Precision Irrigation

Phenomenon/Problem:

Why and how do different irrigation methods change water use and crop yield?

Essential Questions:

- Where does water go as it moves through an irrigation system and agricultural field?
- How do forces and pressure cause water to move through an irrigation system?
- How do the physical features of an irrigation system affect the way water is delivered?
- Why doesn't all of the water pumped through an irrigation system reach its intended location?
- How do environmental conditions affect the movement and transfer of water during irrigation?
- How does irrigation-system design affect the amount of water and energy required to produce a crop?
- How much water must reach the crop to maintain plant growth and yield?
- How can irrigation systems be designed or optimized to conserve water while maintaining crop production?
- What tradeoffs must farmers consider when selecting or designing an irrigation system?

Stimuli: How will students experience and/or observe the phenomenon/problem?

Students first observe photographs or diagrams comparing the irrigation methods. They notice that one system sprays water above the soil surface while another delivers water through drip lines much closer to the soil and crop roots.

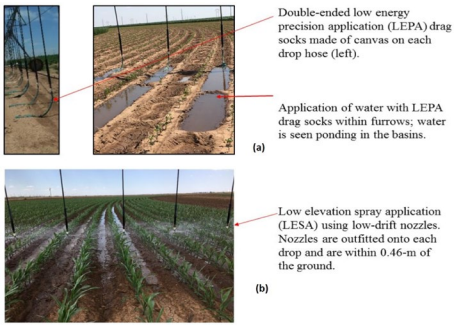


Figure 1. Application methods commonly used on center pivot systems in the Texas High Plains region (a) low energy precision application (LEPA); and (b) low elevation spray application (LESA).

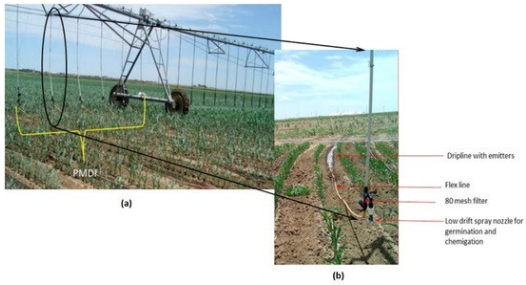


Figure 2: Precision mobile drip irrigation (MDI) system: (a) shown on span 1 to the left; and (b) zoomed-in view of one MDI drop showing sprinkler hardware, filter and dripline dragging between.

Images from: https://www.mdpi.com/2073-4395/7/4/68

Then students examine selected data from the Texas study showing irrigation/water inputs, crop water use, and grain yield under the different irrigation systems.

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Irrigation Method	2015		2016	
	Irrigation Applied (mm)	Grain Yield (kg/m^2)	2016 Irrigation Applied (mm)	Grain Yield (kg/m^2)
LESA	291	0.989	352	1.05
LEPA	312	0.926	357	1.08
MDI	294	0.962	314	1.04

In 2016, MDI received roughly 11% less irrigation than LESA and 12% less than LEPA, yet the researchers reported that grain yields were statistically similar across application methods. MDI also had the lowest crop water use and highest water-use efficiency that year.

MDI received less irrigation water and crop water use differed, but corn yield remained similar. Why?

Related Phenomena/Problems:

- Water released from different irrigation nozzles travels different distances and creates different spray patterns.
- Changing the pressure in an irrigation system changes the rate and pattern at which water is delivered.
- Two irrigation systems pump the same amount of water but deliver different amounts to the intended area.
- Water sprayed high above a crop is more affected by wind than water released close to the soil.
- Smaller water droplets can evaporate more quickly than larger droplets under the same environmental conditions.
- Two irrigation systems produce similar crop yields but require different amounts of water and/or energy to operate.
- Lowering sprinkler heads on a center pivot changes where water lands without changing the crop being irrigated.
- Drip irrigation and sprinkler irrigation create different patterns of water distribution even when operated for the same amount of time.
- Increasing irrigation does not always result in a proportional increase in crop yield.
- Different areas within the same field receive or retain different amounts of water even when a uniform irrigation system is used..
- An irrigation system that conserves the most water is not necessarily the least expensive or least energy-intensive system.
- Farmers must choose among irrigation technologies that differ in pressure requirements, water delivery, energy use, cost, maintenance, and crop performance.

Considerations for Instructional Design:

- Develop and use a model to trace water and energy through an irrigation system and crop field, identifying where water is delivered, transferred, stored, or lost. Compare models of different irrigation technologies to explain how system design changes the pathways water takes. (MOD, Systems & System Models)
- Plan and carry out an investigation to determine how variables such as water pressure, flow rate, outlet size, or delivery height affect the movement and distribution of irrigation water. Use evidence to explain how changing a physical feature of an irrigation system can change its performance. (INV, Cause & Effect)

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- Analyze irrigation, water-delivery, energy-use, and crop-yield data to identify relationships among the resources entering an irrigation system, the water reaching its intended location, and crop productivity. Use patterns in the data to explain why increasing water or energy inputs does not necessarily produce a proportional increase in yield. (DATA, Energy & Matter)
- Construct an explanation for why changing how water is delivered can reduce the amount of irrigation required while maintaining similar crop yields. Connect the physical movement and transfer of water through the irrigation system with the amount of water ultimately available to the crop. (CEDS, Cause & Effect)
- Analyze spatial data, such as soil-moisture, irrigation-application, topographic, or remote-sensing maps, to identify patterns in where water is delivered and retained across a field. Use these patterns to explain why uniformly applying water may not be the most efficient approach. (DATA, Patterns)
- Compare and evaluate irrigation-system designs based on how their physical features affect water movement, distribution, and energy requirements. Optimize a solution using criteria and constraints such as crop yield, water use, energy use, cost, environmental conditions, and system performance. (CEDS, Structure & Function)
- Use mathematical and computational representations of variables such as flow rate, irrigation duration, water volume, pressure, or energy use to compare irrigation strategies and determine how changes to system operation affect resource use and water delivery. (MATH, Scale, Proportion & Quantity)

Explanation:

In the Texas High Plains, farmers rely on irrigation to produce crops such as corn, but the region's water supply is limited. Much of that irrigation water comes from the Ogallala Aquifer, where declining groundwater levels make using available water efficiently increasingly important.

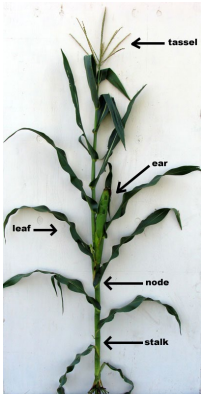
Researchers near Bushland, Texas, investigated whether changing the way irrigation water was delivered could help. They grew corn under different center-pivot irrigation systems, including conventional low-elevation spray application and mobile drip irrigation (MDI), which uses drip lines dragged along the soil surface to deliver water closer to the crop and soil.

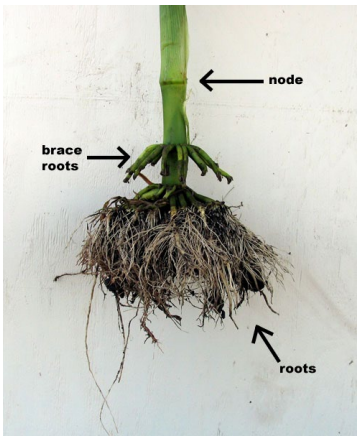
Despite differences in how water reached the field and how efficiently it was used, researchers found that corn grain yields were generally similar among the irrigation systems. Under the more water-limited conditions of the study, mobile drip irrigation also demonstrated greater crop water-use efficiency. This creates the central puzzle:

If corn plants need water to grow, how can changing where and how irrigation water is delivered allow farmers to get similar yields from available water?

Root Structure and Water Need

Corn plants depend on specialized structures to obtain and transport the water needed for growth and reproduction. Roots extend through the soil and absorb water from the root zone. Water then moves through vascular tissue from the roots to stems and leaves, where it supports processes such as photosynthesis, nutrient transport, cell expansion, and stomatal regulation. If roots cannot access enough water, these processes can be disrupted, reducing plant growth and ultimately grain production. However, once sufficient water is available to support plant growth and grain development, supplying additional water does not necessarily produce a proportional increase in crop yield.





Images from: https://passel2.unl.edu/view/lesson/c3ded390efbf/3

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Pathways and Losses
This means that successful irrigation depends not simply on the total amount of water applied to a field, but on delivering sufficient water to locations where plant roots can access it. Not all water leaving an irrigation system reaches or remains within the root zone. Water can evaporate as it travels through the air or from plant and soil surfaces, be carried away from its intended location by wind, run off the soil surface, or move below the active root zone through drainage. Temperature, humidity, wind, soil properties, and existing soil moisture can all influence these pathways.

Physical Irrigation System
The physical design of an irrigation system influences how water moves from its source to the crop's root zone. Pumps create pressure differences that move water through pipes and irrigation equipment. Pressure, flow rate, outlet or emitter size, arrangement of outlets, and delivery height influence the velocity, droplet size, distribution, and location of applied water. Changing these physical features changes how the system functions and, ultimately, where the water goes.

For example, water sprayed through the air must travel farther before reaching the soil and may be more susceptible to wind drift and evaporation. Systems that release water closer to the soil surface or through drip lines shorten that pathway and concentrate water delivery nearer the root zone. As a result, irrigation systems can differ in the proportion of pumped water that reaches locations where it can remain available to plants. Improving water delivery does not change how much water an individual corn plant biologically needs; it can reduce the amount of irrigation water that must be pumped and applied to meet that need. Each system also involves other considerations, such as cost, labor, maintenance, and suitability for a given field.



Image from: https://www.usgs.gov/water-science-school/science/irrigation-spray-or-sprinkler-irrigation

Energy Requirements
Moving irrigation water also requires energy. Energy is used to pump, pressurize, and transport water through the system, and the amount of water moved, required pressure, elevation, friction within pipes, and system design influence those energy requirements. Irrigation design therefore involves tradeoffs among water use, energy use, distribution uniformity, cost, maintenance, and crop production.

Efficiency in Resource Use and Production Yields
In the Texas High Plains study, changing the physical system used to deliver irrigation water resulted in similar corn grain yields across irrigation methods, while mobile drip irrigation demonstrated advantages in crop water-use efficiency under more water-limited conditions. The findings illustrate why crop production depends not simply on how much water enters an irrigation system, but on how effectively the system moves and delivers that water to where plants can access it. By changing the pathway water takes and reducing opportunities for unnecessary loss, irrigation technology can help farmers use available water more efficiently while maintaining crop productivity.

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Note: Farming practices can vary from one operation to another. Decisions are often influenced by factors such as soil conditions, weather patterns, available resources, and the types of crops being grown.

Student and teacher questions about this phenomenon/problem that could be instructionally productive:

- What parts of a corn plant need access to water? Where does that water need to go?
- Does all the water applied to a field become available to the corn plants? Where else might it go?
- What happens to water between the time it leaves the irrigation system and the time it reaches the plant's roots?
- What is physically different about the irrigation systems used in the Texas study?
- How do pressure and flow affect the movement and distribution of water through an irrigation system?
- Why might water sprayed through the air behave differently from water released closer to the soil?
- If two systems pump the same amount of water, will the same amount necessarily reach the root zone? Why or why not?
- Why might applying more irrigation water not result in more corn?
- Where does energy enter an irrigation system, and where does that energy go?
- How could changing an irrigation system reduce water use but increase—or decrease—other resource needs?
- Which features of an irrigation system seem most important for getting water where it needs to go?
- What irrigation system would you recommend for this field?
- How can we now explain the results from the Texas High Plains study?

Explaining the phenomenon/problem or related phenomena could lead students toward developing the following DCIs:

HS-ESS2.C: The Role of Water in Earth's Surface Processes

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-5)

HS-LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)

HS-ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)

HS-ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1, HS-PS3-2)

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1, HS-PS3-4)

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Notes about relevance and authenticity (funds of knowledge, interests, identity)
Why might students be engaged?

- It presents a counterintuitive puzzle. Students may initially assume that less water would mean less crop growth. Similar corn yields from different irrigation approaches create a genuine question about what happens to the water.
- It connects science to visible technology. Center pivots, sprinklers, pumps, nozzles, sensors, and drip lines give students tangible engineered systems to examine.
- Students can investigate the mechanisms themselves. Variables such as pressure, flow rate, nozzle size, delivery height, evaporation, and water distribution lend themselves to hands-on investigations and physical models.
- It addresses a real resource-management challenge. Farmers must produce food while managing limited water and energy resources. Students can see how scientific understanding informs decisions with real environmental and economic consequences.
- There is not one "best" solution. Irrigation systems involve tradeoffs among water use, energy, cost, maintenance, field conditions, and crop production, giving students meaningful decisions to make and defend with evidence.
- The phenomenon connects across scales. Students can move from the anatomy of a corn plant to water moving through an irrigation system, to an entire field, and ultimately to regional water resources.
- It provides an authentic engineering challenge. Students can use what they figure out to evaluate or optimize an irrigation system rather than simply learning how existing technologies work.

Resources/References

Performance of Precision Mobile Drop Irrigation in the Texas High Plains Region

Optimal Performance from Center Pivot Sprinkler Systems

Texas A&M Center Pivot Irrigation

USDA-ARS Wind Drift & Evaporation

Alabama Extension Pressure & Uniformity

USGS Ogallala Aquifer

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