STRATEGIES FOR MANAGING CORN PRODUCTION DURING DROUGHT YEARS: WHAT WORKS AND WHAT DOESN'T

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Due to warmer than normal conditions during March, planting started quickly and then was delayed by wet conditions around May 1. Over the entire growing season, growing degree-day accumulation was above the 30-year normal. During May, June and July, precipitation was significantly below average in southern Wisconsin, while northern Wisconsin had above average precipitation. Drought conditions continued through August and September in the southern half of Wisconsin and were also observed in the northern half of the state. Due to a dry and warm September and October, good grain drying occurred with harvest grain moisture lower than normal in all trials.

Crop productivity is an indicator of drought intensity. Most grain crops have specific stages of development when their yields are most sensitive to drought stress, so timing of stress also influences the amount of yield loss. Stress during mid-vegetative stages may reduce ear size by reducing the number of flowers on the ear and may reduce plant height and leaf size. Usually, drought stress during early vegetative stages has little effect on grain yield, but nodal root growth can be impacted by dry soil during stages V2 to V5. Greatest yield reductions usually occur with sustained drought stress during late vegetative stages and throughout the reproductive stages. Corn's most sensitive stage is a three week period centered on R1 (silking). Stress during this period reduces the number of flowers that are successfully fertilized. Stress after silking will result in increased kernel abortion, and if the stress is not been relieved, reduced seed size.

Like 1988 (Table 1), the impact of the 2012 drought was significant as shown in Table 2. Grain yield in the University of Wisconsin hybrid performance trials was significantly lower at all southern locations.

Table 1. 1988 Wisconsin Corn Performance Trials - Grain Summary

	1978-1987		1988		Percent
Location	N	Yield	N	Yield	change
Arlington	756	185	166	131	-29
Janesville	706	184	166	151	-18
Lancaster	706	146	166	71	-51
Fond du Lac	718	138	151	114	-17
Galesville	718	157	151	162	3
Hancock	719	170	151	198	16
Chippewa Falls	510	141	*	*	---
Marshfield	510	125	126	99	-21
New London/Waupaca	514	152	126	172	13
White Lake	54	135	58	94	-30
Spooner	534	115	116	87	-24

* Chippewa Falls was not harvested in 1988.

Table 2. 2012 Wisconsin Corn Performance Trials - Grain Summary

	2002-2011		2012		Percent
Location	N	Yield	N	Yield	change
Arlington	758	222	160	203	-9
Janesville	702	232	147	183	-21
Lancaster	658	219	147	146	-33
Fond du Lac	631	196	132	189	-4
Galesville	615	214	132	215	0
Hancock	626	207	132	243	17
Chippewa Falls	607	194	162	138	-29
Marshfield	756	170	232	167	-2
Seymour	607	170	162	179	5
Valders	606	180	162	213	18
Coleman/Rhinelander	175	183	70	202	10
Spooner	690	156	210	131	-16

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USDA-NASS preliminary data confirm these findings (Figures 1 and 2). Corn grain yields are forecasted at 124 bu/A. Projected production has been reduced by 20% causing a spike in corn price. Many acres that were planted for grain production ended up being harvested for silage production, especially in the southern two tiers of counties in Wisconsin.

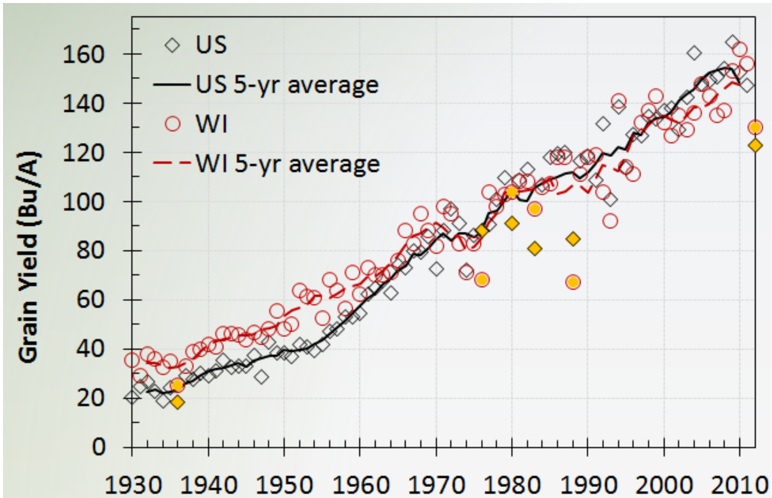

Figure 1. Corn grain yield (Bu/A) in the United States and Wisconsin over time. Filled symbols indicate drought years.

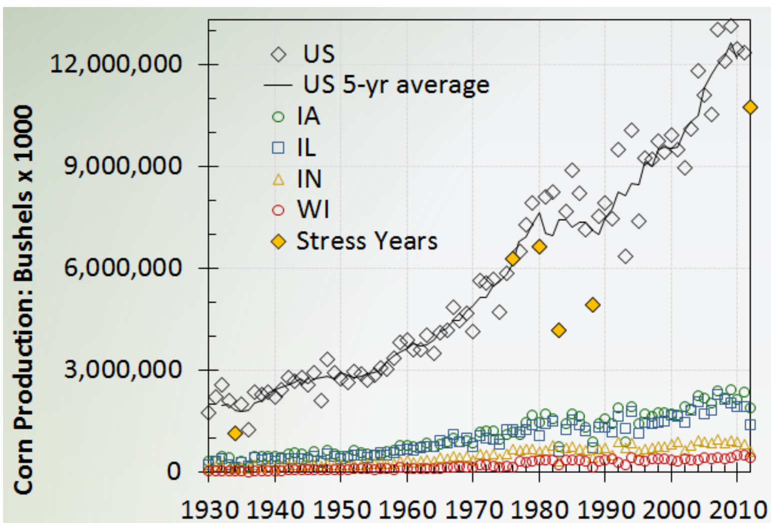

Figure 2. Corn production (Bushels x 1000) in the United States, Iowa, Illinois, Indiana and Wisconsin over time. Filled symbols indicate drought years.

What Happens Within The Corn Plant When Drought Occurs?

In nearly every year, drought affects corn growth and development somewhere in Wisconsin. It will often progress to the point where farmers feel that the dry weather is reducing yield potential.

To begin talking about water influences on corn growth and development and yield we must begin with the concept of evapotranspiration. **Evapotranspiration** is both the water lost from the soil surface through **evaporation** and the water used by a plant during **transpiration**. Soil evaporation is the major loss of water from the soil during early stages of growth. As corn leaf area increases, transpiration gradually becomes the major pathway through which water moves from the soil through the plant to the atmosphere.

Yield is reduced when evapotranspiration demand exceeds water supply from the soil at any time during the corn life cycle. Nutrient availability, uptake, and transport are impaired without sufficient water. Plants weakened by stress are also more susceptible to disease and insect damage. Corn responds to water stress by leaf rolling. Highly stressed plants will begin leaf rolling early in the day. Evapotranspiration demand of corn varies during its life cycle (Table 3). Evapotranspiration peaks around canopy closure. Estimates of peak evapotranspiration in corn range between 0.20 and 0.39 inches per day. Corn yield is most sensitive to water stress during flowering and pollination, followed by grain-filling, and finally vegetative growth stages.

Vegetative development

Water stress during vegetative development reduces stem and leaf cell expansion resulting in reduced plant height and less leaf area. Leaf number is generally not affected by water stress. Corn roots can grow between 5 and 8 feet deep, and soil can hold 1.5 to 2.5 inches of available soil water per foot of soil, depending upon soil texture. Ear size may be smaller. Kernel number (rows) is reduced. Early drought stress does not usually affect yield in Wisconsin through the V10-V12 stages. Beyond these stages water stress begins to have an increasing effect on corn yield.

Table 3. Estimated corn evapotranspiration and yield loss per stress day during various stages of growth.

Growth stage	Evapo-transpiration	Percent yield loss per day of stress (min-ave-max)
	inches per day	%
1 to 4 leaf	0.06	---
4 to 8 leaf	0.10	---
8 to 12 leaf	0.18	---
12 to 16 leaf	0.21	2.1 - 3.0 - 3.7
16 leaf to VT	0.33	2.5 - 3.2 - 4.0
Silking (R1)	0.33	3.0 - 6.8 - 8.0
Blister (R2)	0.33	3.0 - 4.2 - 6.0
Milk (R3)	0.26	3.0 - 4.2 - 5.8
Dough (R4)	0.26	3.0 - 4.0 - 5.0
Dent (R5)	0.26	2.5 - 3.0 - 4.0
Maturity (R6)	0.23	0.0

derived from Rhoads and Bennett (1990) and Shaw (1988)

Pollination

Water stress around flowering and pollination delays silking, reduces silk elongation, and inhibits embryo development after pollination. Moisture stress during this time reduces corn grain yield 3-8% for each day of stress (Table 3). Moisture or heat stress interferes with synchronization between pollen shed and silk emergence. Drought stress may delay silk emergence until pollen shed is nearly or completely finished. During periods of high temperatures, low relative humidity, and inadequate soil moisture level, exposed silks may desiccate and become non-receptive to pollen germination.

Silk elongation begins near the butt of the ear and progresses up toward the tip. The tip silks are typically the last to emerge from the husk leaves. If ears are unusually long (many kernels per row), the final silks from the tip of the ear may emerge after all the pollen has been shed. Another cause of incomplete kernel set is abortion of fertilized ovules. Aborted kernels are distinguished from unfertilized ovules in that aborted kernels had actually begun development. Aborted kernels will be shrunken and mostly white.

Kernel development (grain-filling)

Water stress during grain-filling increases leaf dying, shortens the grain-filling period, increases lodging, and lowers kernel weight. Water stress during grain-filling reduces yield 2.5 to 5.8% with each day of stress (Table 3). Kernels are most susceptible to abortion during the first 2 weeks following pollination, particularly kernels near the tip of the ear. Tip kernels are generally last to be fertilized, less vigorous than the rest, and are most susceptible to abortion. Once kernels have reached the dough stage of development, further yield losses will occur mainly from reductions in kernel dry weight accumulation.

Severe drought stress that continues into the early stages of kernel development (blister and milk stages) can easily abort developing kernels. Severe stress during dough and dent stages of grain fill decreases grain yield primarily due to decreased kernel weights and is often caused by premature black layer formation in the kernels. Once grain has reached physiological maturity, stress will have no further physiological effect on final yield (Table 3). Stalk and ear rots, however, can continue to develop after corn has reached physiological maturity and indirectly reduce grain yield through plant lodging. Stalk rots are seen more often when ears have high kernel numbers and have been predisposed to stress, especially drought stress.

Premature Plant Death

Premature death of leaves results in yield losses because the photosynthetic 'factory' output is greatly reduced. The plant may remobilize stored carbohydrates from the leaves or stalk tissue to the developing ears, but yield potential will still be lost. Death of all plant tissue prevents any further remobilization of stored carbohydrates to the developing ear. Whole plant death that occurs before normal black layer formation will cause premature black layer development, resulting in incomplete grain fill and lightweight, chaffy grain. Grain moisture will be greater than 35%, requiring substantial field dry-down before harvest.

Yield Components and When They Are Determined During the Corn Life Cycle

With the onset of tasseling the corn crop is in a critical growth and development stage for grain yield. The tasseling, silking, and pollination stages of corn development are extremely critical because the yield components of ear and kernel number can no longer be increased by the plant and the potential size of the kernel is being determined.

For example, the potential number of ears per unit area is largely determined by number of seeds planted, how many germinate, and eventually emerge. Attrition of plants through disease, unfurling underground, insects, mammal, bird damage, chemical damage, mechanical damage, and lodging all will decrease the actual number of ears that are eventually harvested. The plant often can compensate for early losses by producing a second or third ear, but the capacity to compensate ear number is largely lost by R1 and from then on no new ears can be formed.

Likewise, kernel number is at its greatest potential slightly before R1, the actual number of kernels formed is determined by pollination of the kernel ovule. The yield component of kernel number is actually set by pollination and fertilization of the kernel ovule. If the ovule is not pollinated, the kernel cannot continue development and eventually dies. No new kernels form after the pollination phase is past.

The only yield component remaining after pollination that has some flexibility is kernel weight. For the first 7 to 10 days after pollination of an individual kernel, cell division occurs in the endosperm. The potential number of cells that can accumulate starch is determined. At black layer formation (R6) no more material can be transported into the kernel and yield is determined.

Management Decisions Will Depend Upon Success of Corn Pollination

By the end of July, the key plant indicator to observe and base future management decisions upon is the success of pollination. Each ovule (potential kernel) has a silk attached to it. When a pollen grain falls on a silk, it germinates, produces a pollen tube that grows the length of the silk which fertilizes the ovule in 12 to 28 hours. If fertilization of the ovule is successful, within 1 to 3 days the silk will detach from the developing kernel. Silks will remain attached to unfertilized ovules and be receptive to pollen up to 7 days after emergence. Silks eventually turn brown and dry up after pollination is over.

Two techniques are commonly used to assess pollination success or failure. The most rapid technique to determine pollination success is the “shake test.” Carefully unwrap the ear husk leaves and then gently shake the ear. The silks from fertilized ovules will drop off. The proportion (%) of silks dropping off the ear indicates the proportion of future kernels on an ear. Randomly sample several ears in a field to estimate the success of pollination.

The second technique is to wait until 10 days after fertilization of the ovules. The developing ovules (kernels) will appear as watery blisters (the "blister" R2 stage of kernel development).

Management Guidelines for Handling Cornfields with Poor Pollination

Typical management options and uses are available for corn that has successfully pollinated. If pollination is unsuccessful, we are usually trying to make the best of a bad situation.

If **pollination is good**, harvest in a normal fashion for either grain or forage use. If **pollination is poor** yet some kernels are developing, the plant can gain dry matter and farmers should wait with harvest. In Wisconsin, many farmers have the option of harvesting poorly pollinated fields for silage use. If there is **no pollination**, then the best quality forage will be as found as close to flowering as possible. Quality decreases after flowering. The challenge is to make sure that no potential pollination occurs and that the forage moisture is correct for the storage structure.

Drought-stressed corn can be grazed or used for forage, either as green chop or silage. Because of the potential for nitrate toxicity, grazing or green chopping should be done only when emergency feed is needed. The decision to chop corn for silage should be made when:

i. You are sure pollination and fertilization of kernels <u>will not or did not occur</u> and that whole-plant moisture is in the proper range for the storage structure so that fermentation can occur without seepage or spoilage losses. If there is no grain now, florets on the ear were either not pollinated or have not started to grow due to moisture stress, and the plant will continue to be barren. If the plant is dead, harvest should occur when whole plant moisture is appropriate for preservation and storage.

ii. If pollination and fertilization of kernels <u>did occur</u> but it was poor, do not chop until you are sure that there is no further potential to increase grain dry matter and whole plant moisture is in the proper range for the storage structure. These kernels may grow some now, if the plant is not dead and in those fields receiving rain. If kernels are growing dry matter is accumulating and yield and quality of the forage is improving.

Green, barren stalks will contain 75-90% water. If weather remains hot and dry, moisture content drops, but if rain occurs before plants lose green color, plants can remain green until frost. Drought stressed corn has increased sugar content, higher crude protein, higher crude fiber and more digestible fiber than normal corn silage. Drought generally reduces yield and grain content resulting in increased fiber content, but this is often accompanied by lower lignin production that increases fiber digestibility.

Forage quality of normally pollinated corn

Corn has two peaks in forage quality: one at pollination and one at harvest maturity (Figure 3). The early peak in forage quality at pollination is high in quality but too wet for ensiling. The later peak is more familiar, and is the one we typically manage for when producing corn silage.

Forage quality of poorly pollinated corn

Coors et al. (1997) evaluated the forage quality of corn with 0, 50 and 100% pollination of the kernels on an ear during 1992 and 1993. These years were not considered “drought” stress years, but they can give us an idea as to quality changes occurring due to poor pollination. These plots were harvested in September.

A typical response of corn to stress is to reduce grain yield. Bareness reduced whole-plant yield by 19% (Table 4). Kernels on ears of 50% ear fill treatments were larger and tended to more than make up for reduced numbers (Albrecht, personal communication). With the exception of protein, as ear fill increased, whole-plant forage quality increased.

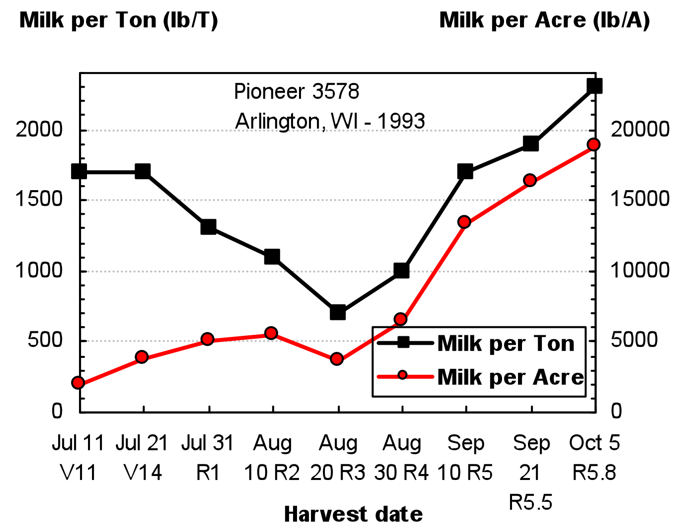

Figure 3. Corn silage yield and quality changes during development.

Table 4. Forage yield (% of control) and quality of corn with differing amounts of pollination grown at Madison in 1992 and 1993 (n= 24).

Ear fill	Forage yield	Crude protein	NDF	ADF	IVTD	NDFD
%	%	%	%	%	%	%
0	81	8.5	57	30	74	52
54	93	8.0	54	28	76	52
100 (control)	100	7.5	49	26	77	54
LSD (0.05)	6	0.3	1	1	1	1

derived from Coors et al., 1997

Forage moisture

If the decision is made to harvest the crop for ensiling, the main consideration will be proper moisture for storage and fermentation. The crop will look drier than it really is, so moisture testing will be critical. Be sure to test whole-plant moisture of chopped corn to assure yourself that acceptable fermentation will occur. Use a forced air dryer (i.e. Koster), oven, microwave, electronic forage tester, NIR, or the rapid "Grab-Test" method for your determination. With the "Grab-Test" method (as described by Hicks, Minnesota), a handful of finely cut plant material is squeezed as tightly as possible for 90 seconds. Release the grip and note the condition of the ball of plant material in the hand.

- If juice runs freely or shows between the fingers, the crop contains 75 to 85% moisture.
- If the ball holds its shape and the hand is moist, the material contains 70 to 75% moisture.
- If the ball expands slowly and no dampness appears on the hand, the material contains 60 to 70% moisture.
- If the ball springs out in the opening hand, the crop contains less than 60% moisture.

The proper harvest moisture content depends upon the storage structure, but is the same for drought stressed and normal corn. Harvesting should be done at the moisture content that ensures good preservation and storage (Table 5).

Table 5. Recommended moisture content (%) for corn stored in various types of storage structures.

Horizontal bunker silos	70-65
Bag silos	70-60
Upright concrete stave silos	65-60
Upright oxygen limiting silos	60-50

derived from Roth et al., 1995

Raising the bar

Depending upon farm forage needs, raising the cutter-bar on the silage chopper reduces yield but increases quality. For example, raising cutting height reduced yield by 15%, but improved quality so that Milk per acre of corn silage was only reduced 3-4% (Lauer, Wisconsin). In addition the plant parts with highest nitrate concentrations remain in the field (Table 6).

Table 6. Nitrate nitrogen of corn plant parts harvested for silage.

Plant part	NO3N
	ppm
Leaves	64
Ears	17
Upper 1/3 of stalk	153
Middle 1/3 of stalk	803
Lower 1/3 of stalk	5524
Whole plant	978

derived from Hicks, Minnesota

Nitrate problems

If drought-stressed corn is ensiled at the proper moisture content and other steps are followed to provide good quality silage, nitrate testing should not be necessary. The risk of nitrate poisoning increases as pollination becomes poorer. Nitrate problems are often related to concentration (i.e. the greater the yield the less chance of high nitrate concentration in the forage). If pollination is poor only about 50 to 75% of the dry matter will be produced compared to normal corn forage.

It is prudent to follow precautions regarding dangers of nitrate toxicity to livestock (especially with grazing and green-chopping) and silo-gasses to humans when dealing with drought-stressed corn. Nitrates absorbed from the soil by plant roots are normally incorporated into plant tissue as amino acids, proteins, and other nitrogenous compounds. Thus, the concentration of nitrate in the plant is usually low. The primary site for converting nitrates to these products is in growing green leaves. Under unfavorable growing conditions, especially drought, this conversion process is slowed, causing nitrate to accumulate in the stalks, stems, and other conductive tissue. The highest concentration of nitrates is in the lower part of the stalk or stem. If moisture conditions improve, the conversion process accelerates and within a few days nitrate levels in the plant returns to normal.

Nitrate concentration usually decreases during silage fermentation by one-third to one-half, therefore sampling one or two weeks after filling will be more accurate than sampling during filling. If the plants contain nitrates, a brown cloud may develop around your silo. This cloud contains highly toxic gases and people and livestock should stay out of the area. The resulting energy value of drought-stressed corn silage is usually lower than good silage but not as low as it appears based on grain content. The only way to know the actual composition of drought-stressed corn silage is to have it tested by a good analysis lab.

Marshfield Plant and Soil Analysis Laboratory
8396 Yellowstone Dr.
Marshfield, WI 54449-8401
Phone: (715) 387-2523

Estimating Yield

Growers need to carefully monitor, inspect, and dissect plants in their own fields as to plant survival potential, kernel stages, and plant moisture contents in determining when to begin silage harvest. Fields and corn hybrids within fields vary greatly in stress condition and maturity. Often questions arise as to the value of drought-stressed corn. In order to estimate pre-harvest silage yields, the National Corn Handbook publication "Utilizing Drought-Damaged Corn" describes methods based on either corn grain yields or plant height (if little or no grain yield is expected). Below is a summary of this publication.

Grain yield method for estimating silage yield

For moisture-stressed corn, about 1 ton of silage per acre can be obtained for each 5 bushels of grain per acre. For example, if you expect a grain yield of 50 bushels per acre, you will get about 10 tons/acre of 30% dry matter silage (3 tons/acre dry matter yield). For corn yielding more than 100 bushels per acre, about 1 ton of silage per acre can be expected for each 6 to 7 bushels of grain per acre. For example, corn yielding 125 bushels of grain per acre, corn silage yields will be 18 to 20 tons per acre at 30% dry matter (5 to 6 tons per acre dry matter yield). See also Table 2 in A1178 "Corn silage for the dairy ration."

Plant height method for estimating silage yield

If little or no grain is expected, a rough estimate of yield can be made assuming that 1 ton of 30% dry matter silage can be obtained for each foot of plant height (excluding the tassel). For example, corn at 3 to 4 feet will produce about 3 to 4 tons per acre of silage at 30% dry matter (about 1 ton per acre of dry matter).

How do our management decisions work during a drought

As we begin to evaluate the success of corn pollination during the 2012 drought, it might be useful to also evaluate which management decisions were most beneficial during this growing season. Although a season like 2012 is rare and extreme, it will likely happen again. Taking some time now to evaluate your management decisions might help during a future growing season.

Our last major drought year was 1988. There were numerous experiments established around the state by Dr. Paul Carter. Below I summarize his results for a number of management decisions that were important at the time including hybrid selection, plant density, date of planting, tillage and rotation decisions. The question is, "How do these decisions affect grain yield during a drought growing season?"

Plant density

The plant density which produces maximum yield has been increasing over time, but what happens during a growing season with drought? During 1988, a plant density experiment was established at nine locations with target densities of 18,000; 24,000; 30,000 and 36,000 plants per acre. At 7 of 9 locations, grain yield either increased or was not affected as plant density increased (Table 7). At Lancaster, grain yield decreased 16 bu/A from low to high plant density, while at Spooner grain yield decreased 27 bu/A. So even during drought years when a response to plant density is not expected, higher plant densities were only detrimental at two locations. The best recommendation would be to manage for potential yield with higher plant density because the only risk for return on investment is minor seed costs.

Table 7. Grain yield (bu/A) of corn planted at target plant densities of 18000, 24000, 30000 and 36000 plants/A at various locations in Wisconsin during 1988.

	Actual Harvest Plant Density (plants/A)				
Location	18100-20500	22500-24100	28600-29900	33300-36800	LSD(0.10)
	Grain yield (bushels/A)				
Janesville	125	133	137	139	7
Lancaster	64	62	50	48	9
Fond du Lac	109	112	118	108	NS
Hancock	160	175	193	188	9
Galesville	133	163	172	174	9
Chippewa Falls	39	34	32	20	NS
Marshfield	88	87	89	85	NS
New London	109	112	118	108	NS
Spooner *	78	71	66	51	11

* At Spooner target plant density was lower and resulted in harvest densities of 15900, 18600, 22000, and 24500.

Date of planting

Earlier planting dates are typically recommended for avoiding drought growing conditions. However, during 1988 the planting dates of May 13 and May 18 were higher yielding than earlier planting dates (Table 8). Some of the better performance of later planting dates has to do with timing of when drought (heat and water stress) occurs during the life cycle of the corn plant. Another interaction is the distribution of rainfall during the growing season.

Table 8. Grain yield (bu/A) response to planting date during 1988 at Arlington, WI.

Experiment 1		Experiment 2	
Planting date	Grain yield (bu/A)	Planting date	Grain yield (bu/A)
April 18	59	April 27	67
May 13	63	May 26	84
LSD(0.10)	NS	LSD(0.10)	8

Tillage

During the 1980s, no tillage was becoming popular as a management practice. Usually due to cool, wet soils corn often experience "slow growth syndrome" and yielded lower than conventionally tilled fields. During 1988, there were no differences between no-till and conventional-till in six experiments conducted at Janesville and Arlington (Table 9).

Table 9. Corn grain yield (bu/A) response to tillage during 1988 at Arlington and Janesville, WI.

Location	Conventional tillage	No tillage	LSD(0.10)
Arlington-Experiment 1	62	64	NS
Arlington-Experiment 2	83	69	NS
Arlington-CS rotation	75	77	NS
Arlington-CSW rotation	70	72	NS
Janesville-Experiment 1	117	112	NS
Janesville-Experiment 2	117	109	NS

Rotation

Rotation is probably the easiest management decision we have available to get "free" yield. During drought (stress) years it is even more important (Table 10). Rotated corn increased grain yield 16 to 36 bu/A (29 to 59%) over continuous corn grain yield.

Table 10. Corn grain yield (bu/A) response to crop rotation during 1988 at Arlington, WI.

Rotation	Grain yield (bu/A)	
Continuous corn	61	56
Corn-Soybean	97	82
Corn-Soybean-Wheat	--	72
LSD(0.10)	16	15

The presentation will cover the effect of management during 2012.

References and Further Reading

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Utilizing Drought-Damaged Corn (NCH-58) www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-58.html

Weather Stress in the Corn Crop (NCH-18) www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-18.html

Growing Season Characteristics and Requirements in the Corn Belt (NCH-40) www.agcom.purdue.edu/AgCom/Pubs/NCH/NCH-40.html