Stress &
the Common Corn Plant

Bob Nielsen
Purdue University
Email: rnielsen@purdue.edu
Web: www.kingcorn.org
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

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

- Rapid growth phase
  - Ear & ‘factory’ size determination

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

- Grain filling phase
  - Kernel survival
  - Kernel weight
  - Stalk rots
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 ...........?
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
Soil temperature & corn emergence

Temps consistently greater than 50F (10C)

8 days or less to emergence

Planting date

Soil temp (F)

Days to emergence


Days to Emergence

0 5 10 15 20 25 30 35 40

0 5 10 15 20 25 30 35 40

20-Mar 03-Apr 17-Apr 01-May 15-May 29-May 12-Jun 26-Jun
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
Germination & Emergence:

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:

Fast & uniform G&E requires:

- 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 seeding depths
  - Uneven distribution of crop residues
  - Soil drying patterns due to tillage traffic
Causes of delayed emergence...

- Variability in seedbed soil temperature
  - Variable soil color and texture
  - Variable seeding depths
  - Variable distribution of crop residues

- Especially important when soil temps. are hovering around 50F (10C).
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
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

V2 Stage

Roots at V2 Stage

Nodal Roots at V2 Stage

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Nodal Root Morphology

Nodal Roots in Corn

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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.
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
• But CRW larvae not found on first trip to field
Occasional kernel damaged by other insects

- But damage mostly to root system and mesocotyl
CRW larvae found on 2\textsuperscript{nd} 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
Root rating = 6?
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, sidewall compaction, and drought conditions
Root System Limited by Soil Compaction

Tillage compaction
2 to 3 inches below surface
Sidewall Compaction Effects on Lambsquarter & Corn

Fan-shaped root pattern caused by sidewall 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

‘Normal’ Plant
Leaf Stage V4

Stunted Plant
That Won’t Survive

Shrunken, discolored, diseased mesocotyl

Seed completely rotted away
Seedling blight on young corn

Stunted V2 Plant That Won't Survive

Shrunken, discolored, diseased mesocotyl

RLNielsen, Purdue Univ., 2000
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

Delayed G&E:
- Prolonged exposure to stresses
- Clock ticking on seed protectants

Same Holds True For Delayed Seedling Establishment

Planting date

20-Mar 03-Apr 17-Apr 01-May 15-May 29-May 12-Jun 26-Jun

Days to Emergence

Days to emergence
0 5 10 15 20 25 30 35 40
0 10 20 30 40

Soil temp (F)
0 10 20 30 40 50 60 70 80 90

35 20 14 8 6 8 7

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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

Days after planting

- 4-leaf
- 9-leaf
- Shoulder-high
- Tassel
- Late silk
- Early blister
- Dent
- Krnl black layer

Miles per acre

- Root lgth
- Shoot wt

Pounds per acre

Source: D. Mengel, Purdue Univ. Agronomy

Grain wt: 9650 lbs
Abt 46% of total above-ground wt
Seasonal nutrient content

Source: D. Mengel, Purdue Univ. Agronomy
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.
  - Row number fairly constant year to year for given hybrid.
- 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 (abt 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.

**Severe Stress:**
Herbicide and possibly chilling injury can easily arrest or interfere with ear development at this stage.
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.

Nutrient deficiency
- Soil compaction
- Drought stress
- Soggy soils
- Cool temperatures
- CRW root feeding
- Herbicide injury
- Cloudy weather
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.

Gravity, wind or human intervention allows the pollen to fertilize the ovules.

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.
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.

A Glass Mostly Full?

Poor tip fill, but still acceptable ear size

18 rows by 34 kernels or about 600 kernels

Milk stage

Blister
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

Incomplete kernel set caused by severe CRW beetle silk clipping
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 (knl stage)</th>
<th>Leaves</th>
<th>Whole plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dough</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>Dent</td>
<td>27</td>
<td>41</td>
</tr>
<tr>
<td>Half-milkline</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: NCH-57. 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

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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
Minimizing risk of stalk rots

- Minimize risk of stress
  - Always use best agronomic practices
  - Avoid/alleviate soil compaction
  - Avoid nutrient deficiencies
  - Attend church regularly!

- Avoid continuous corn rotation
  - Residue conducive for inoculum development

- 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

Read your newsletters:
Nielsen, P&C Newsletter, 16 Aug 2001
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?