

## **Development of Corn Borer-Resistant Corn for Organic Farming Systems**

A final report submitted to the  
Grants Program  
Organic Farming Research Foundation  
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This three-year grant was active from 2006 through 2008. Our apologies for the very belated report, which was due to negligence in getting data analyzed on the part of Margaret Smith (statement put in at her request!).

### **PROJECT SUMMARY, INTRODUCTION, AND OBJECTIVES**

How was this project conceived? The most important part of agriculture is genetics. The weakest part of *organic* agriculture is genetics. Organic agriculture needs breeders. If the world is to get new crops, or improved crops, someone needs to spend decades breeding them.

There are very few independent corn breeders left in the nation, as genetics is being taken over by monopolies, and indigenous genetics has almost completely disappeared. Most of us know each other or know of each other's work. Most of us are interested in maintaining genetic diversity for regional sustainability rather than for monoculture. We are interested in the nutrition of corn, more than large volumes of empty calories for industrial production. We are interested in organic agriculture because the world will run out of the large volumes of water and of petrochemicals that industrial agriculture requires.

We would like for our work to become large scale some day and to benefit many people. We see that there are many problems to overcome and so we decided to work together and combine our different programs.

We cannot compete with big industry as far as a time schedule goes. They have millions of dollars that we don't have, and with molecular genetic and other technologies, they can accomplish what we can in a fraction of the time. We are using traditional, natural breeding methods to solve problems that industry is solving with large-scale robotic approaches and with genetic engineering. We are dedicated to doing the needed things the right way, no matter how long it takes to reach our goals. We thank OFRF for making it possible for us to launch this cooperative effort. We are addressing three very important challenges.

- 1) Corn borers are worms that destroy the corn plant. Addressing them is the largest thrust of this project. We will make many references to **ECB**, European corn borer (*Ostrinia nubilalis*). They are such a problem that industry has created genetically engineered corn, marketed as "Bt corn," to resist them. We are breeding corn that naturally resists ECB so that organic farmers can have some protection from this expensive pest. We are using genes for resistance to ECB that have been discovered occurring naturally in tropical corn populations. These have already been bred into populations adapted to the Midwest and the Northeast by other people prior to our project.

But there is much more work that needs to be done before ECB-resistant corn is ready to move onto organic farms, and their climatic range is limited. These ECB-resistant populations are generally very late in maturity and adapted only to the central corn belt. They are not directly useful in the cooler upper Midwest nor in the drier West. These ECB-resistant populations need to be moved through the process of selfing and yield testing so that they can be released as high-yielding, naturally-resistant varieties. They also need to be evaluated on organically-managed fields.

- 2) Northern Adaptation: Painted Mountain Corn. One of the many legs of this project is to combine the proven borer-resistant lines with fast-maturing, stress-hardy indigenous corn from the West. Painted Mountain corn was chosen because the project leader, Dave Christensen, spent 40 years developing it by rescuing the native corns indigenous to the cool, dry, northwestern climate region. It is the most opposite to the tropical corn from which the borer-resistant genes came. We need to make these crosses, overcome the tropical heritage, and choose the plants with the best architectural traits of commercial parents and the northern metabolism of the indigenous parent. We also need to continue the selection for borer resistance during this process.

With increasing climate change, weather disasters and seasons shortened by weather irregularities, stress hardiness is becoming an essential trait for corn. Commercial dent corn has its ancestry in the humid eastern half of the continent. Races of corn indigenous to the desert mountains of the West have never been utilized. Painted Mountain is flexible. It has 8,000 years of adapting its metabolism to western drought. It has a quick dry-down in fall. It has long cobs that are rare in commercial corn and add to the yield in breeding programs.

- 3) The Ga1-S gene: A grave challenge to corn breeders today is the prevalence of GE (genetically engineered) plants that are spreading their pollen and contaminating everyone's genetics. It is estimated that over 90% of the corn pollen floating around the air in our nation is from GE varieties.

We are working with three different genetic systems that can help protect organic farmers from GE pollen contamination. The best is the Ga1-S gene. Corn with the Ga1-S gene will not accept pollen from populations that do not carry this trait. Commercial field corn hybrids in the U.S. do not carry Ga1-S, and that includes essentially all GE corn hybrids grown in the U.S. So by incorporating this gene into our work, organic farmers could plant their corn right next door to GE corn and it would largely be protected from contamination by cross-pollination with GE corn.

**Below: Hardy Painted Mountain corn, indigenous to the West. Pigments are antioxidants.**



The long term vision of this project is to combine Painted Mountain lines with both borer-resistant and GE-resistant commercial types of corns, and then to combine both types of resistance into one line. The result will be a regionally sustainable organic corn that is resistant to corn borers and will not accept pollen from GE corn that is growing all around it. We are in the third year of bringing the Ga1-S gene into the best lines from Painted Mountain. While the ECB-resistant corns are being developed, we need to learn which inbreds from Painted Mountain combine best with commercial types of corn grown by organic farmers.

To determine this, 40 lines from Painted Mountain have been crossed onto a tester (Early Riser) and the test cross hybrids evaluated for yield under organic management in two years in the west. We have continued to self-pollinate the 40 best lines of Painted Mountain to further improve them and move them toward use in commercial organic corn production.

Our goal was to identify lines of Painted Mountain and lines of ECB-resistant corn for crossing by the 2008 termination date for this project. After this grant ended, we made these combinations and this important work is continuing. The best performing lines from Painted Mountain crossed with the best ECB resistant lines represent an effort to bring ECB

resistance farther north and west.

A diverse group of collaborators addressed these challenges. At Cornell, Margaret Smith continued selection in three populations with natural ECB resistance. Progenies that resulted from crosses of these populations with early maturity lines were moved along in the breeding process. Twenty-three inbred lines from populations with potential ECB resistance were crossed onto a tester (B103/SD46), and these test cross hybrids were evaluated for yield in five environments in the Midwest. These same hybrids were evaluated for ECB resistance for two years in New York. Our aim was to identify naturally ECB-resistant lines and populations of corn selected for organic production methods across the target region and generate more genetic material that would be ready for testing. We have continued the breeding process initiated with OFRF funding with the goal of generating hybrids for commercial release and new ECB resistant lines for ongoing improvement through breeding.

In this era, public breeding of corn is all but disappearing, and universities are generally not funded to work on problems like ECB, which is perceived as a problem that has been solved through GE technology. Without funding from the organic community, our work with natural ECB resistance could not be done. Thank you to OFRF!

## **METHODS AND RESULTS**

### **MARGARET SMITH**

Cornell University was the site for our nursery work developing ECB-resistant corn. Twenty-two inbreds that had been developed from NECB549 and one inbred from Ames 25975 were selected based on their resistance to ECB. These 23 lines were crossed with the single cross tester B103/SD46 to create hybrids. These hybrids were infested with European corn borer to assess their resistance levels in two years (2007 and 2008) in Aurora, New York.

These same 23 hybrids were yield tested in replicated plots in five environments by three partners (Maury Johnson, Richard Pratt, and Walter Goldstein). Yield evaluations were done in East Troy, Wisconsin, in 2007 (seed was sent for 2008, but extensive rains during planting season precluded establishment of this trial); Kenyon and Wells, Minnesota, in 2007 (again, 2008 trials could not be planted due to weather); and Wooster, Ohio, in 2007 and 2008. Each hybrid was grown in a two-row plot with two replications in each environment. Data were collected on stalk lodging (except from Kenyon, MN, in 2007), grain moisture at harvest, and yield. Yield:moisture ratio was calculated as grain yield (bushels per acre) divided by grain moisture at harvest (percent). This ratio serves as an estimate of hybrid efficiency – hybrids that show high yields and earlier maturity (lower grain moistures) have higher yield:moisture ratios.

At Cornell, Margaret also made self pollinations and corn borer resistance selections in various genetic materials that were not yet finished lines. By the final year of this project, 12 fully inbred lines had been developed and selected, using summer nurseries for ECB infestations and winter nurseries to advance self-pollinating generations. These were from NECB549, GEMS0001 x ND248, and Ames 25975 backgrounds. These lines were continued in selection and evaluation nurseries after the end of the project, including test crossing them to make hybrids to evaluate for yield and evaluating their ECB resistance in replicated trials. Additionally, seven progenies from Ames 25975/Mo42<sup>2</sup> and Schmieg/B86 were still

undergoing selection because they were not yet inbred to uniformity.

We formed an initial population of the 'Rachel Carson Synthetic' in Aurora, NY, in summer 2006. This is a combination of many ECB-resistant lines and there is the chance that all the desirable genes for ECB resistance will stack up. These were recombined in our winter nursery in FL and included in yield and corn borer trials in 2008. As noted previously, only one yield trial location could be planted in 2008 (in OH), so yield results were obtained only in one environment.

At our NY location, all the test crosses flowered before the end of July, which is relatively early. We are happy about this because part of our project is to adapt the ECB-resistant corns to northern climates. All crosses were intentionally infested with borers in early July to rate leaf feeding damage, and they were infested again just after flowering to rate the damage to stalks. The stalks were cut open and the borer damage evaluated at harvest time. Promising levels of resistance were apparent in several crosses.

### **THE RESULTS OF OUR THREE ECB-RESISTANT GROWERS**

As explained above, Margaret sent all three growers crosses that are primarily from different lines of the family NECB549, which she crossed with the same hybrid tester, B103/SD46.

Johnson, Goldstein, and Pratt: Grew 160, 80, and 80 plots, respectively, in the Midwest. These three growers tested our work with ECB-resistant corn to determine yield. From each different plot, the grain was weighed and grain moisture was measured to report which lines yielded most successfully in these environments. We are developing borer-resistant corn that will adapt to the North. This information will help us identify which of our lines are the most likely to result in high yielding hybrids that naturally resist ECB.

#### **MAURY JOHNSON**

Seed was planted at two locations (Kenyon and Wells, Minnesota) in 2007. These sites are in southern Minnesota. Maury's plots averaged 120 bu/ac and lodging averaged 2%. Data were taken for yield, moisture, test weight, and root and stalk lodging. Plots at each site were replicated. Maury says, "The plots were managed well, and I believe the data is reliable. In terms of yield, I think some of Margaret's hybrids have promise. In particular I would mention hybrids 8 and 10." A full chart of Maury's results is attached.

#### **WALTER GOLDSTEIN**

The corn was planted on May 24, 2007, in East Troy, Wisconsin, and harvested at the end of November. Walter had almost ideal weather conditions, resulting in the highest yields I believe we have ever had. The corn stood well, with long, slender ears. Walter gave us a chart that gives a full report on yield, moisture, and lodging, which is highly influenced by corn borers. Walter's yields ranging from 150 bu/ac to 260 bu/ac indicate that Margaret's attempt to produce lines of borer-resistant corn are working. The main thrust of this stage was to identify high producing lines for the northern Midwest. Lodging scores are expected to reflect damage from corn borers, which Walter has in his region.

I will quote Walter: "Borers were a real issue in the field on other plantings and damaged

some of our corn that has a lot less resistance than Margaret's. The control is the Prairie Hybrid check. Some of Margaret's hybrids yielded similar to the check and a number had similar lodging scores, which may be indicative of less borer damage. Yes, the work seems fruitful to me. It is really difficult to produce publicly available germplasm that is as good as the commercial hybrids and she seems to be making some progress. The ideal is to produce hybrids with similar yields and lodging scores. I would certainly be interested in testing the top five to seven NECB549 lines again in combination with other inbreds to see how they will do."

### **RICHARD PRATT'S (abbreviated) Ohio State University REPORT**

Yield and agronomic performance (stalk lodging and harvest moisture content) of selected European corn borer (ECB)-resistant lines provided by Margaret Smith (primarily S<sub>4</sub> lines from NECB549 in 23 test cross entries) were evaluated in replicated two-row plots in Wooster, Ohio, in 2007 and 2008. The field was in a three-year rotation of buckwheat–red clover–corn. Compost was used annually as a soil amendment and fertilizer for five years. In adjacent plots, yield evaluations of Ohio State University specialty corns, open-pollinated blue corn, sweet corn, and popcorn also were conducted. Those breeding materials are being developed to provide germplasm with diverse value-added characteristics for interested non-GE seed producers.

Plots were hand-thinned to a final stand of 25,703 plants per acre. The 2007 growing season was somewhat unusual in that a long, hot dry period in June and July was followed by a prolonged cool and wet period. A strong straight-line wind event also occurred in the late summer and many (other) entries in the field lodged as a result. The test crosses in the ECB study were largely unaffected by wind damage. The average performance of the test crosses was very good (164 bu/A), lodging was low (average 3%), and the harvest moisture was acceptable (average 26.6%) – especially for late-planted corn. No particular susceptibility to any pests or diseases was observed. Several entries yielded 170 bu/A or above and two of them also had below average moisture content (nos. 20 and 21). These lines also remained erect (lodging 3% or less).

Ohio had a tough year in 2008, with excessive soil moisture in May and June, dry conditions in July and August, and then fields got hammered by strong winds from the remnants of Hurricane Ike on September 14<sup>th</sup>. The plots looked nice in late August, but were well-flattened by the end of September. As a result, the experiment showed lower average yields (120 bu/A) and much higher lodging (average of 59%) compared to 2007 results. Nonetheless, a lot of growers would have been happy with 120 bu/A in 2008 – organic plots at Bowling Green, OH, yielded 40 bu/A.

Overall, the results were very encouraging and we concluded that these materials showed good adaptation to our organic production system. The carryover nitrogen from red clover and modest applications of compost supported competitive yields. The weed control program (buckwheat in rotation, late-planting of corn following two cultivations, hand-weeding of escapes) was successful. We noted that the local population of honey bees made extensive use of the field, and we have been pleased with its ability to suppress weeds. We were also able to secure a good harvest of oats (nurse crop in red clover) and red clover cuttings were good. We are pleased with this short rotation for research purposes.

**The Montana-North Dakota leg of this project:  
Using indigenous northwestern genetics to create regional adaptation and stress  
hardiness**

**DEVELOPMENT OF INBRED LINES OF PAINTED MOUNTAIN**

While the ECB-resistant lines are being developed and tested, preliminary work was being done with Painted Mountain in the west by Dave Christensen at three locations:

At one of my home plots of 1/4 acre, four things were accomplished:

- A) INBRED LINES. For all three years I advanced my 40 already-established best lines of Painted Mountain by self-pollinating them for their 7th cycle.
- B) TEST CROSSES. For the first year, I put pollen from these 40 lines onto my commercial tester, Early Riser. The purpose was to see, in the second year, which of the indigenous Painted Mountain lines produce good offspring when crossed to a commercial-type line.
- C) NEW LINES OF PAINTED MOUNTAIN. Many new lines of Painted Mountain inbreds were begun. I had identified plants from the general population that had superior plant architecture and ears, as well as kernels that tested high in anthocyanins (antioxidants) and lysine (protein). Many of these new lines actually surpassed the original 40 lines I started with.
- D) CROSSING TO GET BORER-RESISTANCE IN MONTANA

**POLLINATION METHODS**

Hand pollination is not so hard and you can create many wonderful things. I encourage beginners to give it a try. I have a simple method.

You can watch YouTube videos on the professional way to pollinate corn and gain many tips. It usually involves placing a large bag over the pollen tassel and a smaller "slip bag" or "silk bag" over the developing ear. I cut my time in half by bypassing the large bag over the tassel. It is possible that pollen can travel from one plant and lodge on the tassel of another plant, and then you would be getting contaminated pollen. But the chance of this happening is small, and these trials do not require precision. Besides, the strong winds where I live would break the small native plants if a large bag was tied to the top.

So I merely placed a small "slip bag" over the silk and tiny ear the first day it emerged to protect it from pollen. When I want to self-pollinate it, I remove the bag briefly. A piece of the plant's own tassel can be broken off and the pollen shaken onto its silk. Or you may shake some of the pollen into the bag and pour it onto the silk before covering the little ear again. I do this about three times, three days apart, and usually most of the kernels get pollinated.

**Below: Dave Christensen in corn breeder's uniform holding a silk bag.**



**Below: Dave Christensen shaking a broken-off piece of tassel over the silk to pollinate it.**



**Below: Plants in August. Ears are developing. Silk bags are left on long after pollination is complete. Notice many have been detasseled.**



## **A) INBRED LINES**

Sixty kernels of each parent ear were planted in their own section. As they emerged in the cold early days of May, some were stronger than others. The weaker seedlings were killed and 20 of the healthiest allowed to remain to represent each the 40 lines. I found that you must plant at least 20 representatives of a line when inbreeding in order to find one that has all the good genes. Many more would be ideal, if you have lots of land and can hire workers.

Inbreeding can be very depressing for your spirit because 90% of the plants are inferior and have all the bad traits. Inbreeding causes pairing of genes and many problem genes are hiding, especially in unimproved native corns. Problems can include low vigor, chlorosis (lack of chlorophyll), strange plant forms, deformed ears, leaves that scorch in the sun, and plants that just die.

But the good news is that if you are lucky, a few of the plants will have all the good genes, and they will breed true! Most lines will give you one good plant. Many lines will totally fail after four generations. A few lines will give you mostly healthy vigorous plants. These are the ones that I ended up using. However, I tested every line in a test cross because you never know what a plant will do when it is pulled out of inbreeding depression and crossed to make a hybrid. This gets to be fun and educational.

I was very successful in all pollinations. Several lines had individuals that reverted to primitive cob types, which can be expected when inbreeding. However, more lines actually improved as a result of identifying superior cobs to breed.

## **B) TEST CROSSES: PAINTED MOUNTAIN x EARLY RISER HYBRIDS**

The first year (2006), these 40 inbred Painted Mountain lines were crossed to Early Riser, our northern "commercial type" tester, to observe which of my different Painted Mountain lines would interact best when combined with commercial types of corn for improvement. The Early Riser plants were detasseled because they were foreign to the gene pool and I did not want their pollen to spread. Pollen from the 40 Painted Mountain inbred lines was carefully carried and placed onto the silks of 20 Early Riser recipients for each line.

I had estimated that my Painted Mountain lines would flower 2 weeks before the Early Riser, and I staggered their plantings accordingly. However, the Early Riser flowered earlier in our cold than I predicted and it was difficult to find pollen when it was needed. Fortunately, 39 crosses could be made using sparse representatives of the Painted Mountain lines, and only one had to be re-made the second year. The second year I made hundreds of more crosses, above and beyond the scope of this grant, to get crosses made from the better representatives of both parental lines.

**Below is commercial corn that was pollinated by itself first, and then 3 days later pollen from colored native corn was put onto it. The purebred seed may be used to advance the parent line, while the obvious hybrids are used to start the new line.**



Early Riser is not an inbred, but a synthetic, an open-pollinated population. Another thing I learned is that Early Riser had more genetic diversity than we planned on, and a smaller amount of the difference between the 40 Painted Mountain hybrids came from the Early Riser parents. Next time I will use a totally uniform inbred tester.

**Below: You can see the variations between the different lines.**



The second year of this project, an organic farmer made 2 acres available to me for this project. He was Wes Henthorn of the B Bar Ranch 13 miles north of my home. Wes let me use this land for three years. Here I grew several related test plots, including 20 plants each of my 40 crossbred lines in two replicated plots with a different planting sequence on each plot.

It is important to have replicated plots because there are soil variations and one line may be in stressed soil at one plot, but will hopefully have a fairer chance in the second plot. Furthermore, in our dry soil the plants in the outer rows produced twice as much as those in the inner part of the plot that had more competition for water. I had to adjust my yield statistics due to location because there was such variation in location. With the matching trials done at the Dickinson, North Dakota plots, we got a pretty good idea of the performance.

### **Farming challenges at the B Bar Ranch**

The 2-acre field was previously an alfalfa field. We took a tractor over it pulling a Nobel Blade. That is a blade that goes deep into the soil and slices off the top of the alfalfa plant below the crown. It successfully killed most of the alfalfa plants. Also it killed much of the bindweed,

where it went deep enough. But bindweed became a terrible problem. It is also called morning glory. It grows close to the ground and looks harmless. But its roots suck all the water out of the soil and go several feet deep. It stays suppressed with a good cover crop that blocks out the sun. But we had several well-spaced corn plots with bare ground in between. Being an organic farm, we could not put herbicides on the bindweed. The bindweed had full exposure to the sun and every year claimed more of the ground with its deep roots. You cannot grow corn where bindweed is. The bindweed takes all the moisture. I spent hours on my knees digging out bindweed roots with my fingernails in order to save my corn genetics. This was a terrible waste of my time. We recommend yearly rotation with a cover crop in between the corn, and no bare ground. It's better not to grow corn where bindweed exists.

## **SUCCESSFUL RESULTS FROM DICKINSON, NORTH DAKOTA STATE UNIVERSITY**

Par Carr at Dickinson, North Dakota, did the same replicated plots as were grown in Big Timber to test the crossbreds between the 40 Painted Mountain inbred lines and Early Riser plus five "controls," totaling 45 lines tested. They were grown in two large replicated plots, 30 miles apart, for the second and third years of the project (total of 176 plots).

Lines were evaluated for seedling vigor in spring and at harvest for yield, moisture, and root and stalk lodging. One of Carr's full reports is attached describing organic farming and tables of the results. There were some farming struggles, but we got successful results from the Dickinson plots. I will report the significance of what we learned.

The first year they suffered from remarkable heat and lack of rain on soil with very low water-holding capacity. The temperatures reached 108° F. It would have been nice to have had a wetter second year for comparison, but the second year was also heat and drought stressed. So we got very low production but a very important assessment of how the different lines perform under drought and heat stress.

To start with, we planted two controls of commercial hybrid dent corns from our partner, Maury Johnson, at Blue River Organics. They were his fastest maturing corns from Minnesota. Out of 45 hybrids in the trial, these placed 3rd and 4<sup>th</sup>--very good! However, their thick commercial type cobs did not dry out so well, and their moisture content at harvest was by far the highest in the trial. That's a disadvantage.

My analysis is that the larger commercial plants take longer to mature than the Painted Mountain hybrids and so they just didn't mature on time. Also, Painted Mountain lines have long, thin ears. The thinness allows them to dry faster than the thick ears of modern commercial corn. Corn to be grown in short season climates cannot have the thick ears of corn bred to grow in Iowa.

Seeds selected at random from the larger, open-pollinated Painted Mountain gene pool were planted as the final control and only yielded in 8th place. It's not surprising. They represented a wide variety of genetics.

Five Painted Mountain x Early Riser hybrids yielded more than the Painted Mountain pool, in spite of Early Riser parentage. And 35 hybrids yielded lower due to their Early Riser parentage.

**Below: One of the drought-stressed replications at Dickinson, North Dakota.**



Out of 45 lines, the pure Early Riser control rated 43rd, at the bottom for yield. This is good to know because Early Riser was the "commercial type" tester parent that my Painted Mountain lines were all crossed to for their evaluation. Of the 40 Painted Mountain x Early Riser lines, 38 of them did better than their Early Riser parent. This shows Painted Mountain's western ancestry to be of value in drought and heat. Furthermore, since the Minnesota commercial controls beat most of them, I conclude that the Early Riser parentage handicapped the Painted Mountain hybrids.

This was very disappointing because I liked Early Riser. It had good plants and was fast to flower and mature for a modern corn. It was cold hardy. But it was from the East. Now I know not to work with it. These disappointments are part of the learning process. I have learned this lesson many times – that corn adapted to the East coast of our nation suffers horribly in the West. Maury Johnson's control hybrids developed in the middle of the nation were next to the best. Regional adaptability is so important and often overlooked when we choose breeding stock by using performance charts. Regional adaptability is achieved by breeding lines whose ancestors evolved in your region.

## **COMPARISONS BETWEEN GROW-OUTS IN MONTANA AND NORTH DAKOTA**

Half of Early Riser's ancestry is from Iowa and half from Ontario, where it was developed for stalk strength and fast maturity on the eastern coast of Canada. Early Riser performs in the

cool Northeast, which translated into success at high elevations in the mountains of Montana with irrigation. But we learned that Early Riser did not perform well in the drought and heat of ND. I am not going to recommend Early Riser's use for the arid West.

This test crossing was suggested to me by Frank Kutka, my partner in Seed We Need. Frank has a Ph.D. in plant genetics. Actually I did not expect to see much difference between the different crossbreds because they all had the same Early Riser parent. I thought it would nullify differences between the Painted Mountain parents. I did this trial begrudgingly because it was recommended. But at harvest time, I was amazed at the tremendous variety of plant and ear types that occurred from the genetic mixing! Different Painted Mountain inbreds, which didn't look much different from each other, had wildly different interactions when combined with a near uniform commercial corn. At harvest I wrote in my notes, "THIS IS FUN!"

The specific Painted Mountain lines which succeeded, or failed, as hybrids surprised me greatly! I never would have predicted what happened.

I had identified several lines of Painted Mountain that had strong stalks, great roots, no tillers, and very long productive ears. I feel that they are as close to being like commercial type plants as native corn has ever been taken. In my Montana trial, with better soil, the hybrids of these lines stood out as superior. But these same great lines yielded average-to-low as hybrids in the drought-stricken Dickinson trial. The ears often had a higher moisture content. The reason: the plants were somewhat larger, more like modern corn, did not contribute as much stress-hardiness, and took longer to mature.

To the contrary, I had some lines of Painted Mountain which were very fast to mature. They were smaller plants, weaker-stalked, and had smaller cobs. I considered them my worst. I perpetuated them strictly for their early maturity. Yet these made hybrids that filled the top ranks of the yield list and two of them placed highest on the list in spite of their Early Riser parentage.



The photo above shows the dwarf Painted Mountain inbred that was the parent of the hybrid ear in the next photo below.

The photo below shows Early Riser in the center, compared to a typical modern corn on the right. You can see how Early Riser is a better producer in our stressed northwestern climate. The colored kernels result from having Painted Mountain pollen put onto them. The ears to the left are hybrids between Early Riser and the dwarf Painted Mountain parent in the picture above. Notice the size increase by crossing to even my smallest Painted Mountain inbred. Plants with Painted Mountain genetics are more efficient under stress and are able to invest more energy in producing a large ear. Can you believe that the tiny plant pictured above was the parent to ears that were bigger than the Early Riser parents?



There were some wonderful exceptions. The second highest yielding plant was from my black kernelled Montana Morado Maize line, which has the highest antioxidant level. I am very encouraged that this highest nutritional quality individual proved its hardiness. That made my day!

A real disappointment was a line that took me 25 years to develop. It has a different type of dwarfing gene from the Southwest that reduces the height of the plant. In its Navajo ancestor, this stout dwarfing trait helps it to survive drought in their hill planting system. I spent 25 years moving this gene into my northern corn, until only 1/4 of 1% of Southwestern genetics remained. This line was rock bottom, number 45 in yield. This concurs with the results of other field trials. I'm going to have to say "goodbye" to that dream and bury it. The drought stress of the Northern Plains requires a different plant architecture system.

My conclusion: large commercial types of plants are helped most to survive drought and heat by the infusion of genes that reduce the bulky plant size and speed up the maturity.

In conclusion, we collected performance results under varied climate conditions. I identified five inbred lines of Painted Mountain that I have been doing ongoing breeding with. Some were those that yield best under good conditions and some from those that perform the best under stress. I found lines with good traits at both ends of the scale. With climate change affecting different regions differently, diversity will be important. There are no "silver bullets."

I am very happy to have my work evaluated under a variety of environments and to have Pat Carr's professional staff creating organized scientific trials.

#### **D) CROSSING TO GET BORER-RESISTANCE IN MONTANA**

In 2009, after the grant period was over, Margaret Smith sent me one inbred line from her work that proved borer resistant in her tests, Cornell Inbred 73-157 (2008-5:20 SIB). She warned that it takes a long time to mature and may not mature in my short season but that it was the fastest maturing line she had so far.

I planted 10 kernels May 1, which is very early at our 4,400' elevation. Fortunately, there were no frosts and it got an early start. Likewise, the season was also long that year and this line just barely matured. This is some of the slowest maturing corn that I have tried to grow here. It definitely needs this crossbreeding program to adapt it to the North.

Plants had strong commercial type stalks and roots. The ears were uniformly narrow 8-rowed, which is welcome. The ears were very small due to inbreeding depression. The only undesirable trait was tillers, also called suckers. Most plants had 1-3 tillers. The tops of the tillers were "mutant" combinations of tassels and cobs, which is very undesirable. This problem is common in native corn. I was surprised to see it. I chose the plants for breeding purposes that had smaller and fewer tillers.

I had planted selected Painted Mountain lines very late, at staggered dates, so that some would flower at the same time as the slow-maturing borer-resistant line. I was just barely able to get some pollen to match with the silks. Crosses were made both ways, because the Painted Mountain parent would mature faster. The Painted Mountain pollen parents came from the best five inbred lines that I developed at the start of this project. Plus I included some

newer inbred lines that I created during this time. I used a mixture so that my borer resistant pool would have some genetic diversity in it. I created hybrids.

In 2010, I planted my first Borer Resistant x Painted Mountain hybrids, getting closer to the goal of all this work. Two ears were chosen from Borer Resistant parents, and two ears were chosen from two outstanding Painted Mountain parents. A plot of each of the four lines was grown. Plants were excellent. The strongest stalks I have seen. Great roots. Lessening and improvement of tiller type. Wonderful ears. The maturity time was greatly improved over the parent.

The best of these lines were grown again in 2011 without the benefit of a borer trial. I am extremely happy with the metabolism and the type of plants we are getting. They are adapting to Montana rapidly. I will be excited to get the borer tests.

Margaret Smith also sent me several new lines that are ready for me to work with, but we had a record cold spring and I was unable to plant them on time. I hope that weather will allow me to grow her newest lines in 2012.

### **Results of European corn borer tests at Cornell**

Samples of the 2010 harvest were sent to Cornell for Margaret Smith who grew them in 2011.

#### **Margaret Smith reports the borer tests of my first lines:**

There were 13 ears, we planted 40 kernels of each. Of that, 328 total plants established (there was poor germination in this area due to weather, rodents, and birds). We infested all of these plants with 40-60 European corn borer (ECB) larvae at mid-whorl stage. We chose those with less leaf-feeding damage and good nick between pollen shed and silk emergence to self-pollinate. We selfed a total of 142 plants (43% selection intensity at this stage).

All the self-pollinated plants were then infested again with 40-60 ECB larvae shortly after pollination. We rated these plants for leaf feeding damage and at harvest we split the stalks open and measured the total length of tunneling in each plant.

Based primarily on stalk tunneling and secondarily on leaf feeding plus flowering time, we selected 29 self-pollinated ears that came from plants with reasonably good ECB resistance, no undesirable ear traits, and reasonable flowering dates. Cornell researchers tried to avoid selecting only late-flowering plants to retain early maturity for growing plants in cooler and shorter-season climates. These selections should also have good nick (since we selected for that at pollination time).

This represents a final selection intensity of 9% (i.e., we kept 29 plants out of the 328 available for selection). These plants come from 9 of the 13 families Dave originally sent to Cornell, which suggests that most of what Dave sent has some reasonable ECB resistance segregating in it.

Margaret Smith thinks that these plants look like very promising selections to continue breeding with. ECB evaluations show quite a bit of environmental influence so she hesitates to claim for sure that all these are resistant. There could always be escapes or

inaccurately evaluated plants among them. But **they look as good as any other selections we would make, and our experience indicates that most of them will have resistant progeny when grown out again.**

Bottom line – Dave's materials have yielded some good ECB resistant selections that need additional breeding generations to make them more uniform and then to put them in a replicated ECB evaluation to verify their resistance.

And Christensen explodes with a great "WAHOO! I had no idea that borer resistant genes could show themselves so quickly! This exceeds all my expectations!"

### **Ga1-S GENE IN MONTANA**

The Ga1-S gene protects the corn from accepting pollen from a neighboring line that does not carry the gene. We will use it to protect our corn from being contaminated by GE pollen.

In 2007, my Seed We Need partner, Frank Kutka of Dickinson, North Dakota, gave me three lines he had developed but he did not have an isolated location available to advance them at that time. I received 10 kernels each, a total of 30 kernels. One parent was a very slow maturing corn belt Ga1-S corn that had been crossed to Painted Mountain. The hybrids had been selfed so I received S1s. We needed to keep these away from any possible pollen contamination. I did this breeding at a third location in my town, not mentioned above.

I was warned that these lines would be very slow to mature, and they were. The plants were slow to mature at their former location and the kernels were weak from not filling well. I pre-soaked them to give them an early start, and only a few sprouted. I thought they were sterile. But I planted them May 1 in the cold and 28 of them produced vigorous plants!

Of the 40 Painted Mountain inbred lines I had developed, 20 proved to be worth continuing. About 500 of these were planted at staggered dates, hoping some of them would be timed right to receive the Ga1-S pollen. The Painted Mountain was detasseled. At harvest I got 100 fully-pollinated crosses from ideal plants and ears. This surpassed my highest expectations.

The parent Ga1-S plants had their cobs covered with bags, and were sibbed or self-pollinated by hand. This way, those lines could also be advanced with a high percentage of Ga1-S genes and without any further crossing. They can be used in future programs. In 2008, the children of these parent lines were once again covered with bags and advanced with their high percentage of Ga1-S genes. They are still far too slow for northern growing, but we may need them for gene testing. The new crosses to Painted Mountain are going to be the useful ones.

In 2008, the seed from the previous year's best plants were allowed to open pollinate in half the garden. They are genetically 3/4 Painted Mountain. The harvest produced 34 good ears.

The second half of the garden was planted with new inbred lines of Painted Mountain which were detasseled. They received the pollen from last year's crop. This new generation has lots of genetic diversity from which a strain can be created. The harvest produced 68 good ears. The seeds contain 7/8 Painted Mountain genetics. No further crossing needs to be done. This completed my effort on this project for now.

The next stage of the project is to test the plants and identify which ones inherited the Ga1-S genes. This stage of the project will be the most difficult and time consuming. If we cannot locate a lab that does this test affordably, the plants will have to be bred to a tester to identify which ones have the genes. Frank Kutka, my partner in Seed We Need, will be doing this work in 2012.

The Ga1-S gene has been patented. But the restrictions only apply to its use for commercial yellow dent corn. I put the gene onto my high antioxidant black corn, which is gaining demand in the nutrition and nutraceutical markets. So the patent restrictions do not apply. We are well on the way to having a stress-hardy, high nutrition, organic corn for human food and health that could potentially grow right along side of GE corn and not be contaminated.

## **GE TESTING**

My 15 Montana breeding locations are in climates too challenging for any corn production but mine, so there is no chance of GE contamination from stray pollen. There is no other corn around. But I am also breeding with experimental corns coming to me from out of state, including the Early Riser. I use only supplying growers who have repeatedly tested their populations for GE and never found any contamination.

To be certain we are safe, I test the individual cobs I choose to breed from. Those plants are detasseled in case any of the kernels received accidental GE pollen. Only plants that were proved not to be GE-contaminated were allowed to shed pollen. The following year, every cob is tested to insure that not one individual kernel slipped through that was contaminated. I have never known anyone to be this thorough. I do this at my own expense.

Margaret Smith, our eastern source of breeding material, has good control at Cornell. Our four trial growers are in safe locations and, in addition, they are not reproducing breeding stock so GE contamination is not a concern.

## **COLD GERMINATION TESTING**

Cold testing was done the first year of the project. Why? In the North it is important that kernels be able to emerge in our cold springs and grow in lower temperatures. With climate change, weather irregularities, and the recent drought, it is all the more important to get the seeds in the ground and get them growing before the dry heat hits in July. Early planting is a way to beat drought.

I spent a lot of time selecting kernels for the cold germination testing. But the test did not teach me enough that I would spend money on it again.

Problem one: We tested the Early Riser parents that had pollen from different lines of Painted Mountain inbreds put onto them. The Early Riser did not always mature on time in our cold mountain climate. I believe the major problem was the failure of the Early Riser and did not tell us as much about the Painted Mountain pollen parents.

Problem two: The test only observed if the kernels were sterile or viable. They did not give me any comparisons for vigor, quickness of sprouting in the cold, length of sprouts, or the ability to break through the soil. The report basically told us "dead" or "alive." I could have

done that myself. But even with the shortcomings of the cold germination lab test, it did tell us which lines we had to plant more of at our trials to get an equal amount of plants.

The results often supported our field observations, and we got a pretty good picture of which Painted Mountain lines had cold hardiness in the seedling stage and which didn't.

The Painted Mountain x Early Riser hybrids which were tested for cold germination at a lab were also grown for evaluation at three dryland locations: at my one plot in Montana and at two replicated plots by Pat Carr at Dickinson and Richardton, ND. Carr took two different vigor readings in spring. Observing the vigor of seedlings in the ground was more significant than the lab tests.

We had some surprises. There were definitely correlations among lines with common ancestry. Painted Mountain lines with only 1/2 of 1% Navajo breeding from the warmer Southwest uniformly had lower cold vigor. Painted Mountain lines originally from Montana that had been bred for three generations by Marcelo Carena at NDSU in a warmer location also lost some of their cold hardiness.

## **YIELD AND ECB EVALUATION OF TEST CROSSES**

Results from analysis of variance of the data from test cross evaluations done by cooperators in five environments (Rich Pratt in OH in 2007 and 2008, Maury Johnson in two MN locations in 2007, and Walter Goldstein in WI in 2007) are shown in Table 1. Environments (location-year combinations) were a highly significant source of variation for all traits measured, meaning that average yield, grain moistures, plant density, and stalk lodging were different over this set of environments. Hybrids varied highly significantly for grain moisture at harvest and stalk lodging, indicating that the different hybrids also had real genetic differences for these traits. Only stalk lodging showed a significant hybrid by environment interaction, which tells us that the amount of lodging in some hybrids varied depending on the environment in which the hybrid was planted. Given that some environments had hurricane wind damage while others might have had only lodging pressure from ECB, this is not surprising.

Table 1. Mean squares from analysis of variance of yield trial data on 23 corn hybrids grown in five environments in 2007 and 2008.

| Source             | DF  | Mean Squares   |                    |                       | DF | Mean Squares        |  |
|--------------------|-----|----------------|--------------------|-----------------------|----|---------------------|--|
|                    |     | Yield,<br>bu/A | Grain<br>Moist., % | Plant<br>Density, #/A |    | Stalk<br>Lodging, % |  |
| Environment        | 4   | 82684 ***      | 1465.34 ***        | 1326721933 ***        | 3  | 32303.74 ***        |  |
| Rep[Environment]   | 5   | 1164           | 5.28               | 640153                | 4  | 94.69               |  |
| Hybrid             | 22  | 937            | 7.55 ***           | 1960588               | 22 | 415.86 ***          |  |
| Hybrid*Environment | 88  | 655            | 3.07               | 1890004               | 66 | 314.12 ***          |  |
| Error              | 109 | 588            | 2.93               | 2072977               | 88 | 152.78              |  |

\*\*\* Significant at P<0.0001.

Environment means (Table 2, arranged from highest to lowest yield:moisture ratio) show that the hybrids tested were most productive in East Troy, WI, in 2007 (highest average yield and highest yield:moisture ratio). Interestingly, this was also the environment with the lowest plant density by far, raising a concern about whether the hybrids evaluated lack tolerance to higher plant densities. Yields were also high in Wooster, OH, in 2007, but the grain was quite wet at harvest, which drove down yield:moisture ratio values in this environment. Grain moistures

were high at harvest in Wooster, OH, again in 2008 and there was tremendous stalk lodging pressure in this environment from Hurricane Ike, which undoubtedly contributed to the lower yields observed. The MN environments both had low grain moistures at harvest in 2007 but yields at Wells were about 25 bu/acre higher than those at Kenyon. Reported state average corn grain yields were 135 bu/A in WI and 146 bu/A in MN for 2007, and in OH they were 150 bu/A in 2007 and 135 bu/A in 2008 (National Agricultural Statistics Service database). These values are for all corn grown in these states, most of which was conventionally produced (i.e., not organic) and much of which was undoubtedly GE varieties. In comparison to that, our hybrids yielded reasonably well.

Table 2. Environment mean values from yield trial evaluation of 23 corn hybrids grown in five environments in 2007 and 2008.

| Environment                           | Yield, bu/A | Grain Moist., % | Yield: Moist. Ratio | Stalk Lodging, % | Plant Density, #/A |
|---------------------------------------|-------------|-----------------|---------------------|------------------|--------------------|
| East Troy, WI 2007                    | 213         | 16.2            | 13.2                | 12.6             | 18,245             |
| Wells, MN 2007                        | 131         | 16.6            | 7.9                 | 2.0              | 31,576             |
| Wooster, OH 2007                      | 163         | 26.6            | 6.1                 | 3.1              | 25,703             |
| Kenyon, MN 2007                       | 106         | 18.9            | 5.6                 |                  | 31,089             |
| Wooster, OH 2008                      | 120         | 28.1            | 4.3                 | 58.1             | 25,655             |
| Mean                                  | 147         | 21.3            | 6.9                 | 19.0             | 26,432             |
| Standard Deviation                    | 24          | 1.7             |                     | 12.4             | 1,440              |
| Least Significant Difference (P<0.05) | 10          | 0.7             |                     | 5.1              | 595                |

Mean values for the yield data and the European corn borer resistance assessment of the cross hybrids are shown in Table 3. Hybrids are listed from highest to lowest yield:moisture ratio in the table. The tester that each inbred was crossed to (B103/SD46) was also evaluated and is shaded gray in the table.

Three of the experimental hybrids had better yield:moisture ratios than the tester (i.e., the inbred crossed to this tester improved the performance of the tester). All three of these hybrids also had less ECB damage than the tester (i.e., fewer tunnels per plant and less total length of tunneling). They are shaded green in the table below. The parents that were crossed to B103/SD46 to make these hybrids have been selected as promising inbreds. They are being used to create more hybrids to evaluate in organic production systems and will likely lead to hybrids that would produce well under organic management and provide some resistance to ECB for organic growers.

We were very encouraged that all of the test cross hybrids has fewer ECB tunnels and less total length of tunnels than the tester B103/SD46. The only hybrid that had almost as much tunneling as this tester (hybrid 21) involved a cross with an inbred from Ames 25975. All of the other crosses involved inbreds from NECB549, and all of these produced hybrids with less ECB damage than the tester itself. This tells us that the inbreds we selected from the NECB549 background uniformly improve the ECB resistance of things that they are crossed to. That is very good news for going ahead to develop ECB resistant hybrids for organic growers.

The Rachel Carson Synthetic that was evaluated only in 2008 had a grain yield of 118 bu/A (compared to an average of 120 bu/A for all of the hybrids in table 2 in Ohio 2008) at a grain moisture of 33.9% (compared to an average of 28.5% for the above hybrids). It was also rated for ECB and had an average of 4.0 tunnels per plant and total tunnel length of 16.4 cm. This

Synthetic will need work to improve both its yield potential and its ECB resistance, which is not surprising. Mixing the many possible ECB resistance genes together means that different plants in the mixture carry one or more of those genes, but few (if any) plants are likely to carry all of them. Population improvement will be needed to increase the frequency of the resistance genes in this population. That work has been initiated since the end of this project.

Table 3. Hybrid mean values from yield trial evaluation of 23 corn hybrids grown in five environments in 2007 and 2008.

| Hybrid             | Yield Trial Data (WI 2007, 2 MN locations 2007, OH 2007, OH 2008) |                   |                       |                  |                    | European Corn Borer Resistance |                         |                        |
|--------------------|-------------------------------------------------------------------|-------------------|-----------------------|------------------|--------------------|--------------------------------|-------------------------|------------------------|
|                    | Grain Yield, bu/A                                                 | Grain Moisture, % | Yield: Moisture Ratio | Stalk Lodging, % | Plant Density, #/A | Number of Tunnels/Plant        | Tunnel Length/Plant, cm | Number of Larvae/Plant |
| 18                 | 161                                                               | 20.1              | 8.0                   | 7.0              | 26,901             | 2.8                            | 9.2                     | 0.6                    |
| 17                 | 163                                                               | 21.2              | 7.7                   | 6.5              | 26,668             | 2.3                            | 7.6                     | 0.4                    |
| 16                 | 151                                                               | 19.7              | 7.7                   | 14.1             | 27,133             | 2.0                            | 5.1                     | 0.3                    |
| B103/SD46          | 147                                                               | 19.4              | 7.6                   | 17.1             | 27,017             | 3.3                            | 11.6                    | 0.6                    |
| 20                 | 158                                                               | 20.9              | 7.5                   | 23.6             | 26,587             | 3.0                            | 9.1                     | 0.5                    |
| 21 (Ames 25975)    | 156                                                               | 21.4              | 7.3                   | 20.8             | 26,843             | 3.0                            | 11.4                    | 0.6                    |
| 9                  | 157                                                               | 21.6              | 7.3                   | 14.7             | 25,400             | 1.3                            | 3.9                     | 0.3                    |
| 23                 | 153                                                               | 21.5              | 7.1                   | 21.3             | 26,289             | 2.1                            | 6.4                     | 0.4                    |
| 8                  | 154                                                               | 21.7              | 7.1                   | 25.7             | 26,436             | 2.4                            | 7.8                     | 0.4                    |
| 10                 | 145                                                               | 20.4              | 7.1                   | 23.7             | 26,901             | 1.6                            | 5.9                     | 0.4                    |
| 5                  | 148                                                               | 21.1              | 7.0                   | 13.7             | 26,959             | 2.1                            | 8.5                     | 0.4                    |
| 6                  | 147                                                               | 21.6              | 6.8                   | 27.2             | 26,436             | 2.3                            | 7.8                     | 0.2                    |
| 12                 | 148                                                               | 21.8              | 6.8                   | 5.6              | 26,378             | 1.8                            | 6.6                     | 0.2                    |
| 11                 | 139                                                               | 20.5              | 6.8                   | 27.9             | 26,262             | 1.6                            | 6.5                     | 0.2                    |
| 7                  | 152                                                               | 22.4              | 6.8                   | 23.7             | 26,494             | 2.0                            | 6.8                     | 0.3                    |
| 13                 | 147                                                               | 22.0              | 6.7                   | 8.5              | 25,956             | 2.2                            | 9.1                     | 0.2                    |
| 22                 | 142                                                               | 21.6              | 6.6                   | 20.0             | 25,971             | 1.6                            | 4.7                     | 0.2                    |
| 15                 | 136                                                               | 20.7              | 6.6                   | 19.6             | 26,436             | 1.3                            | 4.0                     | 0.4                    |
| 4                  | 143                                                               | 21.8              | 6.5                   | 18.8             | 25,908             | 1.9                            | 6.0                     | 0.4                    |
| 1                  | 138                                                               | 21.7              | 6.3                   | 31.5             | 26,634             | 2.9                            | 9.0                     | 0.2                    |
| 2                  | 143                                                               | 23.2              | 6.1                   | 26.4             | 26,668             | 2.6                            | 8.5                     | 0.3                    |
| 3                  | 129                                                               | 21.8              | 5.9                   | 20.4             | 25,660             | 2.4                            | 7.2                     | 0.1                    |
| 14                 | 124                                                               | 21.7              | 5.7                   | 18.1             | 26,494             | 2.2                            | 7.6                     | 0.1                    |
| Mean               | 147                                                               | 21.3              | 6.9                   | 19.0             | 26,432             |                                |                         |                        |
| Standard Deviation | 24                                                                | 1.7               |                       | 12.4             | 1,440              |                                |                         |                        |
| LSD (P<0.05)       | 22                                                                | 1.5               |                       | 12.3             | 1,276              |                                |                         |                        |

## **CONCLUSION AND DISCUSSION**

### **What I would do differently** Dave Christensen

INBRED LINES: When creating inbred lines to improve a population, it is not efficient to inbreed for seven to ten generations. With a large staff and lots of resources you can do more on a large scale. But on a smaller scale, more could have been accomplished by inbreeding for three generations and then starting again with new parents. Most of the bad genes are discovered and eliminated in the first three generations anyway. Also, you can run any good line into the ground by inbreeding too many times.

**CHOOSING A TESTER:** There were some disadvantages of using Early Riser as a tester line. It came from the East and did not do well in the West. It is an open-pollinated line and the genetic diversity interfered with seeing the input of the other parent. It has tillers, which is not desirable for my program. Next time I would choose an inbred line which has single stalks and has some proven ability in the West.

**CROSSBREEDING:** When crossing a very slow maturing line with a fast maturing line, you must plant one of the lines at staggered dates so that some of them will flower at the same time. Sometimes there were less than a dozen plants that would match. I wish I was able to plant a lot more pollen parents so there would be more plants to choose from.

**BINDWEED MANAGEMENT:** If there is bindweed in the field, you must rotate every year and plant a tall grass that will shade out the bindweed.

## **Accomplishments**

This is a breeding project. It takes generations to create something new, using natural breeding methods. Borer resistant lines are close to being ready for the warmer regions. The faster maturing lines from crossing with Painted Mountain may not be ready for years. The work is continuing by the participants. We thank OFRF for getting an alternative to GE corn launched.

The inbred lines that this grant allowed me to develop have been used in many important genetic programs beyond the ECB project. I have made countless crosses to other modern experimental lines, containing rare nutritional genes, testing them for maturity in our cold climate.

Of all my experiments, the strongest stalks came from the ECB-resistant line! The stalks were thin, which is efficient in a dryland situation, and they were well-rooted. They had the most strength, which I suspect is due to a high lignin content. Because Painted Mountain lacks in stalk strength, it was good news to find very strong stalks in the crossbreds. To look at it another way, I have been seeking the perfect partner for Painted Mountain to improve its stalk strength. Now I can do this and infuse borer resistance at the same time! This is the win/win that the breeder lives for!

## **Still to learn**

The reason for the corn's resistance to borers has not been documented. I would like someone to study the mechanism of natural borer resistance. The high lignin content that I observed in these lines may contribute to borer resistance.

The plants that stood well in dry Montana reportedly lodged early for Margaret in New York. This is expected because the long, moist New England season causes stalk rot and native plants like Painted Mountain do not have the strength of modern nor tropical corns.

Lodging is also caused by borer damage. We need to determine if stalks can be lower in lignin and still resist borers, or if high lignin levels are essential for borer resistance.

## OUTREACH

### Dave Christensen

Our people have been learning that you are here to support organic research where no one else is helping us.

I gave a 20 minute report on our project to Alternative Energy Research Organization in Montana, which has a big interest in sustainable agriculture. I had an audience of about 100 people. I gave a 12-minute report for a group presentation for Montana Organic Association. I created a big sign that said **Organic Farming Research Foundation**.

I mentioned OFRF in 2008 during two talks for 100 people at Bob Quinn's farm tour. I gave the address at the Organic Meet and Greet luncheon in Anaheim, 2009. I give frequent talks, work with many young farmers, and work with Indian reservations, where I don't specifically mention OFRF.

I will share some of the reports on outreach by our project cooperators:

### Margaret Smith

I will be speaking tomorrow at a grower meeting -- "What's New in Organic Dairy and Field Crop Research", that will take place here in Ithaca and will have seven other NY sites connected by video. My talk will include something about this project as well as other work I'm doing on corn hybrids for organic growers.

### Walter Goldstein

We had a field day on Sept. 28th and there were probably 20 people, mostly organic farmers and seed company people. We showed them the field plots including the ECB plots and they were interested in following our progress.

### Richard Pratt

On August 30 Rich Pratt and Mark Casey presented the breeding program objectives as part of the OFFER field day at Ohio State University. Approximately 30 farmers and other interested researchers were able to examine the trials and, as always, a good discussion followed and helpful suggestions were received. He has had good feedback concerning his presentations. Many farmers are particularly interested in our use of buckwheat in the rotation and how it can best be managed. We wish to explore the production of populations and modified hybrids that could be produced in cooperation with farmers and seedsmen.

Richard writes: "I just visited with folks from The Ohio Ecological Food & Farm Association (OEFFA) and they have invited me to give a presentation at their annual meeting in February. I'll plan on presenting an update on the ECB work and the foundation's support of this project there as well."

We welcome OFRF to publish anything that we send to you. The reports our growers submitted to me are very thorough and professional. We have been in the primordial stages of developing genetic lines as breeders. Developing genetic lines takes a long time, but it must be started. Some results will begin showing at the end of this third year. And this third year of trial results will give more dependable conclusions. I am a breeder and a farmer.

Making publications is not my specialty. But I will help you in any way I can to turn our results into a paper or presentation. I have asked our farmers to take pictures this next year.

I believe that this project was Pat Carr's first organic project. He and his staff liked it and have been participating in the organic community ever since.

Growers troubled by borers who do not want GE corn should feel free to contact us. I have sent samples out to several growers. As we get more test results and advance the resistant lines, we will be able to satisfy more of these requests. Our team looks forward to the day when we can offer developed lines.

### **FINANCIAL ACCOUNTING**

This grant covered inbreeding, crossbreeding, replication plots, cold germination testing, yield evaluations, winter nurseries, borer inoculations, borer damage evaluations, and stacks and stacks of records and notes! We had one grower who was not able to plant due to a rainy spring and one harvest that came too late to get seed to the winter nursery. The funds were absorbed by deer fencing, bird netting, unexpected GE tests, and long hours of labor by the participants.

In total, I hand-pollinated 3,000 plants all three years. It took me 16 hrs. a day during 5 weeks of pollination season and 16 hrs. a day for 6 months hand-weeding organic land and harvesting my many projects.

I have enjoyed meeting and working with your wonderful staff. You are fun! Thank you for helping us! I pray for all the projects you are supporting, and for all the people helping to shift mankind's impact on the planet so that the human race can continue.

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