Measuring erosion and sediment yields on slopes and in small catchments

Baoyuan LIU, Yaxian HU

Northwest A&F University
Beijing Normal University

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About us

- Dr. Baoyuan Liu

  Leading expert of soil erosion research in China

  Founder of the Chinese Soil Loss Equation (CSLE)

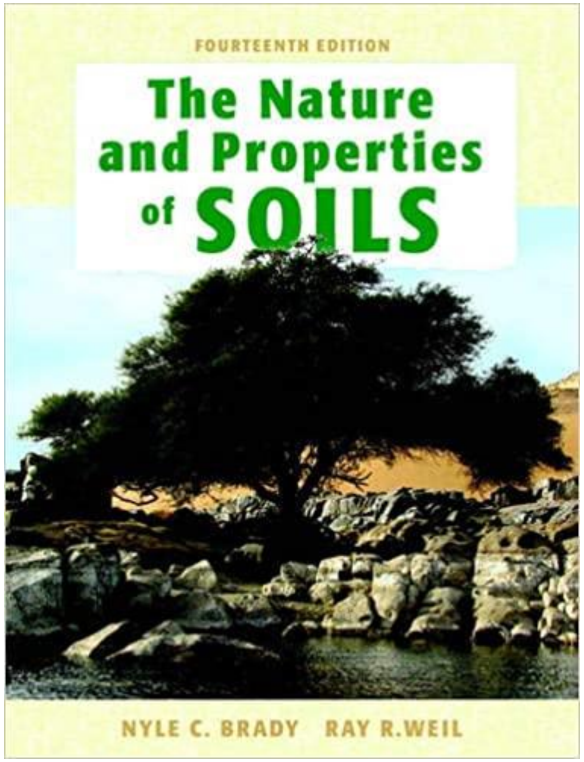
  Parameterize the gradient factor of steep slopes

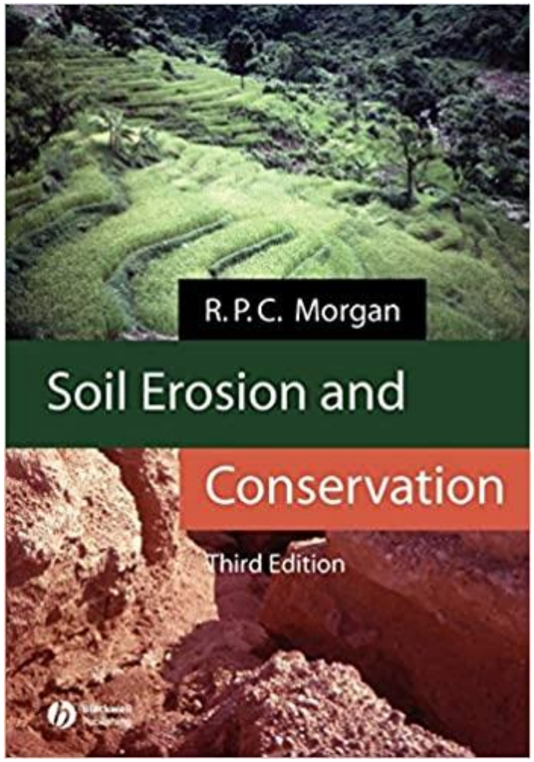
- Dr. Yaxian Hu

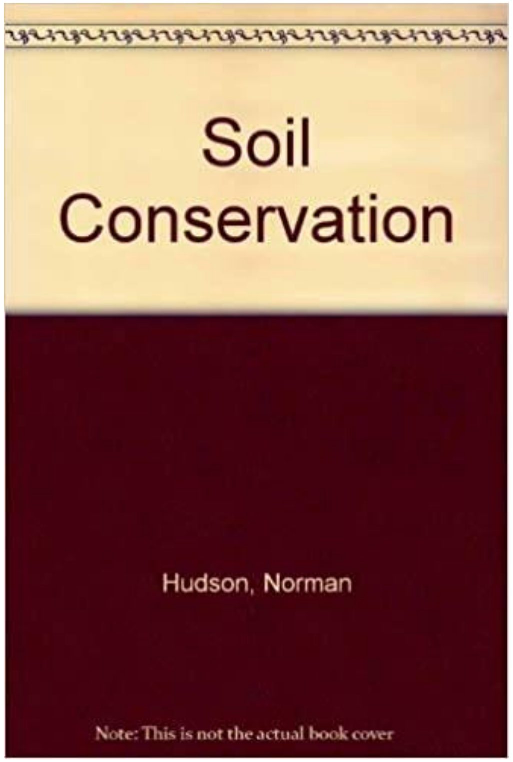
  Soil erosion processes and carbon cycling

  Settling and transport behavior of eroded sediment

Useful books







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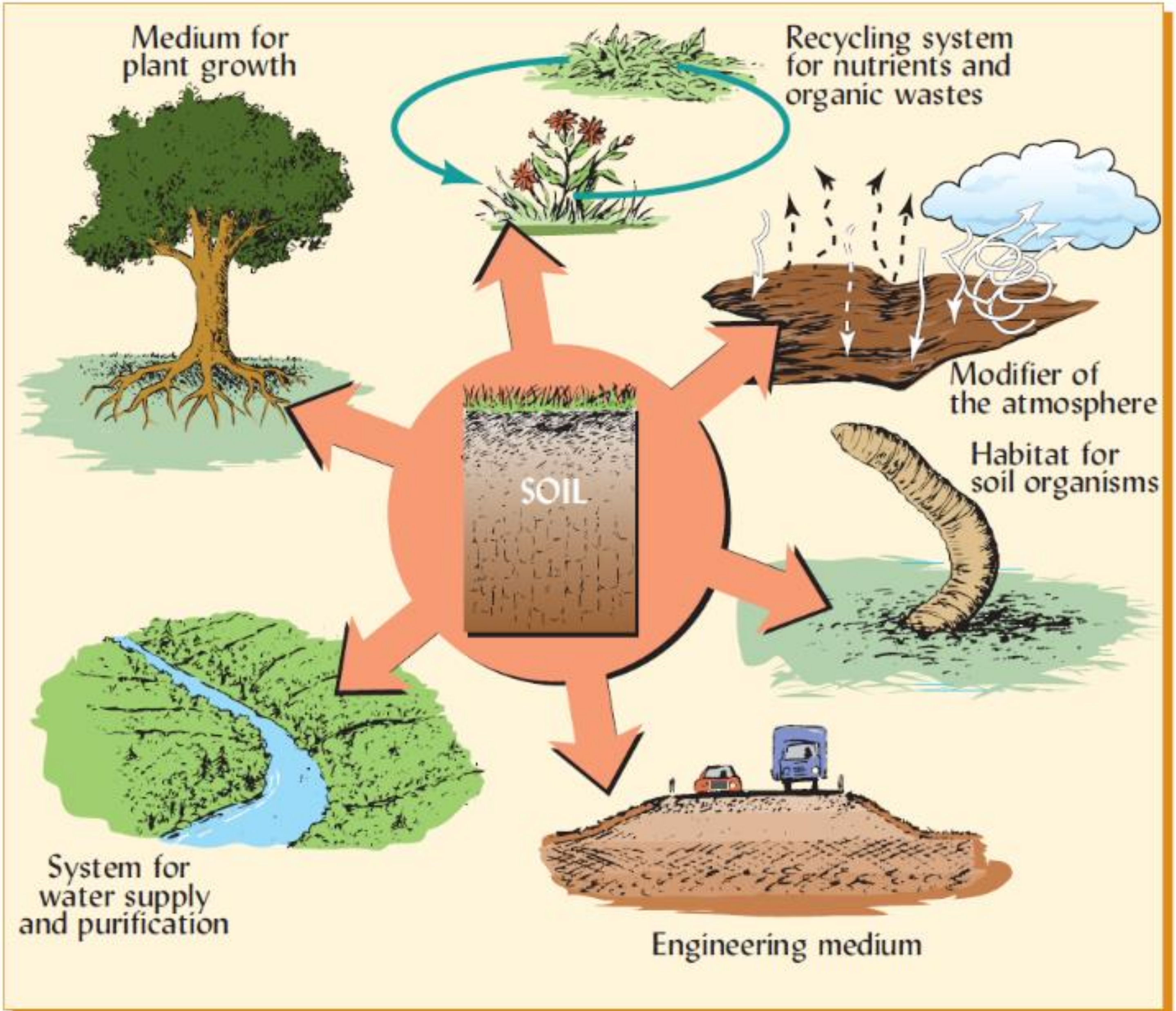
1. Introduction



Nyle Brady and Ray Weil

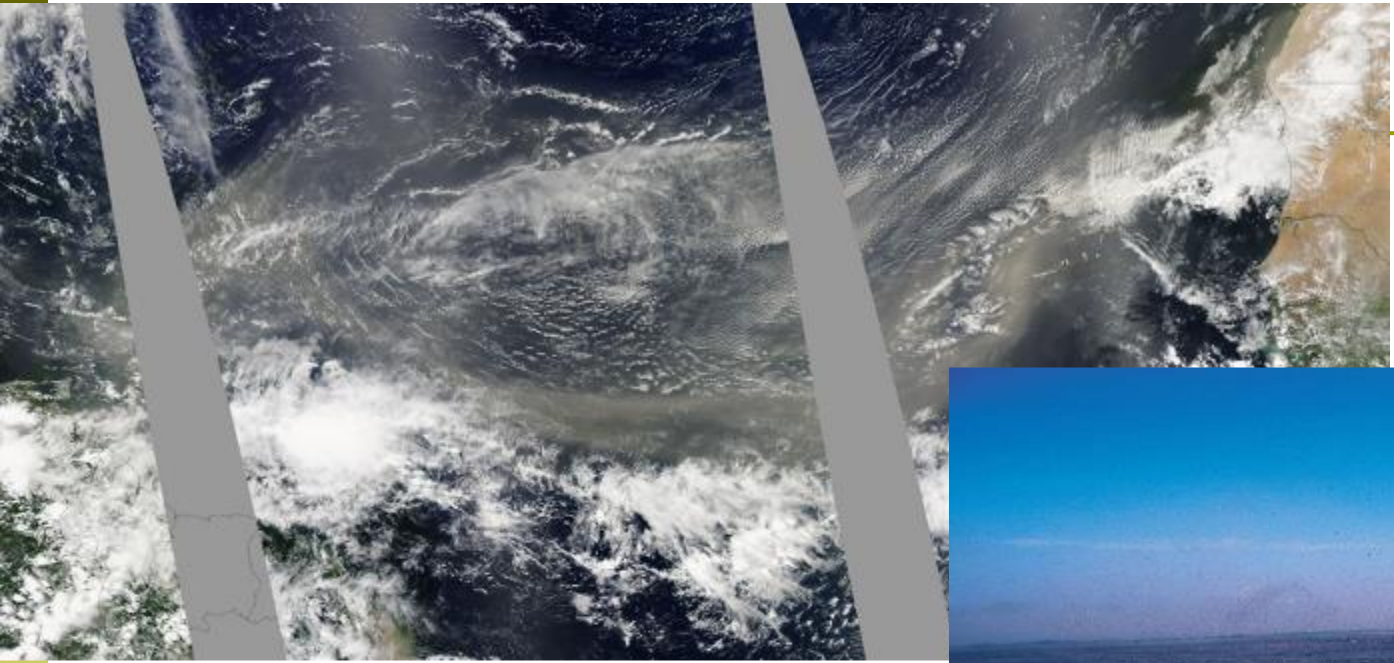
Soil Erosion

In earth science, **soil erosion** is the action of surface processes (such as water flow or wind) that remove soil, rock, or dissolved material from one location on the Earth's crust, and then transport it to another location.

Water erosion

Liquid water is the most common agent of erosion. Rainwater, rivers, and the ocean continually erode rock, sand, and soil. The pounding waves of the Atlantic Ocean eroded the foundations of this home in the Outer Banks, North Carolina.
Photograph by Richard Barnes, National Geographic

Wind erosion



Natural Resources Conservation Service

Wind is a powerful force of erosion. This thick cloud drifting over the Atlantic Ocean is a beautiful example of wind erosion—dust from the Sahara Desert being transported by wind to northern South America.

Image courtesy NASA, by Jeff Schmaltz, MODIS Rapid Response

Tillage erosion

Adopted from Goswin Heckrath

Glacial erosion

Ice, usually in the form of glaciers or ice sheets, is a large-scale agent of erosion. Here, eroded rubble (called moraine) collects in front of the path of a glacier.

Chemical erosion

Chemical erosion describes the process of rocks changing their chemical composition as they erode. Chemical erosion contributed to the beautiful Stone Forest in Yunnan, China, for example. Here, rainwater interacts with the limestone rocks in a process ca
Photograph by Keith Ladzinski, National Geographic

Geological *vs.* Accelerated erosion

Geological/Natural erosion	Accelerated erosion

Photograph by Pete McBride, National Geographic

Photograph by Yaxian Hu

National Geographic

Photograph by Mrs. Emma Love

Soil erosion in northeastern China

Soil erosion in Tibetan Plateau

Therefore,

- **To effectively control soil erosion, we need to**
  - **1) identify the most susceptible regions, season or more specific conditions (soil type, coverage, tillage, etc.) .**
  - **2) establish and apply soil conservation measures.**
  - **3) use modeling to predict soil erosion risk in the future.**

- **All this starts with by measuring and recording.**

2. How to measure water erosion?

2.1 Soil erosion measurements at different scales

- **1) Micro-plot (splash)**
  - Ewald Wollny in 1882, 80 cm × 80 cm
- **2) Typical bounded plot (rectangular)**
  - M.F. Miller in 1917, 6 ft×72.6 ft = 0.01 acre (40.46m^2)
  - In China: 5 m × 20 m = 100m^2
- **3) Field scale**
  - Sampson, A. W. Utah, 1912, 10 acre (4 hm^2)
  - Zizhou in China, 1963, 1.72 hm^2
- **4) Small catchment**
  - 40000-250000 acres (in the US)
  - < 50 km^2 (in China)

1) Micro-plot
--- Splash

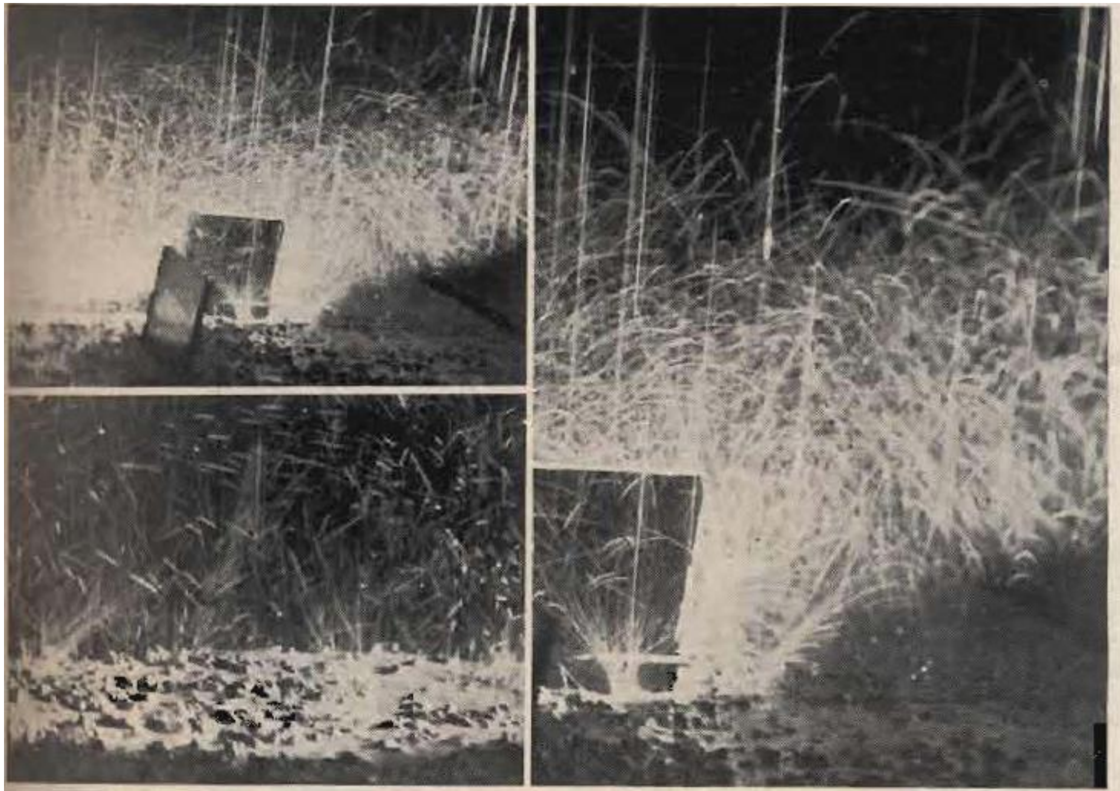


Fig. 3 (Upper left) This photograph was made by directing a sunbeam onto the plot surface during artificial rainfall. Rainfall intensity, 6.6 iph; drop size, 5.1 mm; drop velocity, 19.2 fps; exposure, 1/25 sec. Vertical marks indicate paths of falling raindrops; parabolic curves indicate trajectories of soil and water particles which splash from the soil surface as part of the reaction to the impact of the falling drops • Fig. 4 (Right) This is an enlargement of a section of Fig. 3 • Fig. 5 (Lower left) This is an enlargement of a section of a photograph made in the same manner as Fig. 3, except exposure was 1/100 sec. Long vertical lines indicate falling raindrops, and those lines not vertical indicate particles of soil and water contained in raindrop splash

1) Micro-plot (splash)
--- Ellison splash dish

Dish

- Round shape
- 0.21mm-0.25mm
- clean

Diameter: 3.5 inch

Height: 2 inch

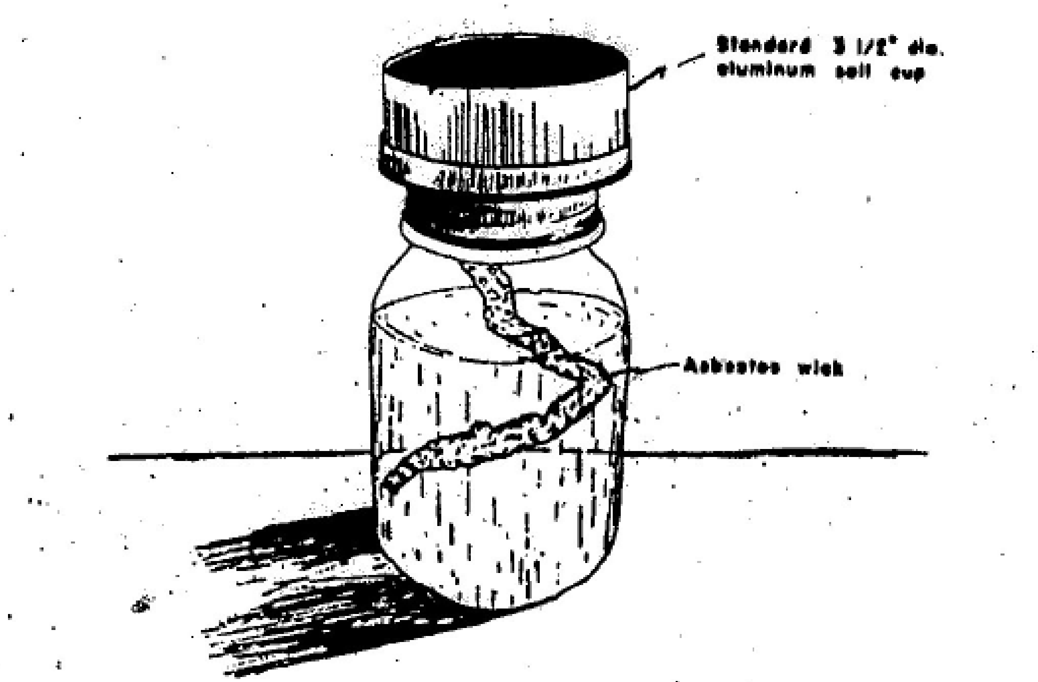


Fig. 2 A splash dish for measuring the capacities of storms (D_2) and also used in laboratory work for measuring the detachability of a soil (D_3)

1) Micro-plot (splash)
--- Ellison splash board

Fig. 6 Splash samplers installed in preparation for an experiment. A surface flow sampler can be seen at the lower end of the plot

1) Micro-plot (splash)
--- Ellison splash board

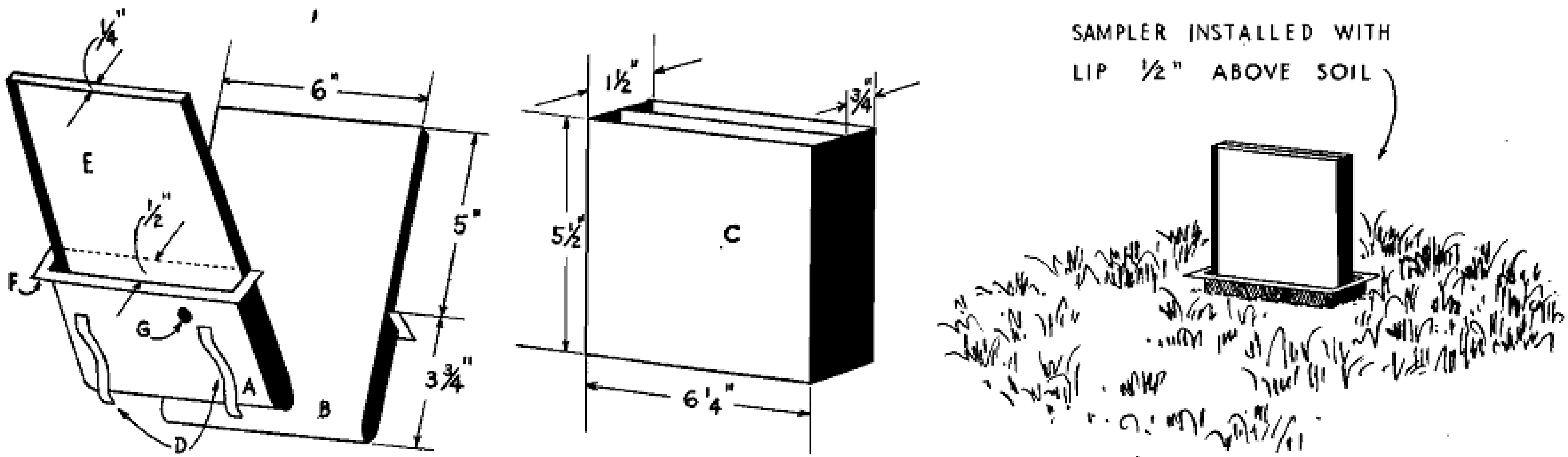


Fig. 1 The splash sampler. A and B, catch pans; C, sample tank with watertight division; D, friction springs to hold pans in tank; E, splash plate to intercept raindrop splash; F, lip on catch pans; G, overflow into C for temporary storage

1) Micro-plot (splash)
--- Morgan splash cup

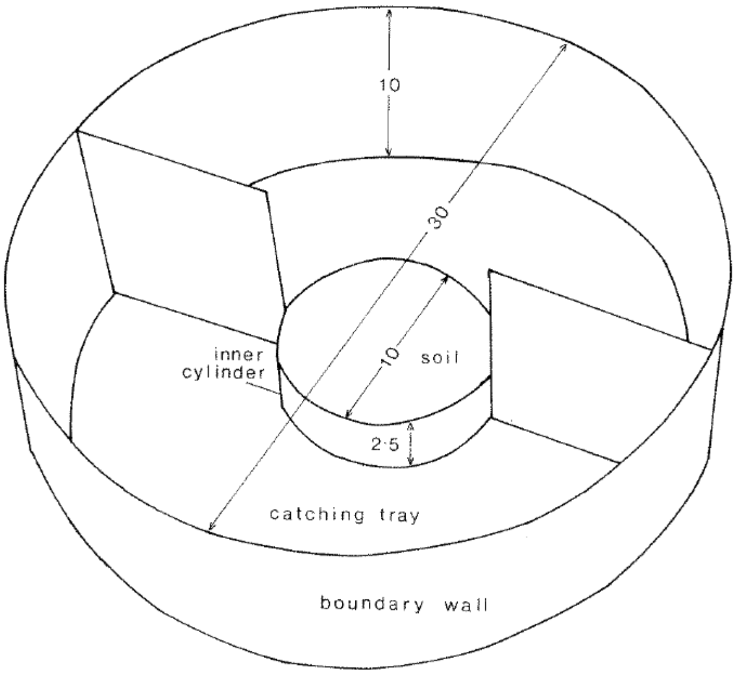


Fig. 1 The field splash cup (dimensions in centimetres).

Morgan, R. P. C. 1978. Field studies of rainsplash erosion. Earth Surf. Processes 3 (3): 295-299.

1) Micro-plot (splash)

'The discovery that raindrop splash is a major factor in the water erosion process marks the end of one era in man's struggle with soil erosion and ushers in another which, for the first time, holds out hope for a successful solution to the problem. The exact nature of the effects of raindrop splash is the phase of the water-erosion process that escaped detection during the first 7 000 years of civilization. It explains why the efforts at protecting the land against scour erosion these 7 000 years have failed. It explains why there is little or no erosion on land with ample plant cover. It explains many things that have puzzled agricultural leaders and practitioners throughout this long and troublesome period.'

Stallings,1957

2) Bounded plot
--- Unit plot

Universal Soil Loss Equation (USLE)

$$A = R * K * LS * C * P$$

Where,

A = estimated average soil loss in tons per acre per year

R = rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = support practice factor

Unit Plot: standard plot, with slope gradient of 9%, length of about 20 m, fallow with tillage is up and down slope with no conservation practices.

2. Bounded (rectangular) plot
--- Unit plot

A *unit plot* is 72.6 ft long, with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, for this purpose, is land that has been tilled and kept free of vegetation for more than 2 years. During the period of soil loss measurements, the plot is plowed and placed in conventional corn seedbed condition each spring and is tilled as needed to prevent vegetative growth and severe surface crusting. When all of these conditions are met, **L**, **S**, **C**, and **P** each equal 1.0, and **K** equals **A/EI.**

Applied side: to calculate soil erodibility
Wischmeier and Smith, 1978

2) Bounded plot

Originally as unit plot, but not ploughed for years

Cannot be treated as unit plot, thus cannot be used to estimate soil erodibility factor

2) Bounded plots
--- with different slope lengths (not unit plot)

2) Bounded plots
--- with different slope gradients (not unit plot)

2) Bounded plots
--- with different tillage practices (not unit plot)

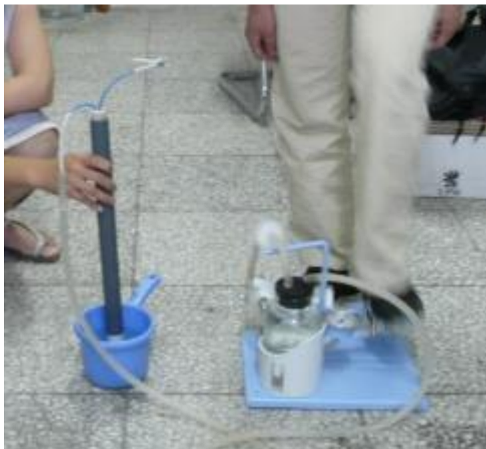
2) Bounded plots
--- with different coverage (not unit plot)

Bare *vs.* Grass

Crop *vs.* Native grass

Shrub *vs.* Pine

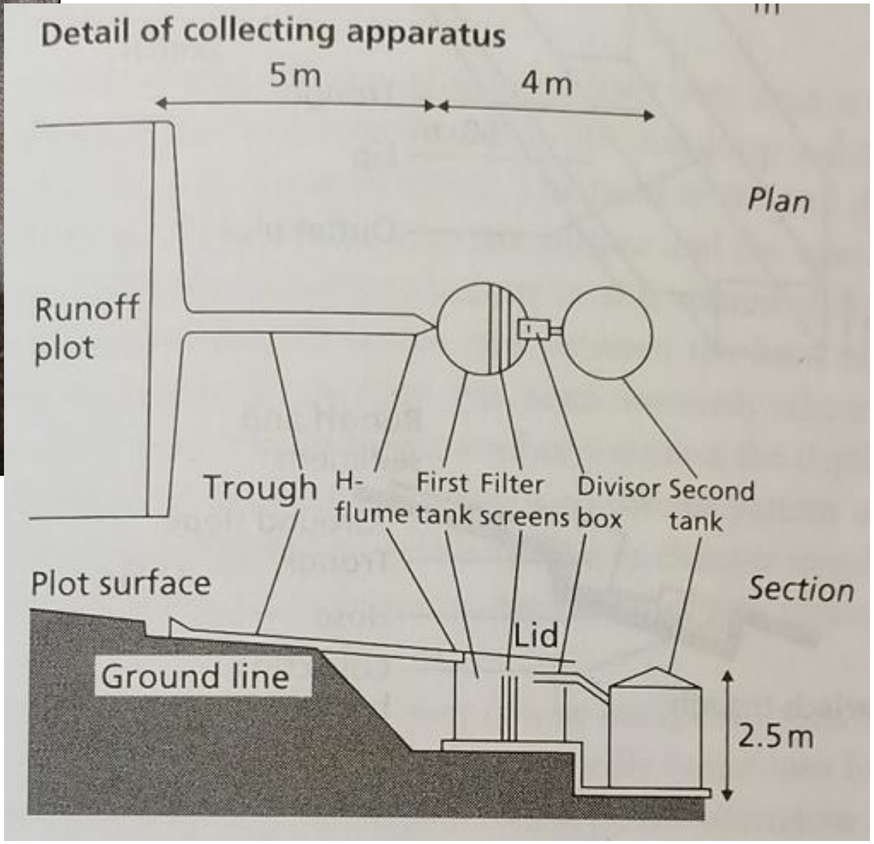
2) Bounded plots
--- for specialized research (not unit plot)



Sub-surface runoff

e.g., non-point source pollution

2) Bounded plot
--- Components of bounded plots



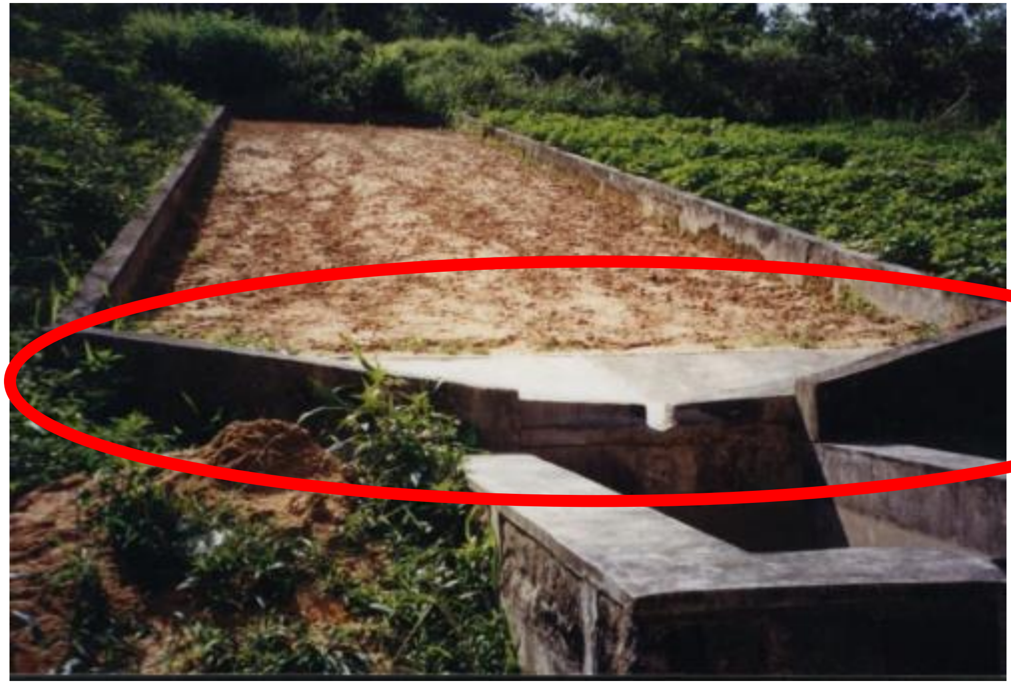
Morgan, Soil Erosion and Conservation

2) Bounded plot
--- sediment tank

2) Bounded plot
--- trough

The trough is too low, and soils on the eroding slope are very likely to collapse over into the trough and overestimate the erosional soil loss.

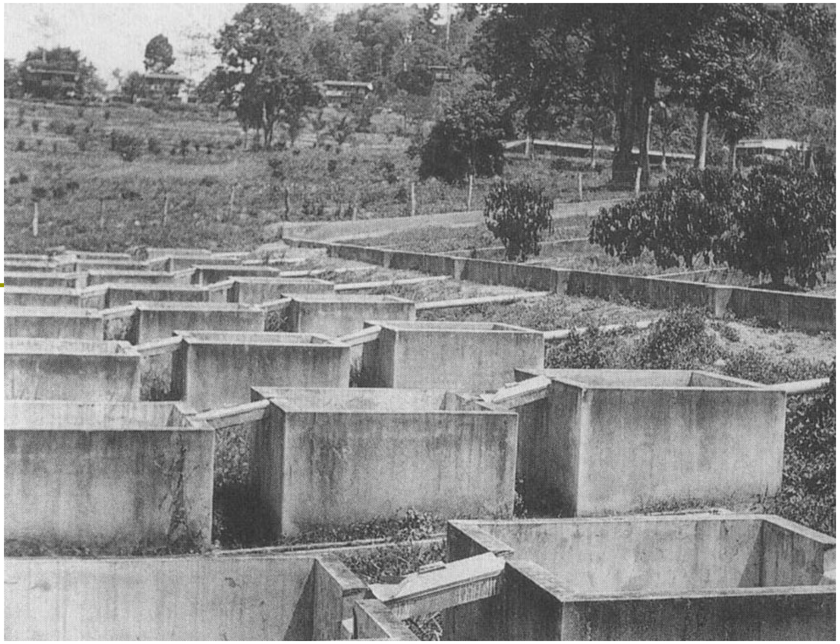
2) Bounded plot
--- trough

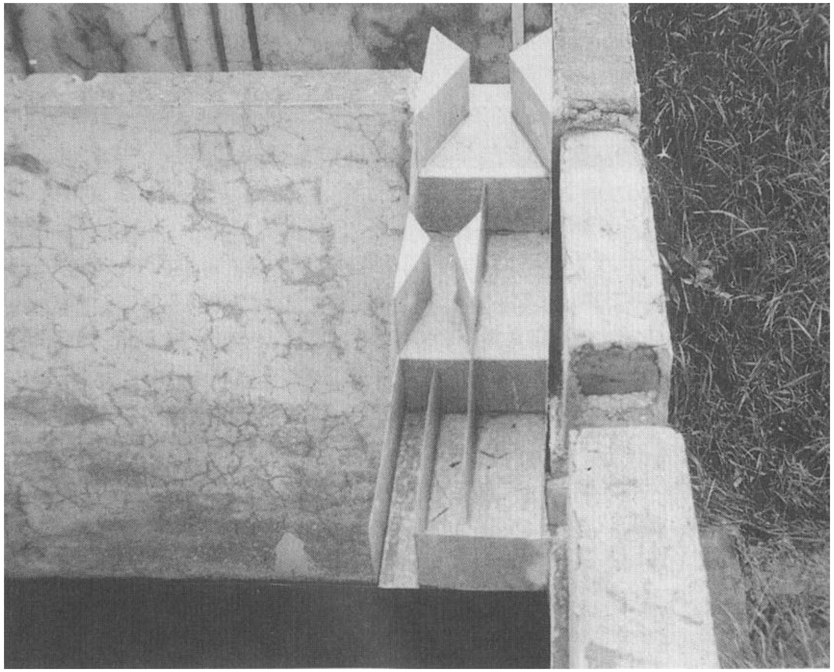


The trough is oversized, and eroded sediments are apt to stay in the big area of the trough instead of running into the collector.

2) Bounded plot
--- sediment divisor

2) Bounded plot
--- sediment divisor





2) Bounded plot --- Sediment sampling

Challenges: sediment particles can settle through water and thus accumulate at the bottom. Even after stirring, it is nearly impossible for conventional manner to ensure the sediment suspension is well blended.

Column sampler: it can sample a sizeable column of suspension from the sediment barrel or trap, efficiently overcoming the bias by conventional manner.

3) Erosion investigation at field scale --- H-Flume

Data Logger

Ultrasonic water level meter

Turbidity

3) Field scale
--- (micro H-flume)

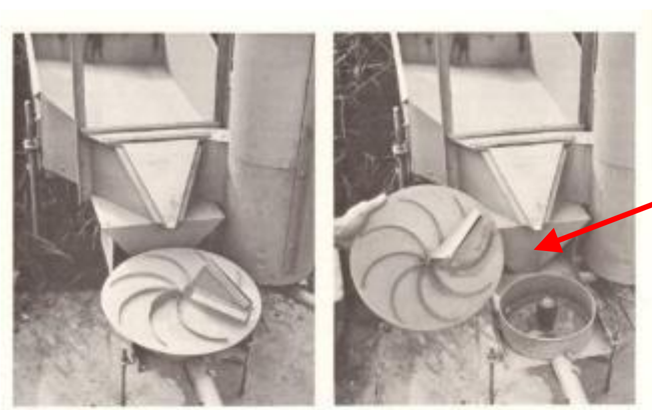
3) Field scale
--- Sediment sampling with turbidity meter

- Turbidity meter can automatically record the data.
- But, it cannot detect large sediment concentration beyond its scale.
- Thus, not applicable for regions susceptible to severe soil loss.

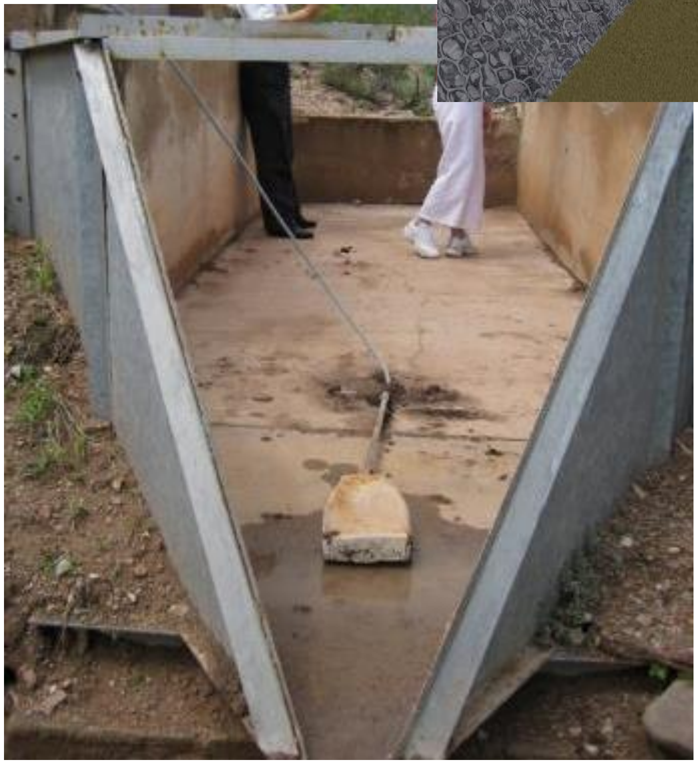
3) Field scale
--- Sediment sampling with Coshocton wheel

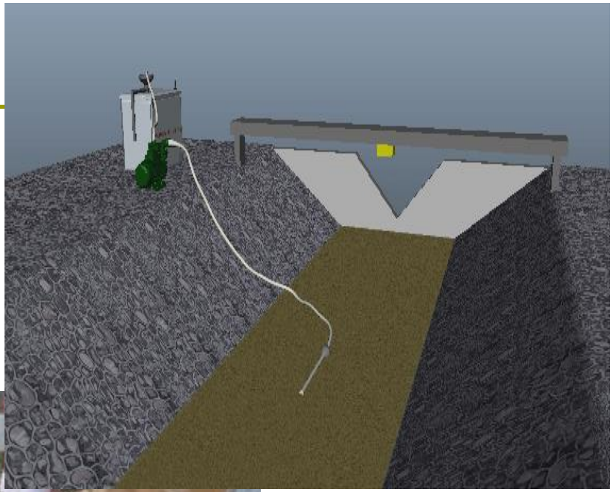
water level meter

Coshocton wheel



3) Field scale
--- H-Flume





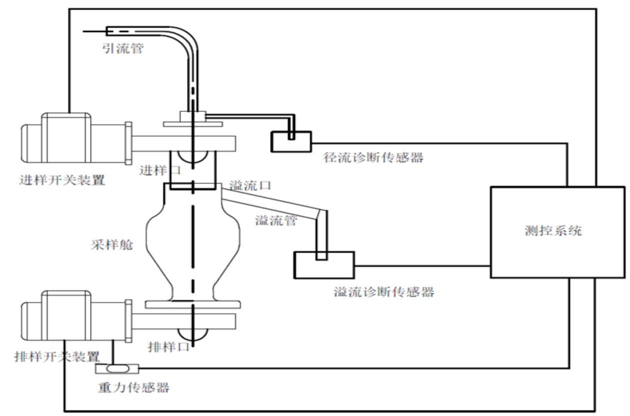
3) Field scale

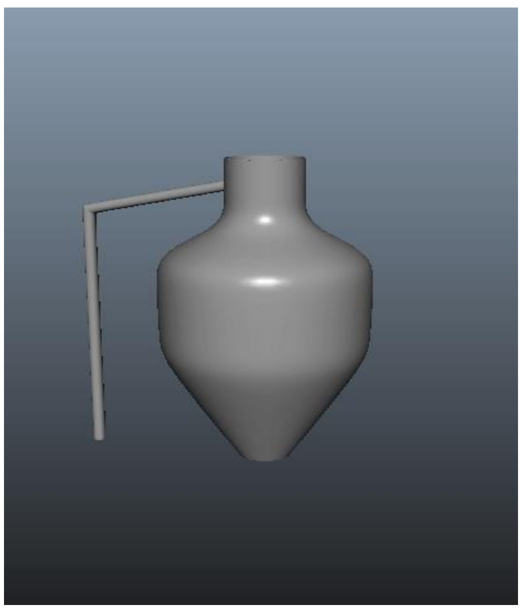
— Sediment sampling with ISCO auto sampler at programable intervals

- Sampling (rotating) intervals are programmable as you need.
- Take the samples back, weigh, and then calculate sediment concentration.

3) Field scale

--- Sediment sampling with auto sampler by weighing





Protocol: collecting - weigh - record - overturn

Assumption: sediments are heavier than water.

4) Small catchment
--- Weir

4) Small catchment
--- V-shaped Weir

4) Small catchment
--- Rectangular Weir

2.2 Commonly applied methods to improve erosion measurement

A. Rainfall simulation

B. Isotopic fingerprint (tracers)

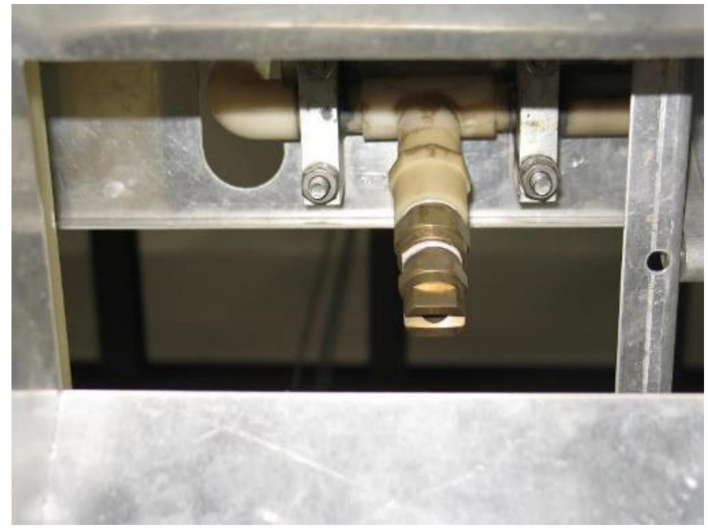
C. Remote sensing

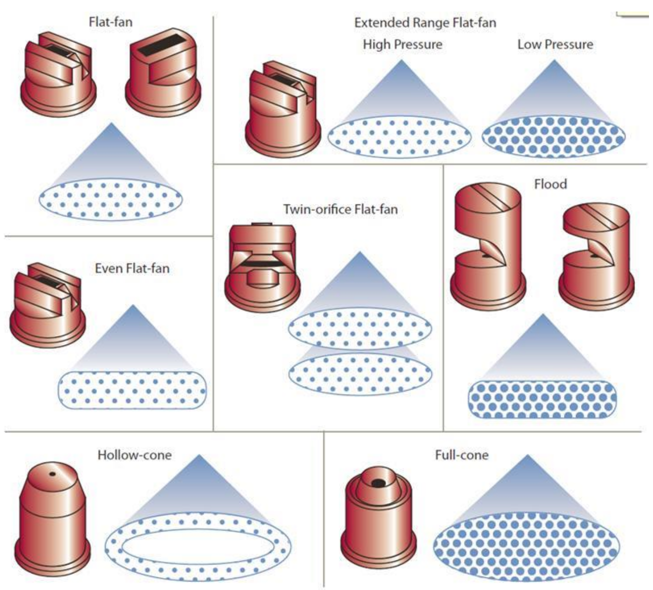
A. Rainfall simulation
--- Basic requirements of rainfall simulation

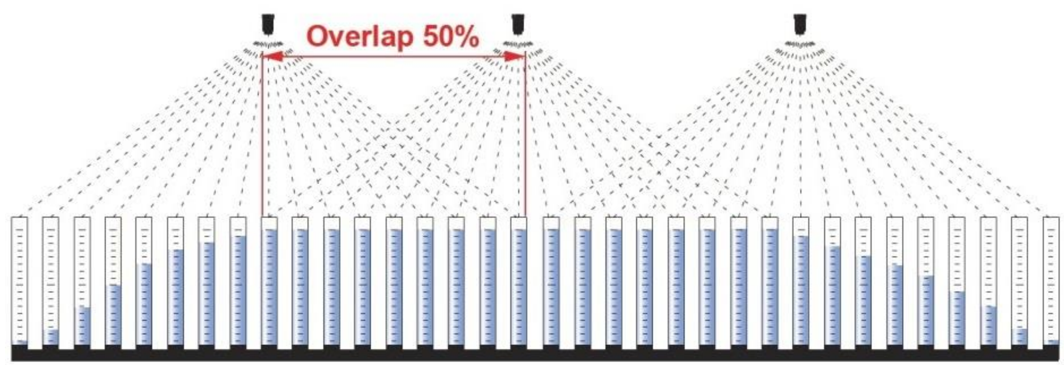
1. Able to simulate the desired rainfall intensity
2. Drop size similar to natural raindrops
3. Terminal velocity of drops similar to natural raindrops
4. Kinetic energy of drops similar to natural raindrops
5. Drop impact angles similar to natural raindrops
6. Even spatial distribution over the subject area
7. Might need shield to protect falling drops from wind
8. Easy to operate

A. Rainfall simulation
--- nozzle

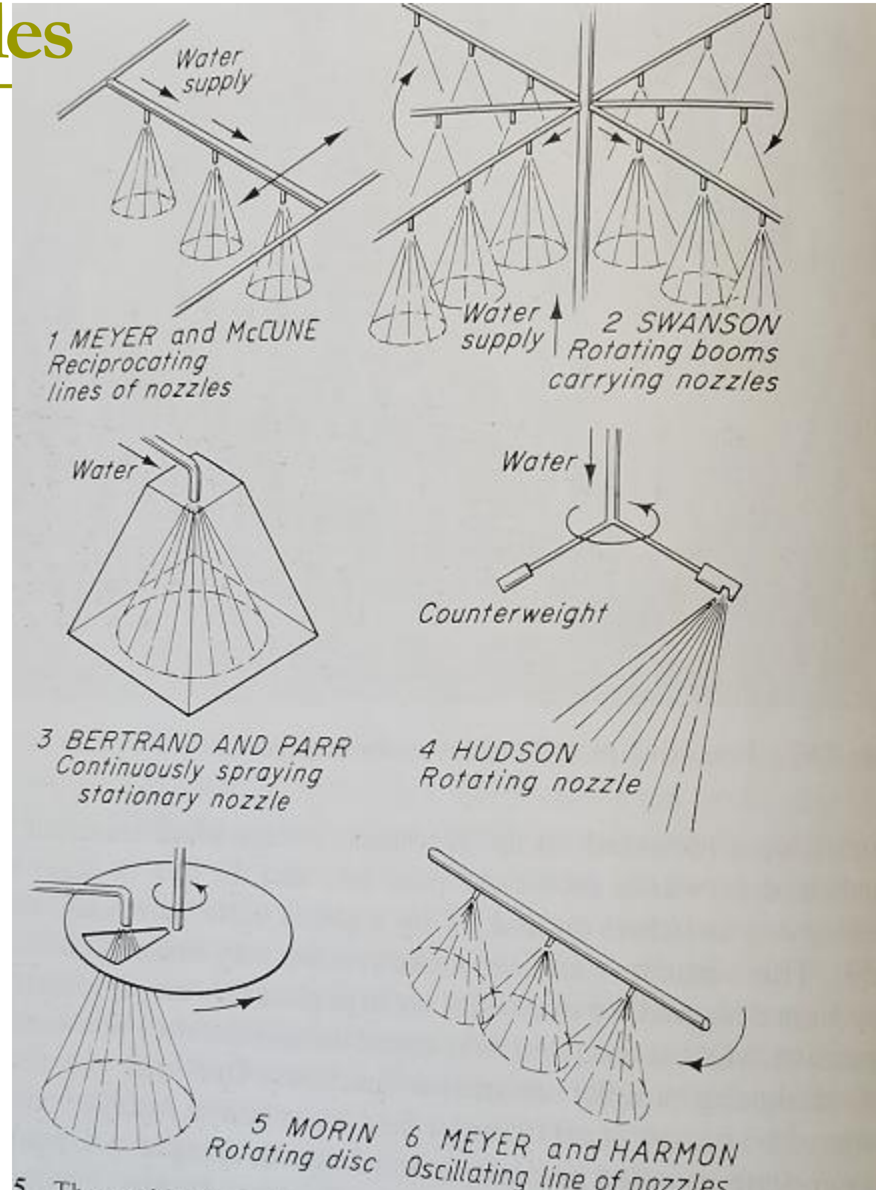
Spraying system --- veejet







A. Rainfall simulation
--- working pricinples



Hudson

A. Rainfall simulation
--- the hall

- Tall enough falling height for water drops to achieve terminal velocity
- Spacious enough to limit spatial variation of raindrops

A. Rainfall simulation
--- indoors over small flumes

A. Rainfall simulation
--- indoors over large transformable flume

Flume transformable as needed:
Gradient, Slope type
Width, Length
etc.

A. Rainfall simulation
--- portable equipment in the field

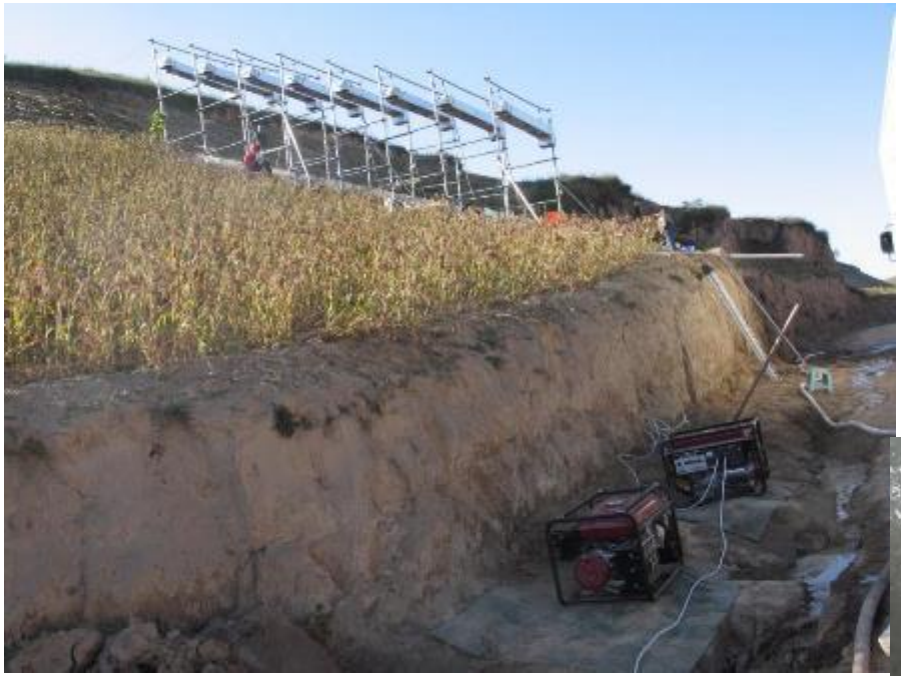
A. Rainfall simulation
--- raining in the filed

A. Rainfall simulation
--- Control panels

A. Rainfall simulation
--- Runoff and sediment collection

A. Rainfall simulation
--- Soil moisture sampling

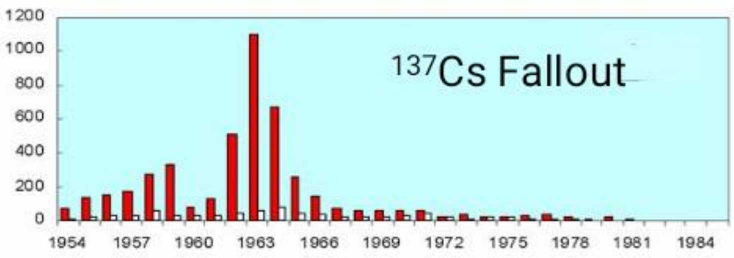
A. Rainfall simulation
--- Electricity and water supply

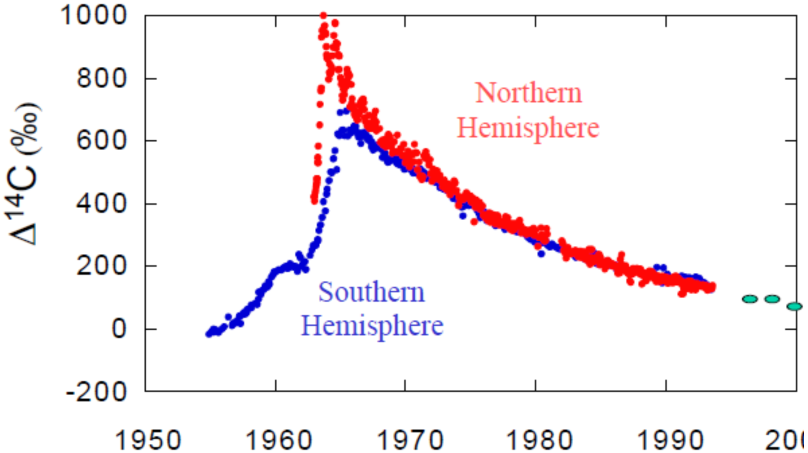


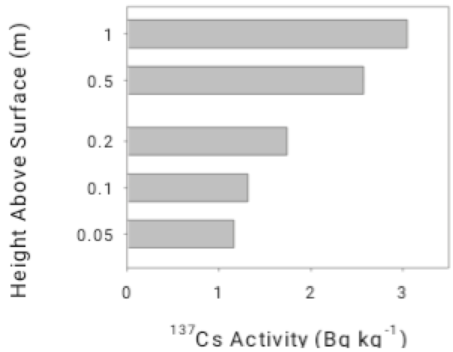
A. Rainfall simulation
--- Packing and transport

B. Isotopic fingerprint ---^{137}Cs

- ^{14}C
- ^{137}Cs (half life about 30.17 years)
- $^{239+240}Pu$ (half life about 6500 to 24100 years)

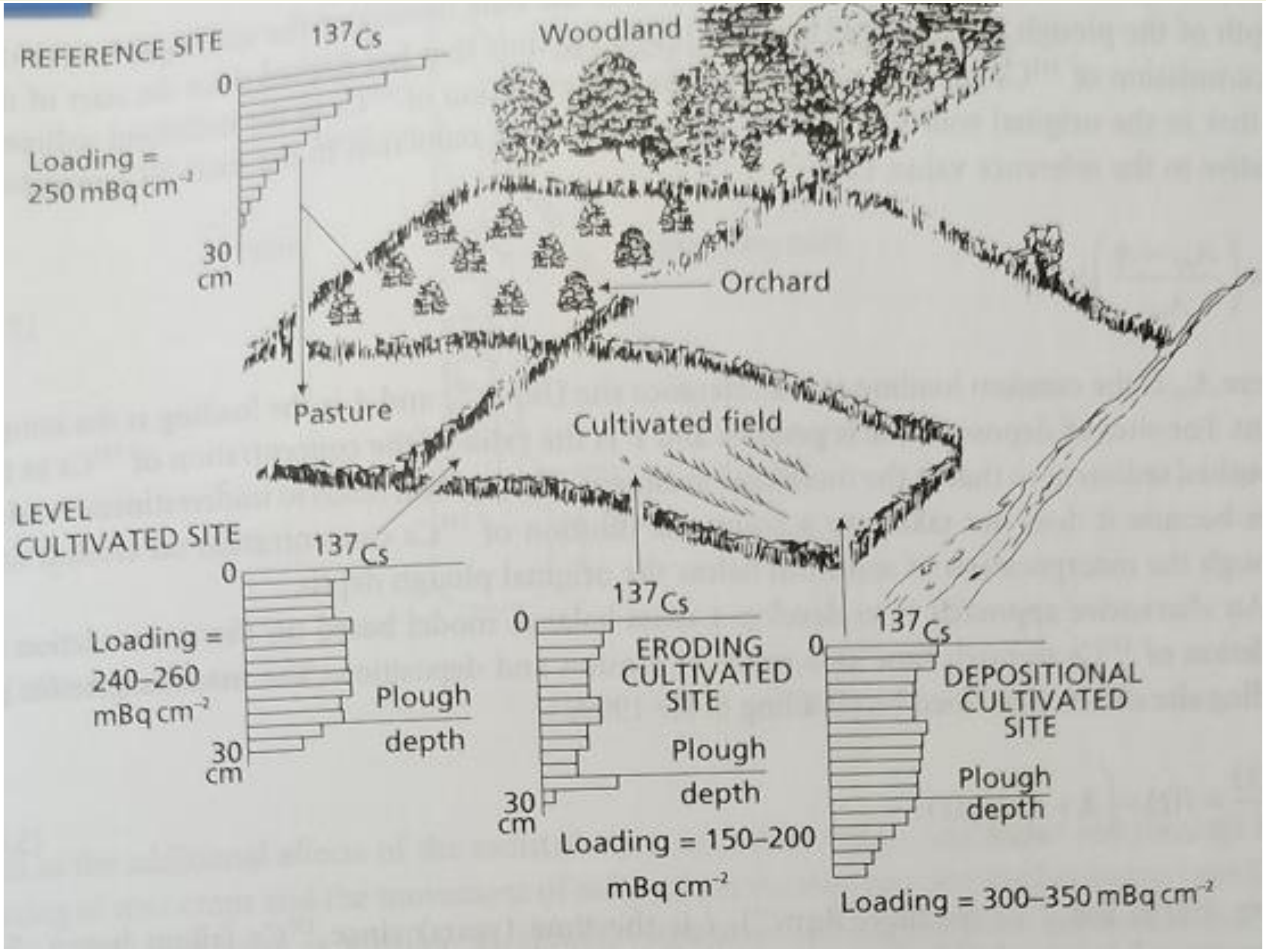






Adopted from Scott van Pelt & Asmeret Berhe

B. Isotopic fingerprint ---^{137}Cs



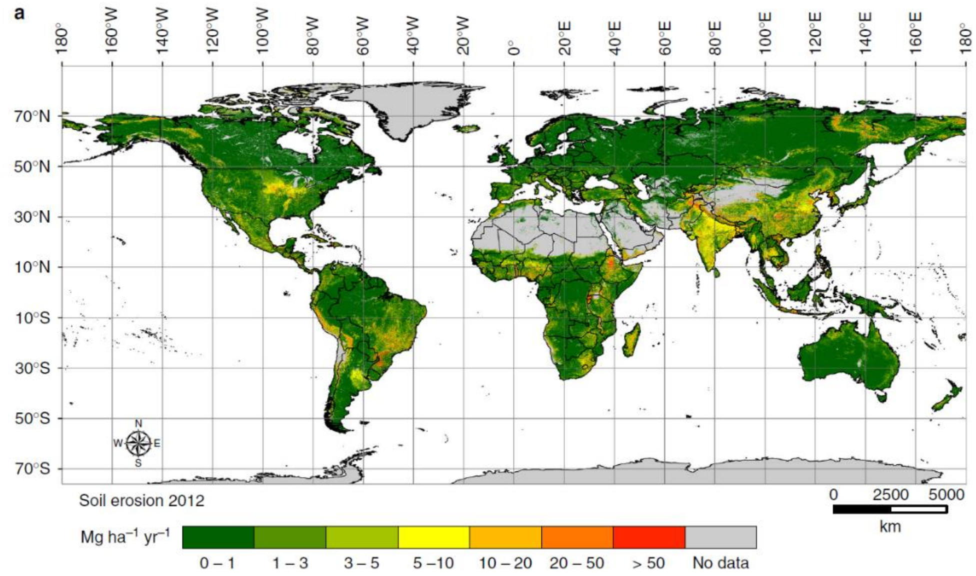
(Morgan after Walling and Quine 1990)

B. Isotopic fingerprint
--- soil sampling

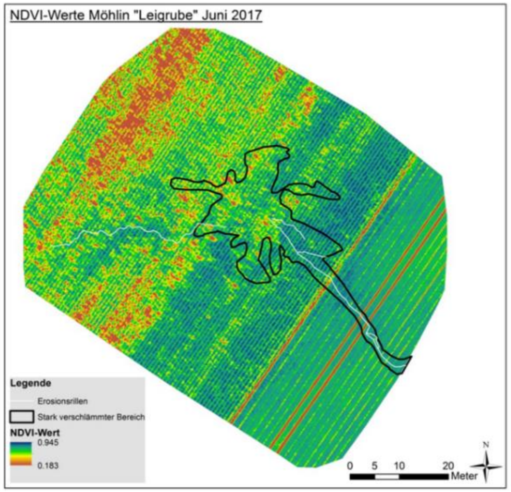
B. Isotopic fingerprint
--- Drying and grounding

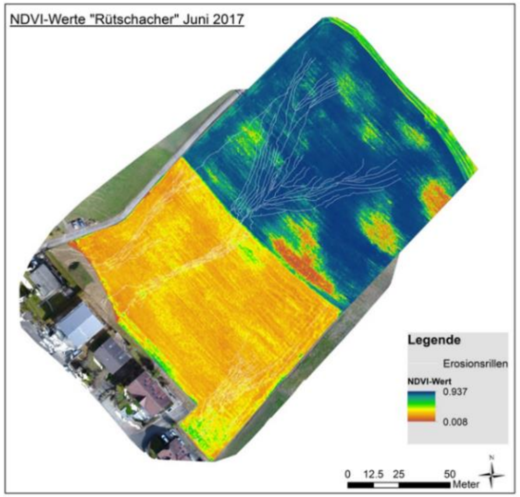
B. Isotopic fingerprint
--- Measurement by gamma-ray spectrometer

C. Remote sensing
--- Satellite and drone



Borrelli et al., 2017



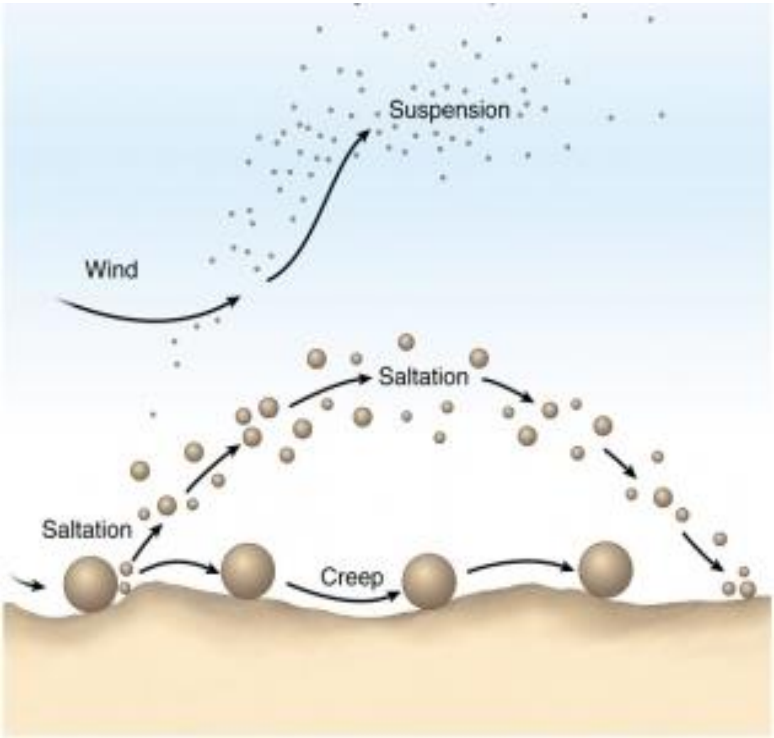


Courtesy:
Nikolaus J. Kuhn

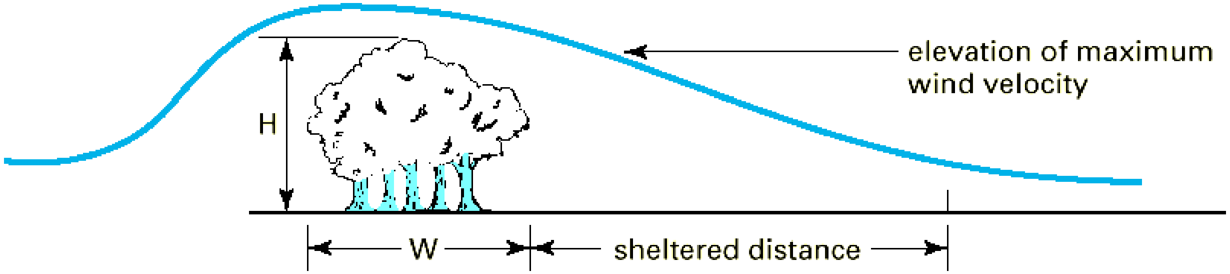
3. How to measure wind erosion?

Wind erosion

Note that the photo was taken in early spring before most crops were planted and before the trees had fully leafed out. (Photo courtesy of USDA Natural Resources Conservation Service)



http://www.trunity.net/sam2/view/article/51cbf4467896bb431f6af4c8/



http://nptel.ac.in/courses/104103020/module7/lec3/1.html

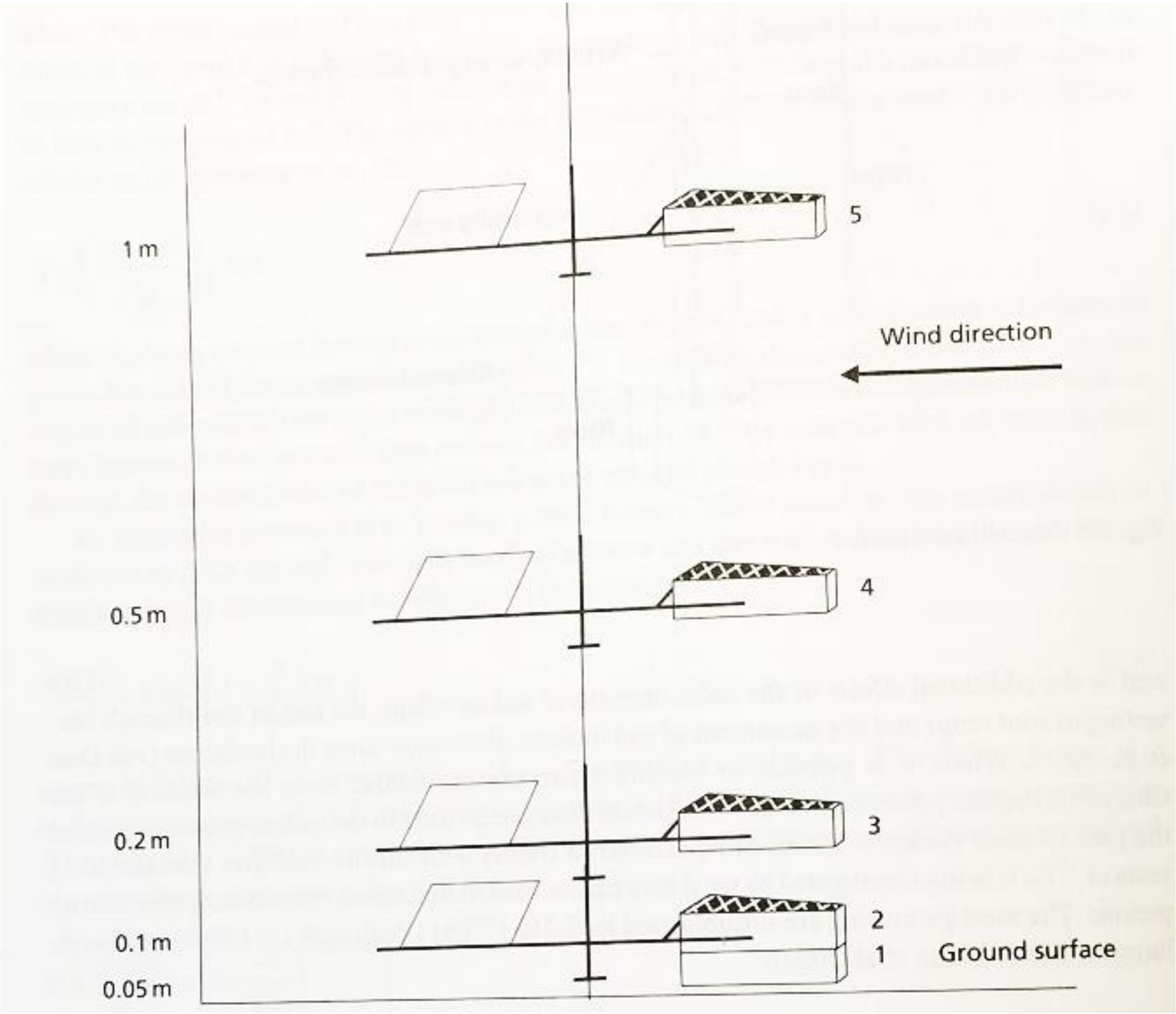
Unlike water erosion…

Wind erosion has some unique challenges:

- Wind direction is always changing and highly unpredictable
- Wind velocities have great vertical variation from the ground to the above
- Difficult to identify the amount of eroded dust blown in and out of the targeted area

Wind erosion measurement

--- Big Spring Number Eight sampler

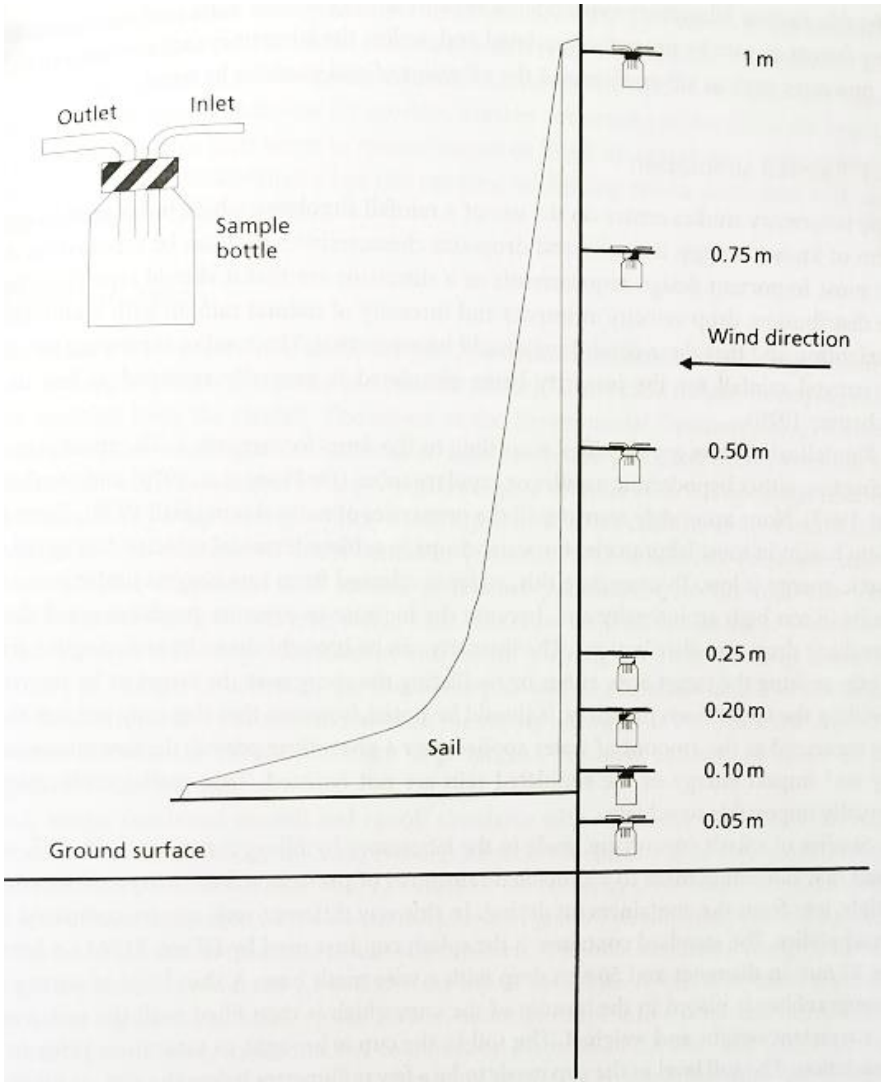


Sizes of inlets for the different catchers are:

1) 10 * 20 mm
2) 20 * 20 mm
3) 30 * 20 mm
4) 50 * 20 mm
5) 50 * 20 mm

Wind erosion measurement

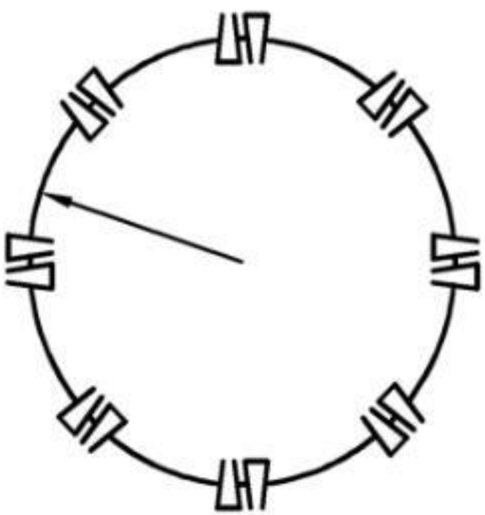
--- Wilson and Cooke bottle sampler

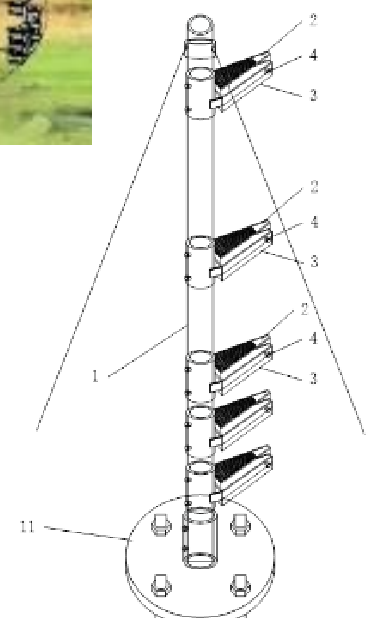


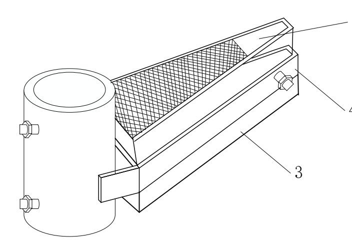
The dimensions can be varied according to the material used to build the sampler. The sampler used by the National Soil Resources Institute had an inlet pipe of 10 mm diameter and an outlet pipe of 15 mm diameter.

Wind erosion measurement

--- Wind Erosion Circle designed by Baoyuan Liu







Wind erosion measurement

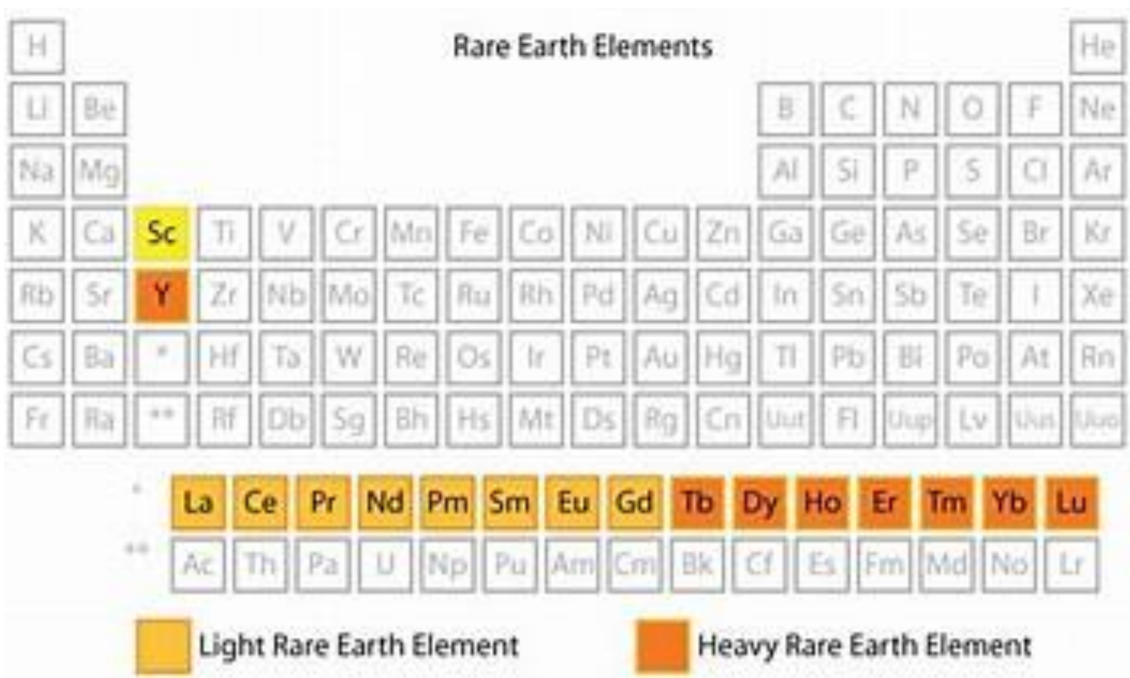
--- wind tunnel

Adopted from Wolfgang Fister

Wind erosion measurement

--- Rare-Earth Elements (REE)

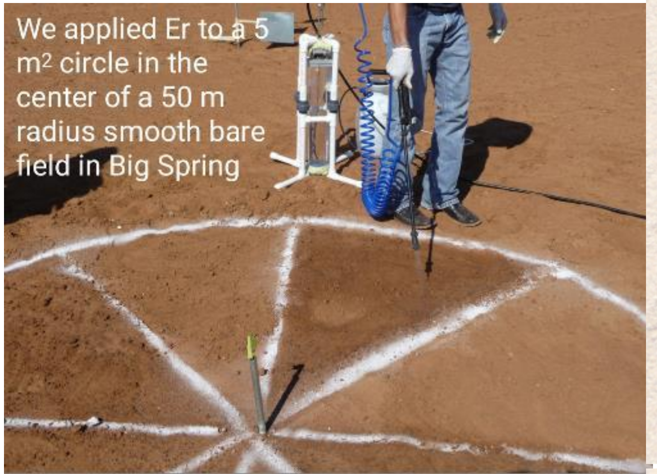
- Rare-Earth Element (REE): a set of 17 chemical elements
- Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Pm, Sm, Sc, Tb, Tm, Yb, Y

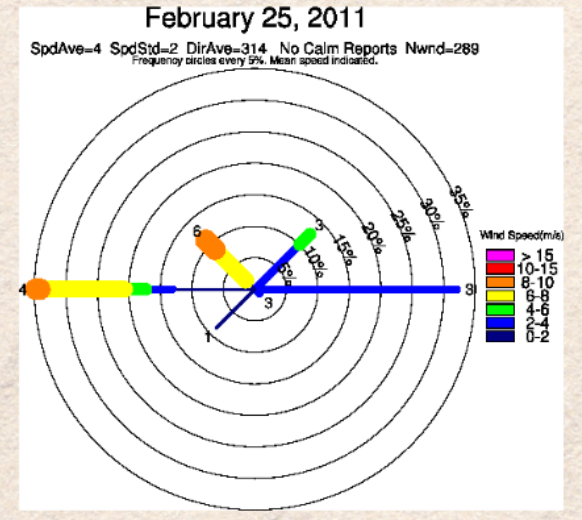


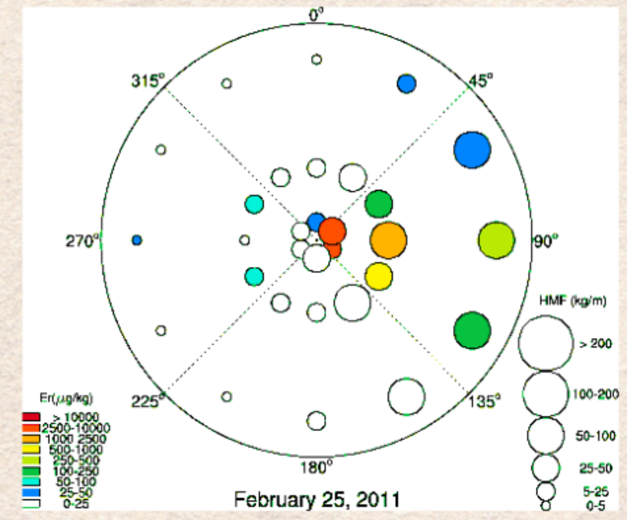
https://sciencenotes.org/rare-earth-elements/

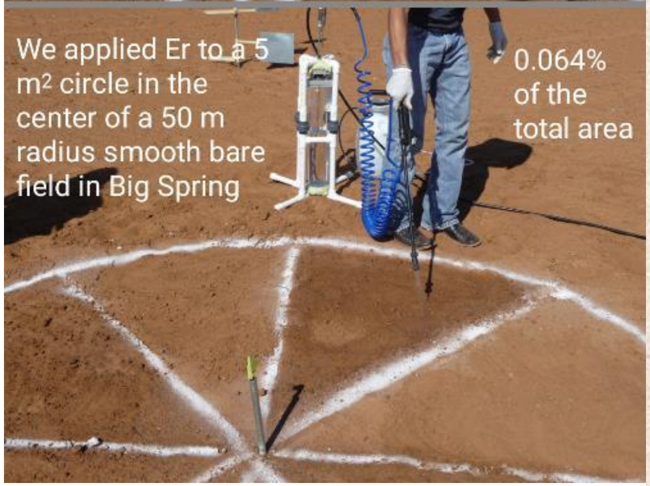
Wind erosion measurement

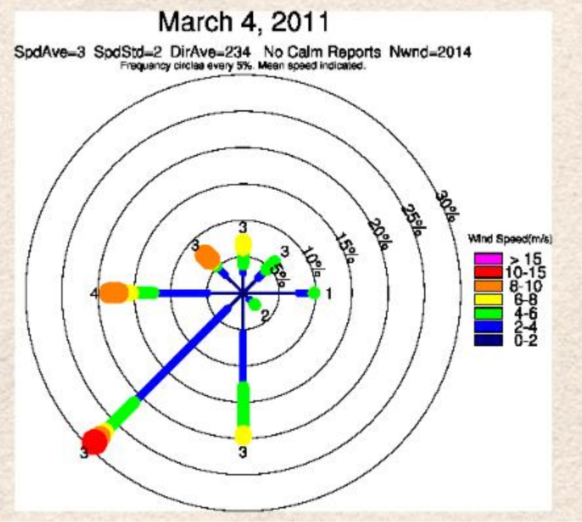
--- Rare-Earth Elements (REE)

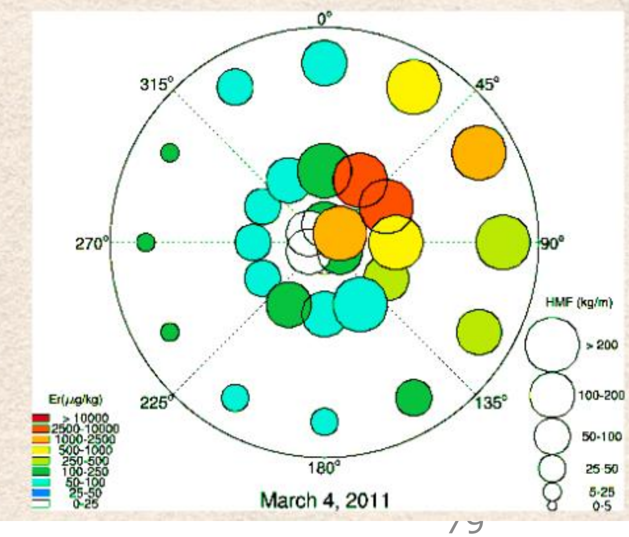












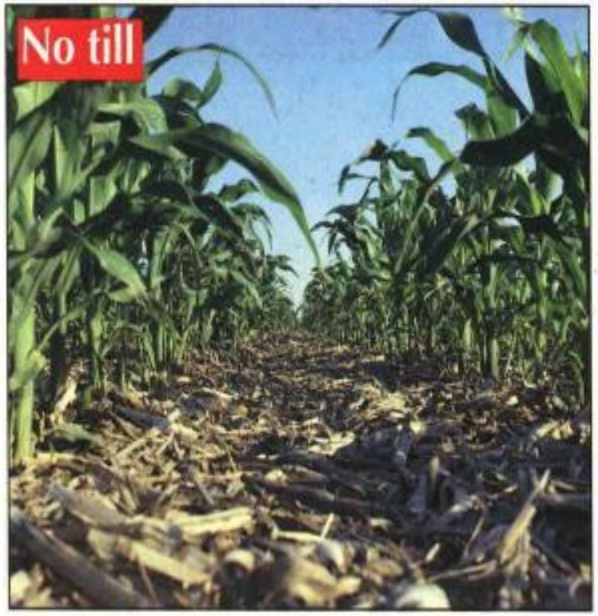
Adopted from Scott van Pelt

4. How to control soil erosion?

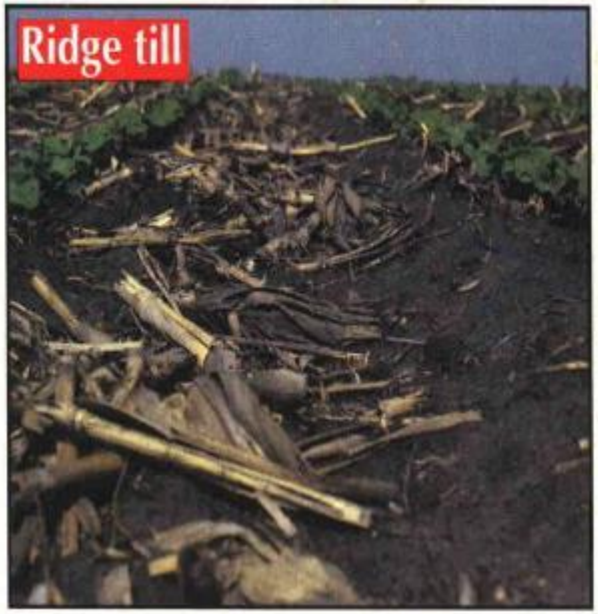
Residue management is farming to intentionally leave the past year's crop residues on the soil surface to save soil.

How to measure residue

1. Use any line that is equally



Soil is left undisturbed from harvest to planting except for nutrient injection. Plant or drill in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Control weeds with herbicide; cultivation may be used for emergency weed control.



Soil is left undisturbed from harvest to planting except for nutrient injection. Plant in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Ridges are rebuilt during cultivation. Control weeds with herbicide and/or cultivation.

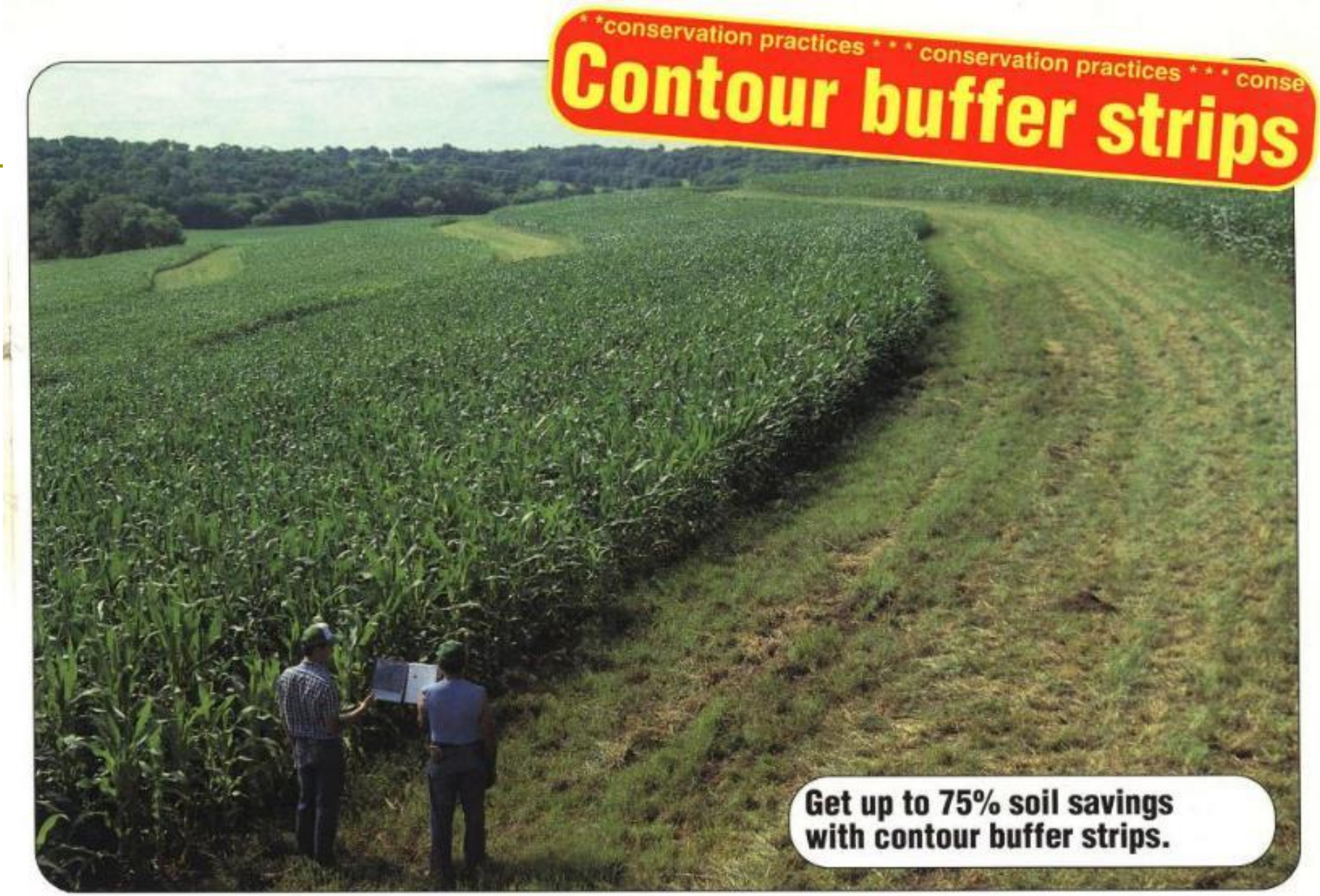
Soil is disturbed prior to planting (spring or fall tillage). Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Control weeds with herbicide and/or cultivation.

Contour farming is preparing the soil, planting, and cultivating crops around a hill nearly on the level, rather than up and down the hill.

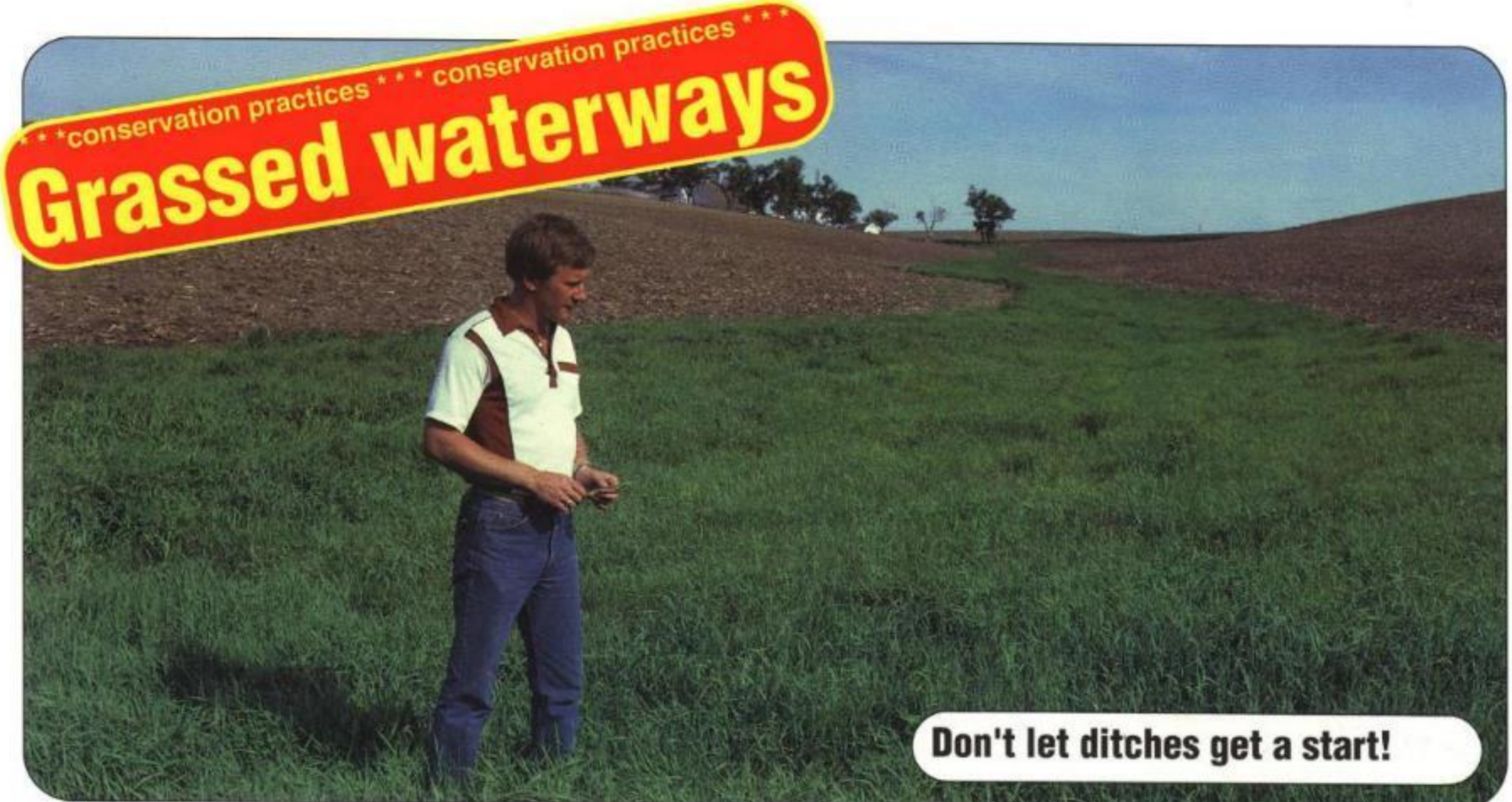
Specs:

The lay of your land, or the shape and steepness of the slopes on your land, determines the row pattern of your contours. Your land may be

- The grade of any row may vary up to 4%, but that variance cannot occur on more than one fourth of



Contour buffer strips are strips of perennial vegetation alternated with wider cultivated bands, farmed on the contour.



Grassed waterways are areas planted to grass where water usually concentrates as it runs off a field. Grass in the waterway slows the water and guides it off the field, significantly reducing gully erosion.

Keep them working

Proper maintenance will protect your investment in a grassed waterway. The following tips will help keep

Crop rotation is growing different crops on the same piece of land—often changing crops year by year.

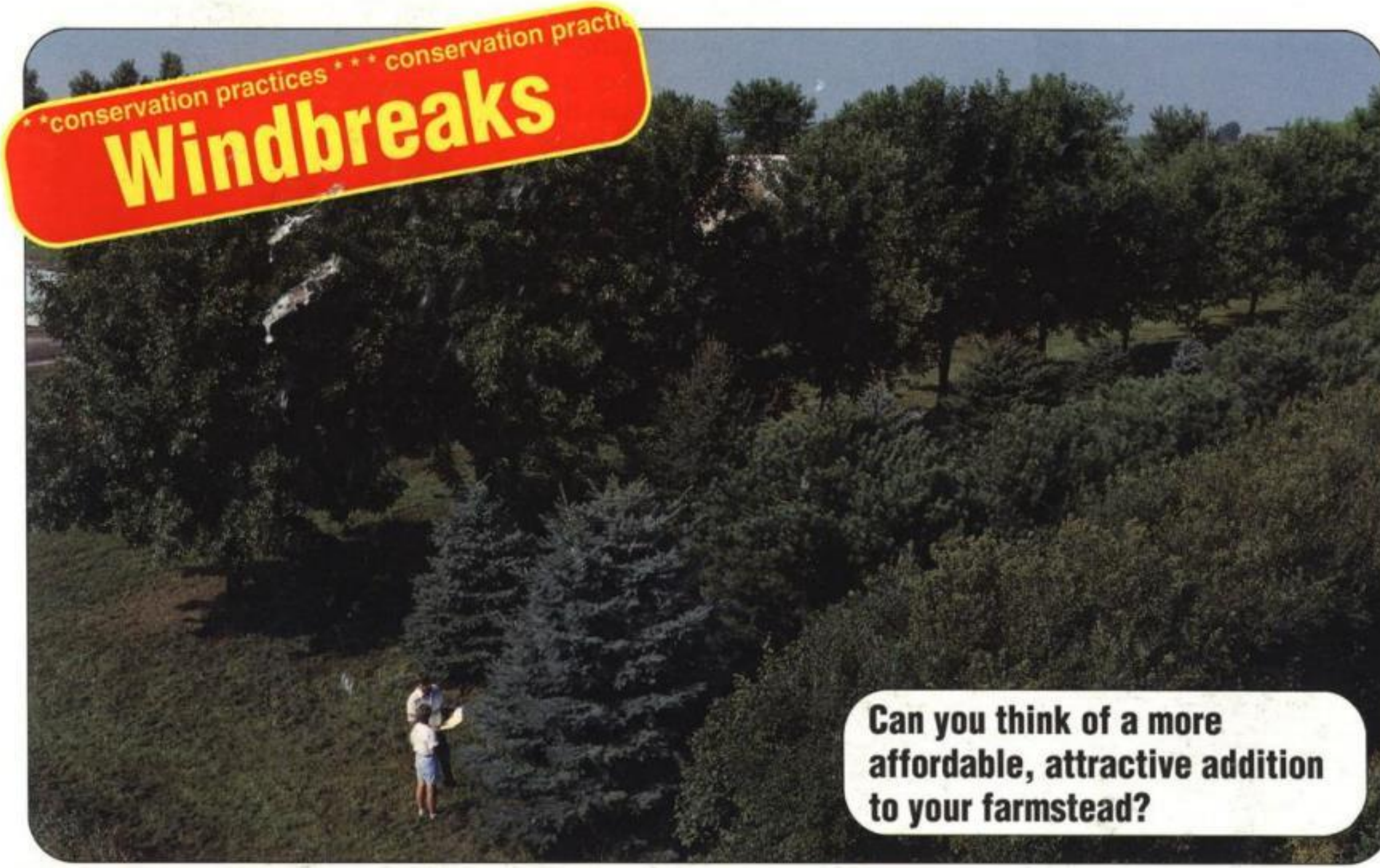
Adjusting the rotation

Weather conditions, unexpected herbicide carryover, and marketing

Terraces are earthen structures that intercept runoff on moderate to steep slopes. They transform long slopes into a series of shorter slopes.

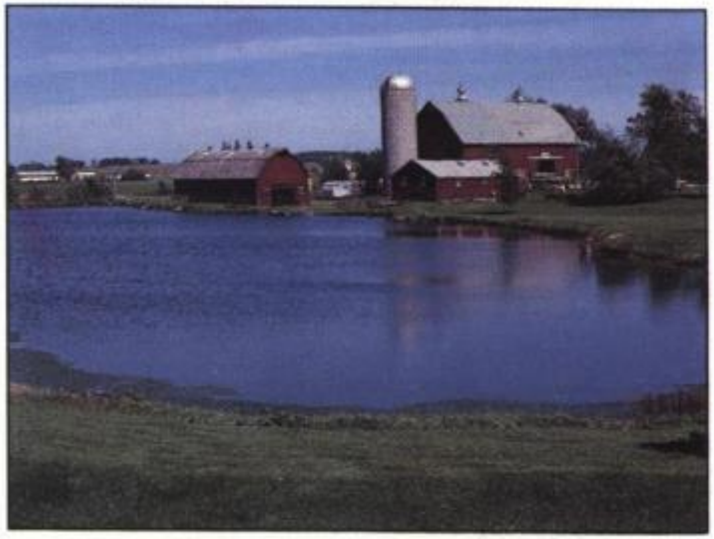
Narrow base terraces have 2:1 slopes on both the frontslope and backslope.

Broadbase terraces are flatter looking terraces that are farmed on both slopes. They should not be built on land slopes greater than 8%. Farmable slopes should not be steeper than 5:1 (5 feet horizontal to every 1 foot of vertical drop).



Windbreaks are a belt or rows of trees and shrubs planted next to a farmstead.

Farm pond



Ponds may be made by building a dam or digging a pit. A farm pond provides water for livestock, **controls gully erosion, provides recreation,** and **offers fish and wildlife habitat.** Considerations include location for a dependable source of non-contaminated water; protection from siltation; proper outlet; and capacity and storage.

Filter strips

Filter strips are strips of vegetation a minimum of 15 to 25 feet wide that **remove sediment, organic matter, and other pollutants from runoff.** They can be used on cropland next to streams, ponds, and lakes, or other areas to reduce sediment loads that could reach waterways. Also used to **treat polluted wastewater** as part of a waste management system.

Tree plantings

Planting trees by hand or machinery to establish a stand of trees can be an **effective conservation measure** in open areas or sparse woodlands where soils are adapted to hardwood forests. Considerations include fall seeding, fencing livestock out, and controlling weeds and other vegetative competition.

Wildlife upland habitat

Wildlife upland habitat management is creating, maintaining, or improving an area's food and cover for upland wildlife. The area is protected from grazing. Specific plants used are chosen for specific wildlife. Options include **nesting cover, winter cover, travel lanes, food plots,** and **water sources.** Applies to odd, non-farmable areas; fence rows; field edges; wetlands; and any other land with wildlife habitat as the primary concern.

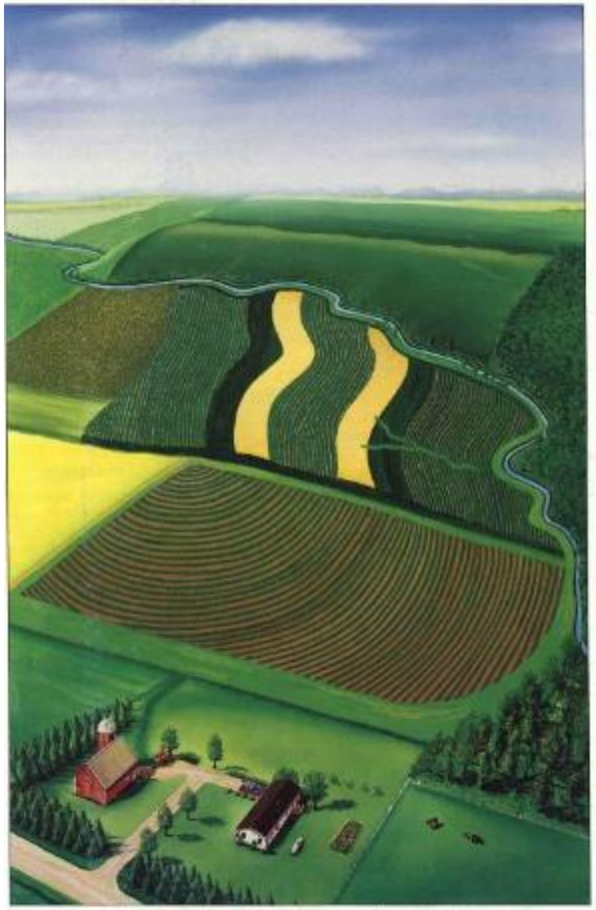
Cover crop

A cover crop is a crop of close-growing grasses, legumes, or small grains grown to **control soil erosion** during periods when the major crops do not furnish enough cover. Cover crops are often seeded in the fall to **protect the soil** until the next spring's planting of major crops, and may **add organic matter** to the soil and trap excess plant nutrients.

Water and sediment control basins

Water and sediment control basins are short earthen dams built across the slope and minor drainageways. They are used in areas not suited to terrace systems. Basins **trap sediment, reduce gully erosion,** and **reform the land surface.** Use in combination with conservation tillage, crop rotations, field borders, and cross slope farming.

Conservation system options. . . . . . by slope class



An artist's sketch of C, D, and E slopes (above) shows a complete conservation system. The 18 smaller field drawings to the right show systems that meet conservation compliance requirements. C slope is 5 - 9%; D slope is 9 - 14% ; E slope is 14 - 18%. The systems are examples of some common conservation choices. There are literally hundreds of combinations that may be used; these example systems may be used as guidelines in helping to choose the most workable system for slopes on your farm.

Possible systems for C slopes

Corn-soybean rotation: cross-slope farming; no-till corn into bean stubble to leave 40% residue cover; spring mulch till into cornstalks for soybeans leaving 40% residue cover after planting.

Corn-soybean rotation; contour spring plow corn stubble; mulch till into bean stubble to leave 20% residue after planting; terraced.

Continuous corn rotation; mulch till to leave 50% residue cover after planting.

Corn-soybean-oats-meadow rotation; spring plow meadow and corn; spring mulch till oats to leave 20% residue after planting.

Corn-soybean rotation; contoured; spring mulch till to leave 30% residue cover after planting corn, and 40% residue cover after planting soybeans.

Continuous corn rotation; contoured; spring mulch till to leave 20% residue cover after planting.

Possible systems for D slopes

Corn-soybean rotation; contoured; no-till corn into bean stubble to leave 50% residue cover; no-till soybeans into corn stubble to leave 80% residue cover after planting.

Continuous corn rotation; no-till to leave 50% residue cover after planting.

Continuous corn rotation; contoured; spring mulch till to leave 50% residue cover after planting.

Corn-soybean rotation; terraced and contoured; spring mulch till to leave 20% residue cover after planting corn, and 30% residue cover after planting soybeans.

Corn-soybean-corn-oats-meadow rotation; stripcropped; plow meadow & corn; leave 20% residue cover after planting oats.

Continuous corn rotation; 20% buffer strips; mulch till to leave 30% residue cover after planting.

Possible systems for E slopes

Corn-soybean rotation; mulch till to leave 30% residue cover after planting corn, and 40% residue cover after planting soybeans; terraced.

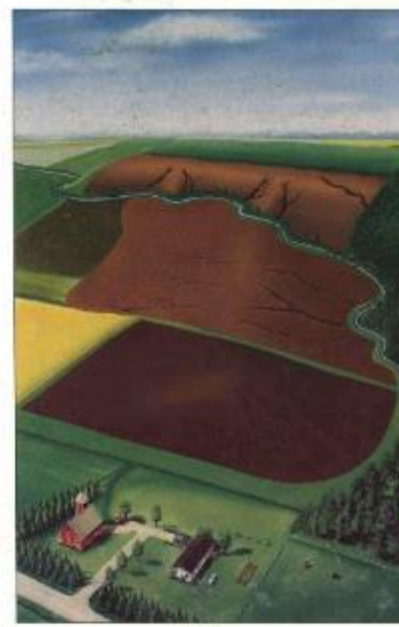
Corn-corn-corn-oats-meadow-meadow-meadow rotation; contoured; spring plow meadow; spring mulch till second and third year corn to leave 30% residue cover after planting.

Corn-oats-meadow rotation; spring plow meadow; mulch till oats to leave 20% residue after planting.

Corn-corn-corn-oats-meadow-meadow rotation; stripcropped.

Continuous corn rotation; no-till to leave 50% residue cover after planting.

Continuous corn rotation; 40% buffer strips; spring mulch till to leave at least 30% residue cover after planting.



Useable conservation system options are shown on these two pages—six each for C, D, and E slopes. Choose among them to treat the bare, eroded fields at left.

Thank you very much!

Baoyuan Liu: baoyuan@bnu.edu.cn
Yaxian Hu: huyaxian@nwafu.edu.cn