Maximum yield potential occurs...

- ...when the seed corn is in the bag.
- Once the seed is in the ground, that crop's yield potential is exposed to the effects of a wide array of biotic and abiotic stresses.

Effect of stress on yield

- Is ultimately equal to the effects on the components that define grain yield.
  - Plants per unit area (population or stand)
  - Ears per plant (degree of barrenness)
  - Kernels per ear (potential vs. actual)
    - Kernel rows per ear
    - Kernels per row
    - Weight per kernel

Because these yield components develop throughout the season, the timing of stress determines which yield component(s) are affected.

Effect of stress on yield

- May be direct...
  - Plant death (stand loss)
  - Pollination interference (kernel number)
  - Kernel survival (abortion)
  - Ear rots (yield & quality)
  - Dropped ears due to ECB damage to shank (ear loss)

- May be indirect...
  - Stunting of plants (factory size)
  - Leaf diseases (factory output)
  - Root diseases (factory output)
  - Stalk lodging (harvestability)

Timing of stress

- As in comedy, timing is everything!
- Similar stresses occurring at different developmental crop stages can cause very different levels of crop damage.
- The earlier the stress, the more likely the crop can compensate if it recovers from the damage.
- Early prolonged stress, or repeated stresses, may decrease the crop's ability to tolerate stress later in the season.
- Stress near pollination (hail, drought, etc.) generally has the most severe yield impact.

Critical times for corn

- Pollination phase
  - Especially 2 wks before to 2 wks after
  - Kernel 'set' determined

- Grain filling phase
  - Kernel survival
  - Kernel weight
  - Stalk rots

- Rapid growth phase
  - Ear & factory size determination

- Stand establishment phase
  - Germination & emergence
  - Establishment of nodal roots

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Stand establishment phase

- Germination & emergence
  - Ideal conditions:
    - Occurs less than 7 days after planting
  - Your experience says ………?

Stand Establishment does not end with successful G & E. It also includes...

- Establishment of nodal roots by V6
  - Ideal conditions:
    - Occurs 25 to 35 days after emergence
  - Your experience says ………? 

Stand Establishment:

Why is “fast” desirable?

- Less time for exposure to potentially severe stresses before plants are well established.
- Effects of stress are often less when plants are growing vigorously.
- A side benefit is more efficient use of the entire growing season.

Why is uniform desirable?

- Delayed plants cannot compete with older, more established plants.
  - At best, delayed emergers will contribute little to yield.
- Potential yield losses...
  - 8 to 20 % loss if 25 % or more of stand is 2 or more leaf stages “behind”
  - Univ. of IL

Fast & uniform G&E requires:

- Adequately warm soils
  - Consistently higher than 50°F (10°C)
- Uniform temperature within the seed zone

Fast & uniform G&E requires:

- Adequately moist soils
  - Uneven = Uneven G&E
  - How moist should it be?
- Purdue “Soil Moisture Assessment System”:
  - Too wet = Dead kernel
  - Too dry = Inert kernel
  - Just right = Germination

Soil temperature & corn emergence

Temps consistently greater than 50°F (10°C)

Days to emergence

G&E: Germination
Fast & uniform G&E requires:

- Adequate & uniform seed-to-soil contact
- Imbibition of moisture req’d to begin germination
- Poor substitutes...
  - Seed-to-residue!
  - Seed-to-rock!
  - Seed-to-clod!

Fast & uniform G&E requires:

- Pest-free conditions
  - Grubs, wireworms, seedcorn maggots
  - Seed rots and seedling blights
  - Prying agronomists!

Germination & Emergence:

- Surface soil free of crust or compaction that would interfere with the emergence of the coleoptile (spike)

Causes of delayed emergence...

- Variability in seedbed soil moisture
  - Soil variability for texture and natural or artificial drainage
  - Uneven seedling depths
  - Uneven distribution of crop residues
  - Soil drying patterns due to tillage traffic

Causes of delayed emergence...

- Uneven seed to soil contact
  - Rough, cloddy seedbeds
  - Uneven distribution of crop residues
  - Coulter running too deep
  - Incorrect furrow opener adjustment
  - Incorrect furrow closer adjustment

Especially important when soil temps. are hovering around 50F (10C).
When good fields turn bad

- Successful emergence (fast & uniform) does not guarantee successful stand establishment.
  - The next crucial phase is the establishment of a vigorous nodal root system.
  - Success is largely dependent on the initial nodal root growth from about 2-leaf to 6-leaf stages of development.

Until nodal roots are established...

- Seedlings depend primarily on the energy reserves of the kernel.
  - These energy reserves are translocated from the kernel through the connecting mesocotyl ‘pipeline’ to the young stalk and leaf tissues.
  - Therefore, a healthy kernel, seed roots, and mesocotyl are vital until nodal roots are well established.

Mesocotyl?

- Tubular, white, stemlike tissue that connects kernel and base of coleoptile (the ‘crown’)
- Mesocotyl cell elongation elevates coleoptile to soil surface
  - Mesocotyl elongation varies with seeding depth

What about seed roots?

- Seminal (seed) roots originate from the node located within the seed embryo.
  - Composed of the radicle root and lateral seminal roots.
  - Serve mainly to anchor seedling.
  - Take up minimal amount of water & nutrients.
  - Cease new growth shortly after seedling emergence.

From emergence to knee-high

- Damage to the kernel or mesocotyl prior to establishment of nodal root system will stunt or kill the seedling
  - Most sensitive from emergence to about 3-leaf collar stage of development
  - Stresses include fertilizer salt injury, seedling diseases, insect feeding damage, excessively wet or dry soils

Insect injury to kernel

- Injured plant technically alive, but severely stunted.
**Nodal root system**

- Nodal roots originate from stalk nodes.
  - One set of roots develops from every below-ground node plus 1 or more above ground nodes.
  - Nodal root sets develop sequentially over time.
  - Begin elongation shortly after seedling emergence.
  - First set is noticeable by 2-leaf collar stage.
  - By 6-leaf collar stage, will be the main roots of plant if development has occurred normally.

**Nodal Roots at V2**

**Nodal Root Morphology**

- Cool soils slow development
  - Delays development of nodal roots and prolongs the seedling's dependence on the dwindling kernel reserves.
  - Increases exposure time to damaging soil-borne pathogens, insects or pesticides prior to successful nodal root establishment.
  - Delays roots’ encounter with soil nutrients.
  - Decreases available growing season.
  - Plant development is literally behind schedule.

**From emergence to knee-high**

- Damage or stress to the 1st few sets of nodal roots can severely stunt or delay a corn plant’s development.
- Most sensitive from emergence to about 6-leaf collar stage of development.
- Fertilizer salt injury, seedling diseases, herbicide injury, insect feeding damage, excessively wet or dry soils, soil compaction (tillage or planter)

**Injury by 1st-Yr WCRW Larvae**

- Root injury by 1st-yr WCRW variant not unusual by itself.
  - Variant is slowly spreading throughout Indiana.
- Typically, WCRW egg hatch (late May to early June) coincides w/ corn at V6 or older growth stages.
- Severe CRW populations can be severely damaging to roots.

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Good Field Turned Bad:
- C/SB, planted late May
- Fast, uniform emergence
- Late June, turn for worse
- Stunted plants near death

Strange Patterns:
- Sometimes along the rows
- Sometimes across the rows
- Sometimes perpendicular to rows

Interesting Quirk Regarding Tire Tracks:
- Plants healthiest in tire traffic areas of field

Plants Literally Near Death
- Transition occurred in less than a week

Surface Two Inches = Bone Dry
- Some soil moisture at seed depth and deeper

Root systems w/ evident CRW feeding damage
- No CRW larvae found on first trip to field
Occasional kernel damaged by other insects • But damage mostly to root system and mesocotyl

CRW larvae found on 2nd trip to field • Following light shower & cooler soil surface temperatures

Storm in mid-July caused dramatic root lodging in fields severely affected by CRW larvae

Root lodging resulted in plant death in some fields • Lodging pulled plants nearly completely out of soil

What was different in 2002?
- Timing of crop growth stage and occurrence of multiple stresses
  - Corn planted very late due to wet spring.
  - CRW egg hatch at or just before VE of corn.
  - Rapid drying of upper several inches of soil prior to time of nodal root development.
  - Week of unusual heat and subsequent stressfully hot surface soils in mid-June.
  - In some fields, severe sidewall or tillage compaction also contributed to stress on root development.
Sidewall compaction

- Lengthy, wet spring delayed field work
- Tillage often done on the “wet side”
  - Shallow horizontal compaction
- Corn often planted on the “wet side”
  - Vertical sidewall compaction
- Followed by rapid onset of drought conditions during early nodal root development

Tillage on the “wet side”...

Stunted Growth

- Caused by tillage, compaction, sideways compaction, and drought conditions

Root System Limited by Soil Compaction

Seedling Blight in Corn

- Example of a field of corn in northwest Indiana planted mid-April 2000 under “good” conditions.
  - Emergence described as uniform and acceptable
  - Early seedling development described as uniform and acceptable
Stunting & death of plants

- Areas of fields with significant plant stunting or death developed 4 to 6 wks after planting
  - Often on ‘higher’ and ‘lighter’ areas of field
  - Not where you would expect seedling blight

‘Normal’ and stunted plants

Farmer: Why seedling blight?

- After all, seed fungicide treatments are better than ever!
  - Captan®, Maxim®, Apron®
  - Furthermore, problems were not always occurring in lower wetter areas of fields.
  - Where we usually worry about disease
  - Rather, on the higher & lighter soils

Purpose of seed treatments?

- Obviously, to protect seed and seedling from early fungal diseases.
  - Pythium, rhizoctonia, etc.
  - More specifically, protection until the plants’ permanent (nodal) roots are well established.
  - Generally ‘in place’ by V4 to V6.

Fungicidal seed treatments

- Sadly, the life span of seed treatments is typically no longer than 2 to 3 weeks after planting.
  - Furthermore, once seed coat breaks due to germination, fungicidal protection is often compromised.
So, why seedling blight?
- Early planting, cool soils, slow G&E
  - Pronounced on lighter colored soils
- Cool soils for 4 to 6 wks after planting
  - Pronounced on lighter colored soils
  - Slow corn seedling development
    - Including nodal root development
- Seed treatment eventually ‘gives up ghost’
  - Pathogens ‘move in for the kill’

Soil temperature & corn emergence

Rapid growth phase
- At about leaf stage V5 (five visible leaf collars) the corn plant shifts from vegetative to reproductive modes
  - The tassel & final ear initiate about then
  - Ear size determination period begins
  - Size of ‘factory’ is determined
    - Overall plant growth accelerates
    - Nutrient uptake skyrockets

Seasonal corn plant growth

Seasonal nutrient content

Ear size determination
- Prior to about V5, little effect of stress on ear size because final ear not initiated yet.
- From about V5 to V15, stress can limit ear size potential
  - After stage V5, some herbicide labels restrict application either by completely cutting off or limiting to use of drop nozzles.
**Ear shoots everywhere!**
- An ear shoot forms at every stalk node except the upper six or seven.
- Can be found behind the base of the leaf sheaths, even at the lowermost nodes below ground.

**Ear shoot prioritization**
- Initially, the ear shoots found at the lower stalk nodes are longer than the ones at the upper stalk nodes because the lower ones are created earlier.
- As time marches on, the upper one or two ear shoots assume priority over all the lower ones and become the harvestable ears.

**Ear size & stress**
- Fortunately, row number determination is stress tolerant.
- Row number more heritable than is ear length.
- Ear length (kernels per row) is more sensitive to stress.
- Remember, conditions prior to flowering determine number of potential kernels, conditions at pollination or afterward determine number of actual kernels.

**Not much to look at...**
- By V9 (about thigh-high), the uppermost ear shoots and the tassel can be easily located.
- Fraction of an inch long
- Tassel branches are visible
- Ears are mostly husk
- Leaves at this point, yet the cobs are about halfway complete in their size determination.

**Arrested ears are strange...**
- Just a few examples...

**Causes not always obvious...**
- The appearance of an arrested ear gives hints of the timing of the stress.
- But, not always the cause of the stress.
‘Beer Can’ Ears

- Normal lower ear development, then nothing.
- Remnant ear initial usually visible that suggests ear development simply stopped.
- Some believe it is related to the occurrence of chilling injury between V5 and V9.

Stay tuned: Purdue research will investigate this possibility beginning in 2003.

Rapid growth: NOT!

- Severe stresses during the rapid growth phase can greatly limit the ability of the corn crop to “take off.”
- Affects “factory” size
- Can affect ear size determination

Factory size & stress

- Conditions prior to flowering determine the eventual size of the photosynthetic ‘factory’
- Conditions after flowering determine the actual output of that ‘factory’ during grain filling.

Pollination Phase

- Defined by tasseling, silking & pollen shed
- THE most critical period for corn
- Drought + heat = most impact
- Cloudy weather
- Silk clipping by insects
- Hail damage
- Severe leaf diseases
- Severe nutrient deficiency

‘Natural’ Corn Plant Sex

- Pollen produced in the tassel anthers contains the male genetic material.
- Ovules produced on the ears contain the female genetic material.
- This ‘natural’ sex has been going on for thousands of years!

Male Flowers of Corn

- Between 500 to 1000 spikelets form on each tassel.
- Each spikelet contains two florets.
- Each floret contains three anthers...
  - Look somewhat like the double barrel of a shotgun.
  - Pollen is dispersed through pores that open at the tips of the anthers.
Anthers & pollen shed
- Anthers emerge first from middle of the central spike, then slowly from the remainder of tassel over about 7 days.
  - Normal plant-to-plant developmental variability within a field often results in 10-14 day duration of pollen shed.

Normal plant-to-plant developmental variability within a field often results in 10-14 day duration of pollen shed.

Corn Pollen
- The ‘dust-like’ pollen represents millions of individual, nearly microscopic, spherical, yellowish- or whitish translucent pollen grains.
  - Peak pollen shed usually occurs in mid-morning.
  - If anthers are wet (rain, dew) then pollen does not shed.
  - Pollen shed slows to a stop in heat of the day.

Pollen Survival
- A pollen grain’s outer membrane is thin.
  - Once dispersed into the atmosphere, pollen grains remain viable for only 1 to 2 hours before they desiccate.
  - Yet, with only a 15 mph wind, pollen grains can travel as far as ½ mile within only a couple of minutes.
  - Thus, the concern of pollen drift from transgenic fields to non-transgenic ones.

Silking
- Every ovule (potential kernel) develops a single silk (functional stigma of the female flower).
  - Up to 1000 ovules develop per ear.
  - Usually 400 to 600 successfully develop into harvestable kernels.

Pollen & Silks
- Pollen grain lands on a receptive silk and germinates within 30 minutes,
  - Pollen tube penetrates into silk itself,
  - Pollen tube develops down to ovule within 24 hours where fertilization occurs

Pregnancy Test for Corn
- Success of pollination can be determined early by inspecting silks.
  - Within a day or two of successful fertilization, a silk will collapse at its point of connection with the kernel and detach.
Unsuccessful Pollination?
- Persistent silk clipping by insects during pollen shed.
- Silk delay from drought stress.
- Silk dessication by heat & low humidity.
- Silk 'balling' or 'knotting up' inside the husk leaves.
- Herbicide injury to tassel or ear development.

Keep it in perspective
- Unusually long ears (many kernels) may not pollinate completely
  - Tip silks miss out on pollen because of their late emergence.
- Actual kernel set may be very acceptable.

Grain filling phase
- Time period from pollination to kernel black layer (physiological maturity)
- Yield losses can occur from
  - Stand loss
  - Incomplete kernel set
  - Lightweight kernels
  - Premature plant death

Stand loss during grain fill
- Yield effect more severe than earlier in the season.
  - Crop can only compensate for missing plants by increasing kernel weight.
  - Kernel number already determined
  - Kernel weight compensation only likely to occur for plants adjacent to missing plant(s)

Incomplete kernel set
- The degree to which kernels have developed on the cob
  - Success or failure not always apparent from windshield surveys of a corn field
  - Failure may be due to a combination of:
    - Pollination problems (already discussed)
    - Kernel abortion

Kernel abortion
- Kernels may abort due to stress that occurs from blister to the early milk stages of kernel development.
- Symptoms are shrunken, white or yellow kernels, often with a visible yellow embryo.
Causes of kernel abortion
- Primarily severe photosynthesis problems
  - Severe drought stress
  - Severe heat stress
  - Severe nutrient deficiency
  - Severe leaf diseases
  - Leaf loss due to hail damage
  - Severe ECB stalk tunneling
  - Excessively warm nights during or shortly after pollination
  - Consecutive cloudy days shortly after successful pollination

Lightweight kernels
- Kernel abortion is much less likely once kernels have reached early dough stage,
  - Severe stress can continue to affect eventual yield by decreasing photosynthesis and, consequently, kernel weight.
  - Drought & heat
  - Corn borer damage
  - Hail defoliation
  - Disease defoliation
  - Stalk rots
  - Early killing frost

Premature plant death
- Severity of yield loss depends on timing and magnitude of death
  - Leaf death alone (e.g., light frost)
    - Plant may be capable of remobilizing stored carbohydrates from stalk tissue to the immature ear.
  - Whole plant death (e.g., killing frost)
    - Prevents remobilization
    - Kernel black layer soon forms

Timing of death & yield loss

<table>
<thead>
<tr>
<th>Time of death (kernel stage)</th>
<th>Whole plant</th>
<th>Leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dough</td>
<td>35</td>
<td>6</td>
</tr>
<tr>
<td>Dent</td>
<td>55</td>
<td>27</td>
</tr>
<tr>
<td>Half-milkline</td>
<td>41</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: NCH-57. [http://www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-57.html](http://www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-57.html)

Physiological maturity
- Physiological maturity occurs shortly after the kernel milk line disappears and just before the kernel black layer forms at the tip of the kernels.
  - Once kernels are physiologically mature, they are safe from further effects of physiological stress.

Stresses & stalk rots
- Methods of infection
- Fungal causes
- Relationship with plant stresses
- Ways to minimize stalk rot risk
Several fungi often involved
- All are part of the complex of microorganisms in the soil that decompose dead plant material.
  - Anthracnose, fusarium, diplodia, gibberella
- Survive from one season to the next in
  - The soil, or
  - Infested corn plant residues

Entry into the corn plant
- Fungal spores blown into base of leaf sheath germinate and grow directly into the stalk tissue.
- Fungal spores enter directly through wounds (hail, ECB, mechanical injury).
- Infect root system directly, causing root rot, later stalk rot

A disease of ‘old age’
- Fungi typically don’t infect corn at early stages of development.
  - Yet, fungi are present in soil and plant residues 12 months out of the year.
  - Rather, develop at mid- to late grain fill stages
  - Early August to early September

Why ‘old age’ disease?
- Young, healthy roots and stalks are fairly resistant to fungal infection.
- Susceptibility to rots increases as …
  - Cell maintenance & repair diminishes due to lack of carbohydrate replenishment
  - Carbohydrates remobilize from stalk tissue to fulfill demands of developing ear
  - The incidence of both increases during the course of grain fill

Carbohydrate availability
- For most of today’s corn hybrids, the carbohydrates necessary for the grain filling process are manufactured ‘on the fly’ by photosynthesis.
- If the photosynthetic ‘factory’ is hindered by plant stresses, carbohydrate output will also be restricted.

Photosynthetic stresses
- Any plant stress occurring any time during the season can affect the photosynthetic productivity of the plant ‘factory’ during grain fill.
  - But, especially stresses that occur during the grain fill, including
    - Hail, leaf diseases, cloudy conditions, soggy soils, dry soils, extreme heat, nutrient deficiencies, ECB or SWCB infestation
**Plant’s response to stress?**
- When the carbohydrate demands of the plant cannot be met by the photosynthetic output of the ‘factory’,
  - Developing ears take priority and root & stalk cell maintenance suffers
  - Fungal infection of roots (root rots) soon follows
  - Plant may cannibalize carbohydrate reserves stored in lower stalk tissue.

**Cannibalization**
- Refers to the remobilizing of stored carbohydrates from stalk tissues and transport to the developing ear.
  - Weakens the physical integrity of stalk
  - Increases susceptibility to stalk rots
  - Especially likely when plant stresses occur
    - From early to mid-grain fill and/or
    - When potential ear size (yield) is large

**Typical plant stresses?**
- Excessively dry soils at times
- Excessively wet soils at times
- Severe N deficiency
- Consecutive days of cloudy weather
- ECB infestations
- Hail damage
- Leaf diseases (GLS, anthracnose, NCLB)
- High yield potential itself

**Minimizing risk of stalk rots**
- Hybrid selection
  - ‘Stay-green’ trait infers less cannibalization
  - Stalk strength characteristics
  - Disease tolerance, esp. leaf diseases
  - Bt trait where ECB or SWCB are prevalent
  - Stress tolerance in general
  - Avoid excessively high populations

**Minimize risk of stress**
- Always use best agronomic practices
- Avoid/alleivate soil compaction
- Avoid nutrient deficiencies
- Attend church regularly!
- Avoid continuous corn rotation
  - Residue conducive for inoculum developmt
- Use tillage where appropriate
  - Esp. helps avoid diplodia and anthracnose

**Late-season scouting**
- Beginning in early August, scout fields or areas within fields that are likely to be at high risk for stalk rots
  - Susceptible hybrids
  - Severe drought or soggy soil stress
  - Severe nutrient deficiency
  - Severe insect or leaf disease infestations
  - Exceptionally high yields
Late-season scouting

- Pinch or slice lower stalks for evidence of disintegrating stalk tissue
- Dig up plants and inspect roots for health and integrity
- Schedule high risk fields for early harvest
- Continue scouting during harvest
  - Stalk health condition can change rapidly
  - Gibberella stalk rot favored by October rainy period 2001

Hungry for More?

- Or didn't catch what I said the first time?