority areas (Datta & Taghvaeian, 2023).
- Enhances turf quality and health through precise water delivery and greater uniformity (Bowman et al., 2012).

CON

- High upfront costs and complexity in setup (Datta & Taghvaeian, 2023).
- Requires specialized personnel for management and maintenance (Bowman et al., 2012).

SAVING

- Up to 40% compared to traditional irrigation (Bowman et al., 2012).
- Improved water-use efficiency by targeting specific areas of need (Datta & Taghvaeian, 2023).

HIGH EFFICIENCY HEADS AND NOZZLES



- **Rotary Nozzles:** Between 30–50% water savings with slower, steady spray and improved infiltration.
- **Pressure-Reducing Spray Heads:** Up to 10-20% water savings by maintaining optimal pressure for water distribution.
- **Low-Flow Rotors:** Up to 40% water savings with lower flow rates and more uniform water distribution.
- **Matched Precipitation Nozzles:** Up to 20% water savings by ensuring uniform water application across all sprinkler heads.

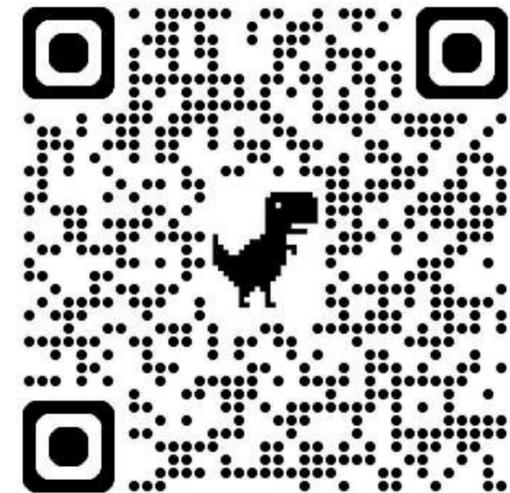
HIGH-DENSITY POLYETHYLENE PIPES

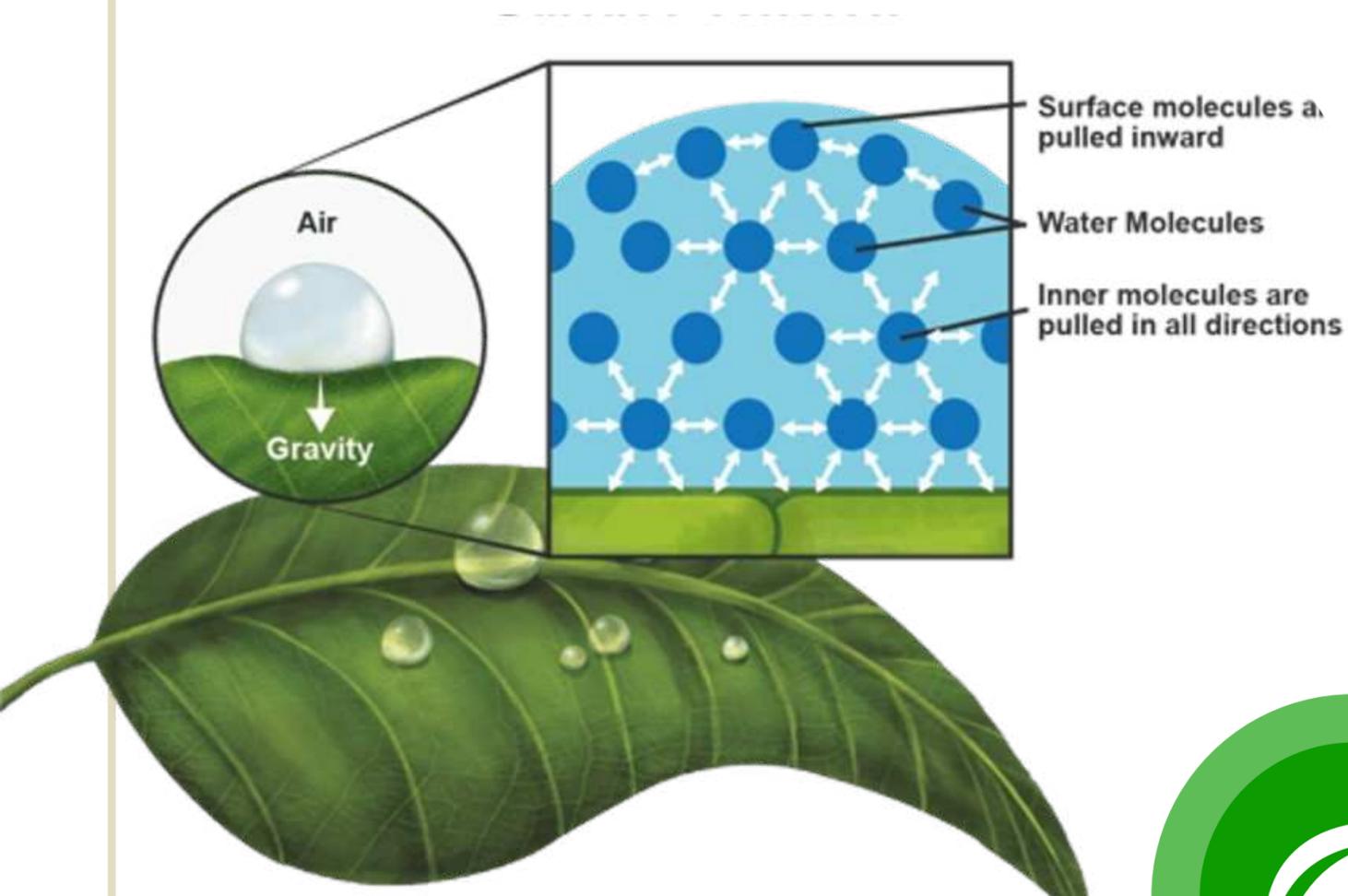
PRO

- Highly durable, resistant to corrosion and chemicals.
- Flexible, allowing for easy installation in uneven terrains.
- **Leak-resistant joints**, reducing water loss.
- Impact-resistant, minimizing damage during installation and use.
- Long service life (50+ years).

CON

- Higher initial cost compared to PVC, **often cost-prohibitive**
- Requires specialized equipment for installation (fusion welding).
- Can become brittle in extremely cold temperatures.
- Can be more complex or challenging for large diameters.

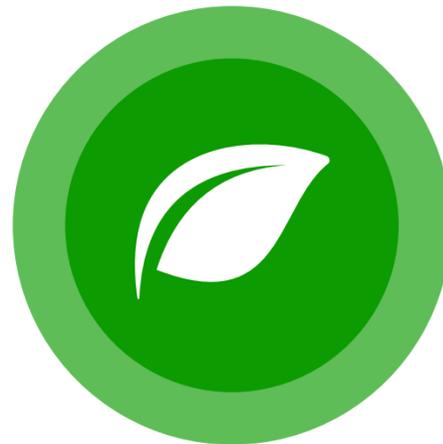




Other Tools: Soil Surfactants

“**Surfactants** are compounds that lower the surface tension (or interfacial tension) between two liquids, between a gas and a liquid, or between a liquid and a solid.”

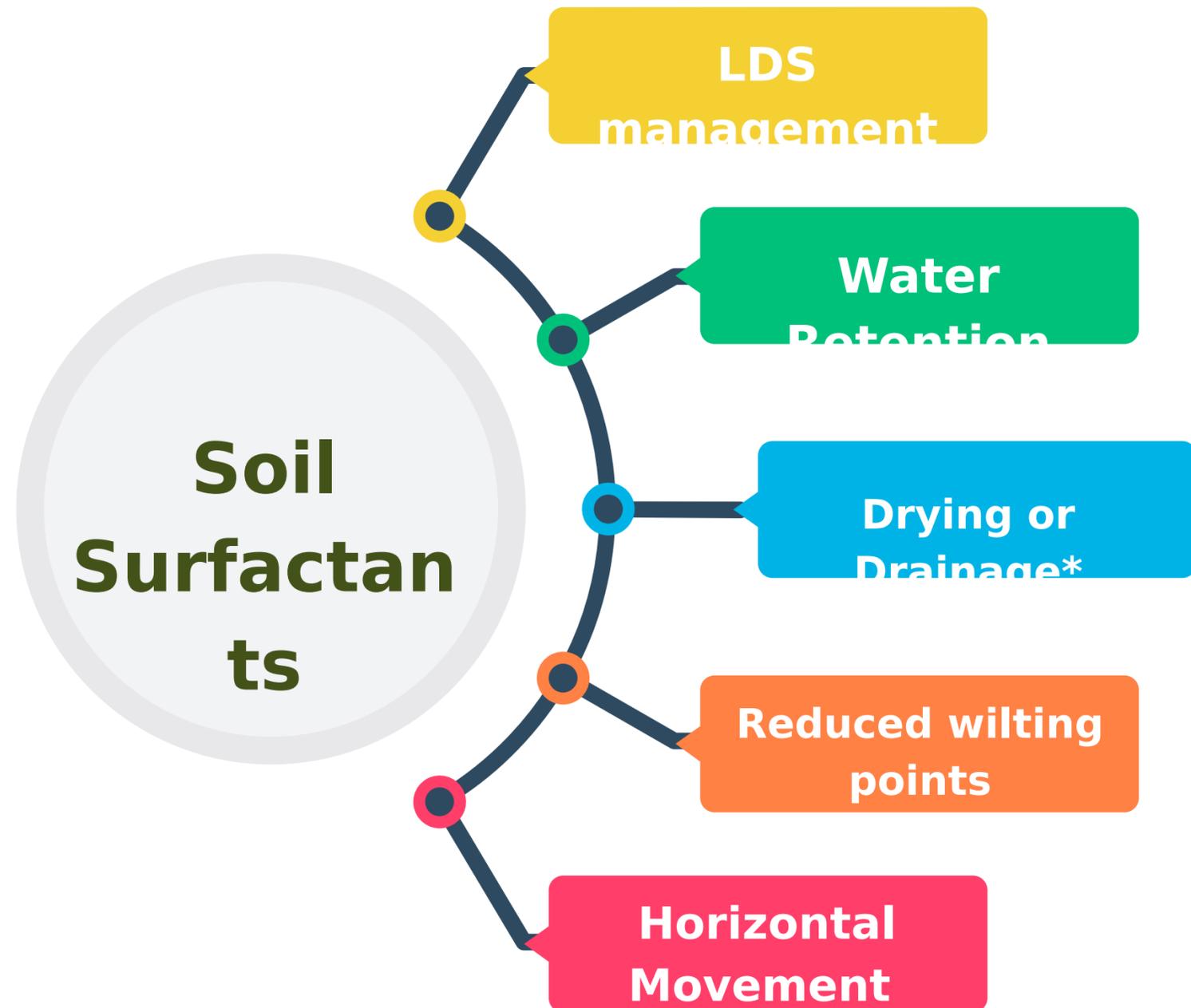
Fidanza, M., Kostka, S., & Bigelow, C.
(2020)





Soil Surfactants

Surfactants have demonstrated the potential to offer several benefits in turfgrass management.





Sand, Silt, and Clay

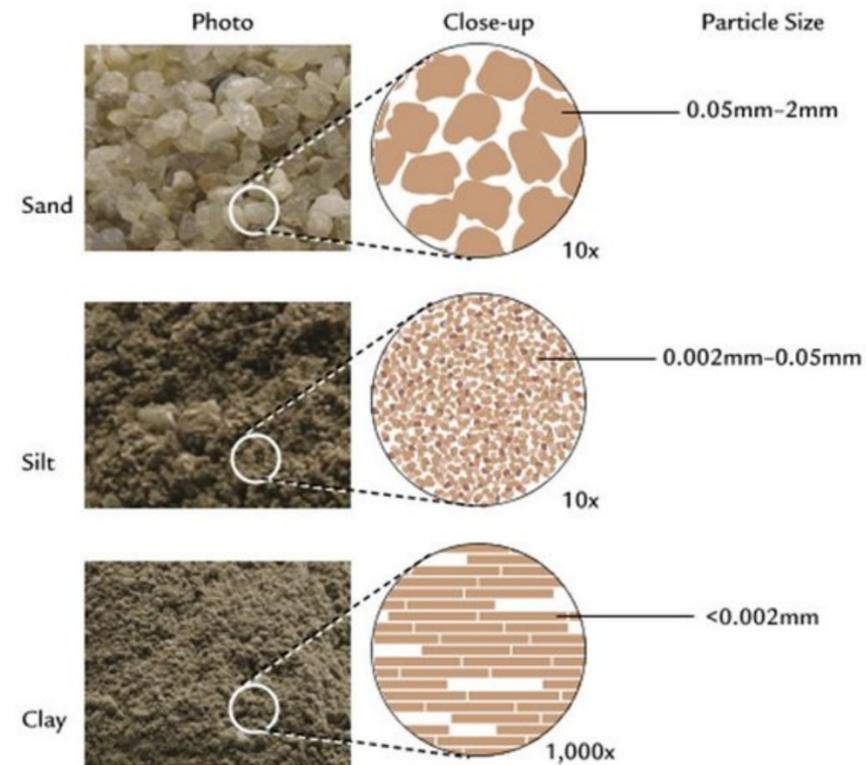


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USGA

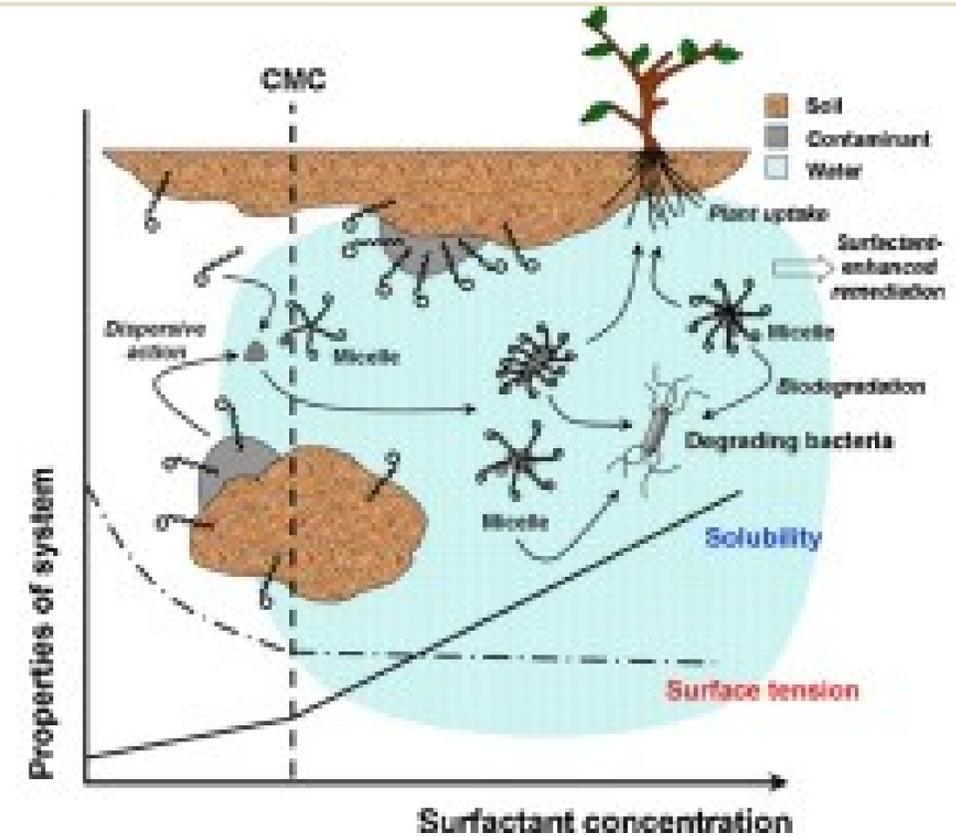
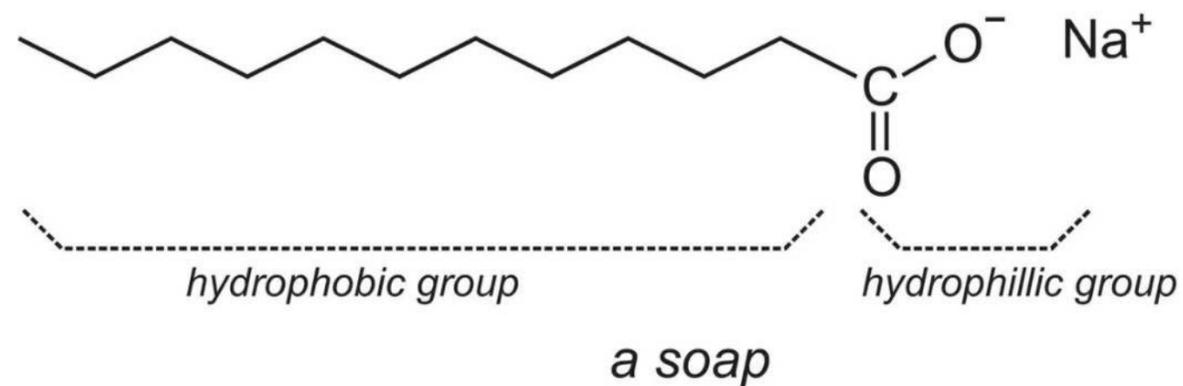
Hydrophobicity and Localized Dry Spot (LDS)

Hydrophobicity in soils is believed to occur due to a coating of complex, water-repellant, organic compounds (i.e., humic acid and fulvic acid) on soil particles.

This tends to be most problematic in sandy soils.



Soil Surfactants: In a nutshell



Surfactants, which closely resemble soaps or detergents, contain both **water-loving** and **oil-loving** components. This allows them to essentially make liquids “wetter” and meet less resistance as they move across surfaces, such as soils that have become coated in waxy chemicals.



**Surfactants will generally
improve soil moisture
uniformity, and can be a
valuable water conservation
tool**



Soil surfactants
reduced
preferential flow

(We'll revisit
this)



Greater volumetric
water content
resulted in greater N

(and
this)



There's extensive evidence that soil surfactants can improve moisture uniformity on sand-based rootzones.

[Effects of a soil surfactant on grass performance and soil wetting of a fairway prone to water repellency](#)

by Dekker et al (2019)

Key Findings

- Surfactant applications improved soil wetting, reduced water repellency, and minimized localized dry spots.
- Treated plots had **>80% green grass coverage**, outperforming untreated plots during dry periods
- Surfactants **improved irrigation efficiency** by reducing water waste.



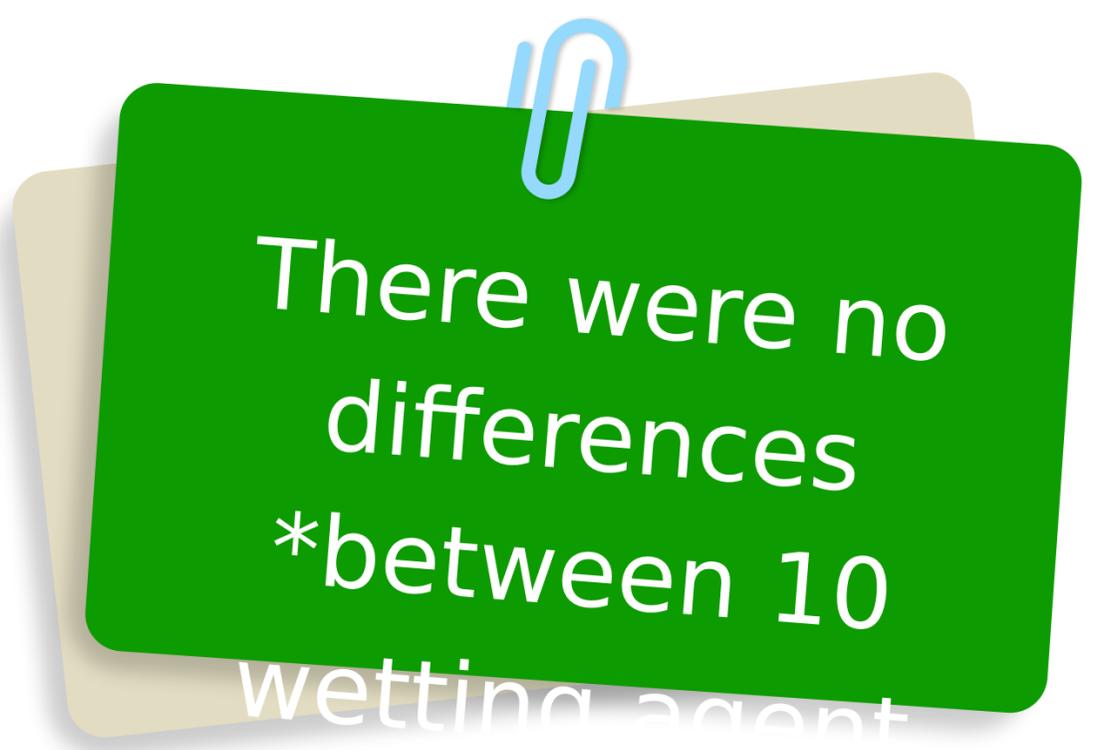
Even on native soil fairways, there can be **benefits**

[Identification of wetting agents for water conservation on deficit-irrigated hybrid bermudagrass fairways](#)

by Xiang et al (2021)

Key Findings

- All treated plots maintained **improved turf quality** compared with untreated
- Soil volumetric water content was greater by **up to 16%**
- Up to **21% irrigation water savings** while maintaining turf quality at acceptable levels



There were no differences
*between 10

wetting agent

(We'll also revisit this)





**Understand Local Needs;
Don't Rely Solely on
Promotional Language.**



The claim:

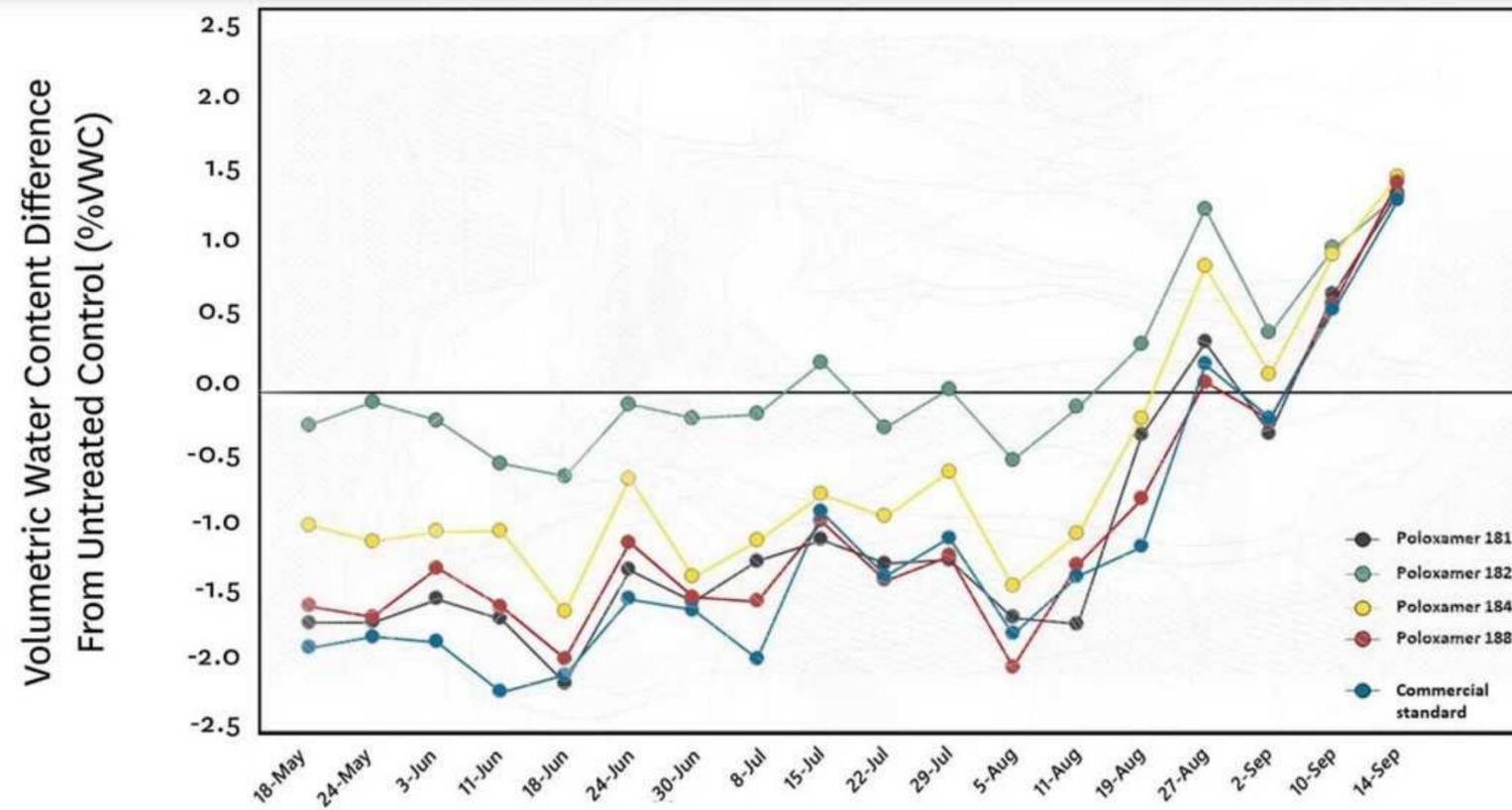
- **Penetrants:** Enhance water infiltration, reducing water repellency on soil surfaces
- **Retainers:** Retain moisture within the root zone for sustained turf hydration

The reality:

- Lab findings have been hard to replicate in field studies.
- Terminology lacks standards and is often marketing-driven.
- Timing, soil, turf, and environment drive surfactant performance.



2021 Wetting Agent Active Ingredient Trial



O'Brien et al.
(2023)


**Arkansas
Research,
USGA
Article**





Soil Surfactants

J. Hydrol. Hydromech., 68, 2020, 4, 306–312
 DOI: 10.2478/johh-2020-0032
 ISSN 1338-4333

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Communication of soil water repellency causes, problems, and solutions of intensively managed amenity turf from 2000 to 2020

Michael Fidanza^{1*}, Stanley Kostka¹, Cale Bigelow²

Table 1. Soil surfactant products for the turf industry in the USA market in 2019.

Chemical Class	<i>n</i>	Chemical Category	<i>n</i>	Formulation Category	<i>n</i>
Nonionic	142	Block Copolymer	112	Block Copolymer	94
				Block Copolymer - Alcohol Ethoxylate Blends	3
				Block Copolymer + Alkylpolyglycoside	5
				Block Copolymer - Maleic Acid Blends	3
				Block Copolymer - Solvent Blends	2
				Modified Methyl Capped Block Copolymer	1
				Oleic Acid Esters of Block Copolymer	1
				Other Block Copolymer Blends	3
		Alcohol	2	Alcohol Ethoxylates	2
		Alkylpolyglucoside	4	Alkylpolyglucoside	4
		Botanical	1	Yucca plant extract	1
		Organosilicone	1	Organosilicone	1
Polyalkylene	5	Polyalkylene	5	Hexahydroxy Polyalkylene Polymers	1
				Octahydroxy Polyalkylene Polymers	4
				Polyoxyethylene - Alkylpolyglucoside Blends	2
				Polyoxyethylene - Block Copolymer Blends	2
				Polysorbate Polyoxyethylene Copolymer	13
Polyoxyethylene	17	Polyoxyethylene	17	Anionic Blends	11
				Blends of Anionic and Nonionic	7
				Not Disclosed	32
Anionic	18	Anionic and Blends with Anionics	18	Anionic Blends	11
				Blends of Anionic and Nonionic	7
Unknown	32	Not Disclosed	32	Not Disclosed	32

Total Products in the Marketplace: 192

Table 2. Soil surfactant products for the turf industry in the UK and Republic of Ireland markets in 2019.

Chemical Class	<i>n</i>	Chemical Category	<i>n</i>	Formulation Category	<i>n</i>
Nonionic	43	Block Copolymer	32	Block Copolymer	19
				Block Copolymer + Alkylpolyglycoside	3
				Block Copolymer + Fatty Amine + Organosilicone + Acetic Acid	1
				Block Copolymer + Glycol	1
				Block Copolymer + Organosilicone	1
				Block Copolymer + Succinate	1
				Block Copolymer + Terpene-derived Surfactant	1
				Block Copolymer + Not disclosed	2
				Alkyl-terminated Block Copolymer	1
				Alkyl-terminated Block Copolymer + Block Copolymer	1
				Oleic Acid Esters of Block Copolymer	1
		Alcohol	1	Ethoxylated Fatty Alcohols	1
		Botanical	2	Yucca plant extract	2
		Organosilicone	3	Organosilicone	3
		Other / Not Categorized	2	Other / Not Categorized	2
Ducosate Sodium Sulfate	1				
Polyalkylene	2	Polyalkylene	2	Hexahydroxy Polyalkylene Polymers	1
				Octahydroxy Polyalkylene Polymers	1
Polyoxyethylene	1	Polyoxyethylene	1	Polysorbate Polyoxyethylene Copolymer	1
Anionic	4	Anionic and Blends with Anionics	4	Anionic + Alcohol Ethoxylate	1
				Anionic + Block Copolymer	1
				Anionic - Not disclosed	2
Unknown	18	Not Disclosed	18	Not Disclosed	18

Total Products in the Marketplace: 65



Taking your own data can be the best way to know what works

Firmness or volumetric water content measurements collected before and after soil surfactant applications can shed light on site-specific impacts

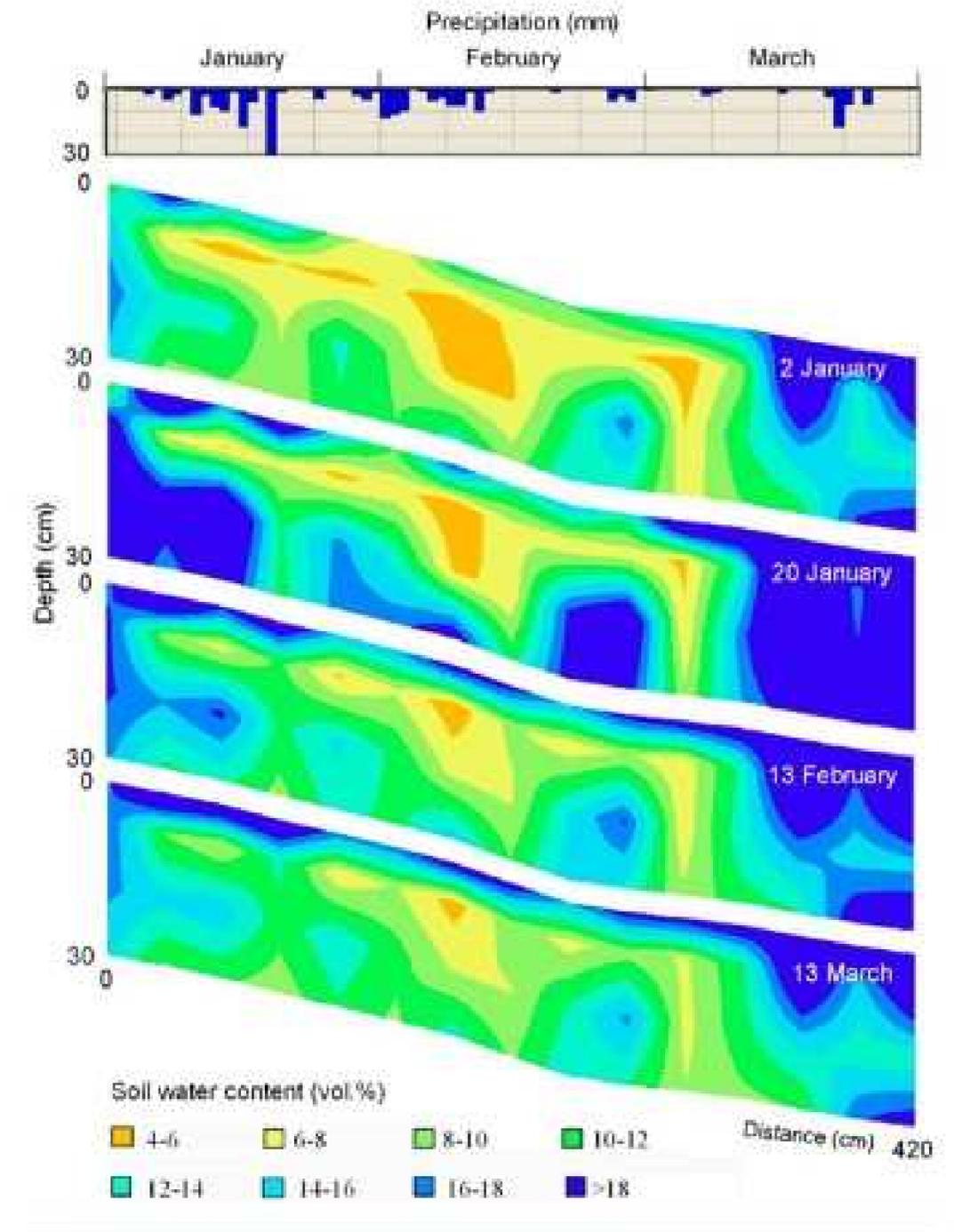


**Benefits may extend to pest
and nutrient management,
but this is not
straightforward and needs
further study**



Reductions in preferential flow can be beneficial

- Water repellency can accelerate pesticide leaching to groundwater (Blackwell 2000).
- Inconsistency in soil moisture uniformity can make pesticide performance and movement (fate) less predictable.



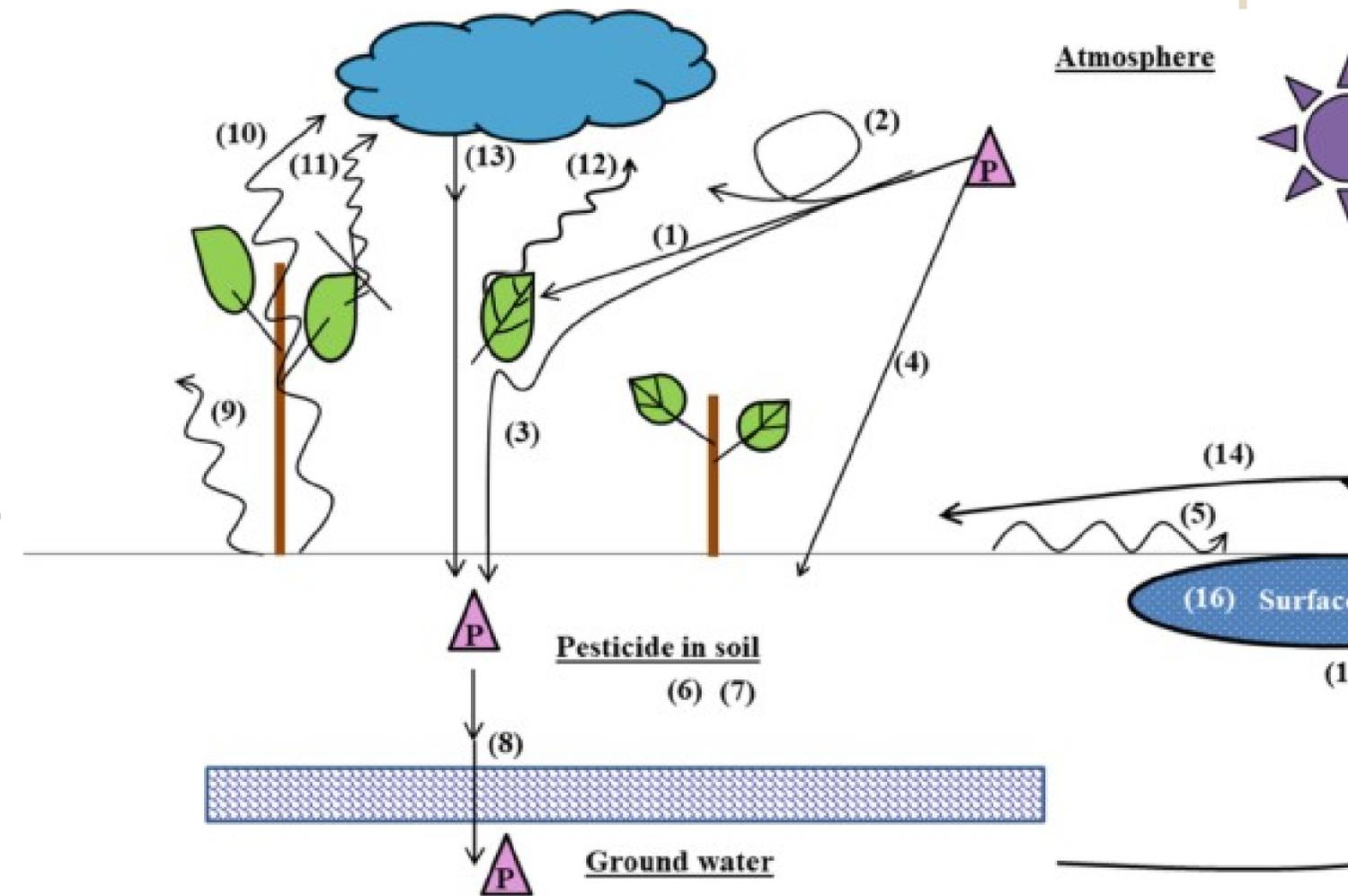
Oostindie et al.,
2011



Study findings are inconsistent on this issue

Chens et al. (2019) found surfactants **improved fungicide penetration** and **distribution uniformity** but **increased leachate by 28%**, raising runoff risks.

- Chang et al. (2020) found wetting agents **did not reduce runoff or nutrient loss** in non-hydrophobic sandy loam soils.





**There is still a lot we don't
know.**



Knowledge Gaps and Food for Thought

- Significant knowledge gaps remain about soil surfactant ingredients and actions, despite increasing product availability.
- Most research has been conducted in golf compared with other turfgrass systems.
- Application timing may matter more than rates (or even product), but more research is needed.
- Soil complexity makes predicting surfactant behavior challenging, particularly in native soils.
- Performance depends on microbial activity and soil conditions, with models being developed to guide use
- Impacts on some pesticide and fertilizer movement and efficacy remain uncertain.





Thank You!

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