Organic Corn Production
IN KENTUCKY

Organic Corn Production in Kentucky

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Cover photo: William Martin

Introduction

William Martin, UK Agricultural Economics

The number of organic dairy cows in Kentucky has been steadily increasing for years, yet there's not enough organic corn produced in the state to feed the growing herds. In fact, most of the organic corn consumed in Kentucky is produced outside of the state. The growing organic livestock and poultry industries in Kentucky face the same feed constraints. In short, a new market has developed in the state, but few local farmers are taking advantage of it.

Kentucky farmers are no strangers to corn, but the mere mention of *organic corn* often elicits strange looks. While the image of a hand-hoe and a backyard garden might come to mind for some, the reality is that most organic cornfields are virtually indistinguishable from their neighboring conventional cornfields.

Growing corn organically, however, utilizes different management, cultural and marketing practices and requires new skills. And, importantly, organic production must follow an approved farm plan that allows farmers to sell their corn as certified organic.

Transitioning to organic production can be a challenging undertaking, but it comes with its rewards. The price of certified organic corn is consistently 1.5 to 2.0 times the price of conventional corn. Unfortunately, that does not mean that an organic corn farm is 1.5 to 2 times as profitable as a conventional farm. Managing weeds and soil fertility can be difficult, often requiring additional labor. Even with additional labor, most organic farms do not match the yields of their conventional counterparts. And

organic corn is just one element of a longer rotation. Nevertheless, many studies have shown that it can be more profitable than conventional production. It is an especially viable enterprise for those who are constrained by land and are looking for ways to intensify their production.

This publication is designed to be both an introduction to a new enterprise as well as a practical manual for those interested in pursuing organic corn production on their own farms. Pertinent topics are organized into seven individual sections: organic certification, the organic corn marketplace, marketing, profitability management, fertility, and post-harvest handling. Additionally, readers who wish to do further research on the subject will find a collection of resources listed in the last chapter.

Organic Farm Planning under the USDA's National Organic Program

Michael Bomford, Kentucky State University

The United States Department of Agriculture (USDA) has regulated organic agriculture since 2002. By federal law, farmers growing organic products for sale in the U.S. must develop and follow a farm plan that responds "to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity."

In other words, a detailed and unique plan is tailored to each organic farm. The plan includes cultural aspects of the operation, such as row spacing and orientation, cultivation, or irrigation methods. It considers the organisms used on the farm, through crop rotation, variety selection, habitat for beneficial insects, and even the microbes introduced for nitrogen fixation or biological control. Finally, it considers the mechanical tools and equipment used, such as cultivators, mowers, seeders, and harvesters. All

aspects of the farm plan are supposed to work together to reduce the farm's dependence on external inputs by retaining nutrients and working with renewable resources such as sunlight, soil, wind, and rainfall. The farm is intended to host a diverse array of living things, including abundant soil life, a complex cropping system, and healthy populations of beneficial organisms to keep pests in check. In these ways, organic farms are intended to mimic natural ecosystems.

A USDA-accredited organic certifier must approve the farm plan and inspect the farm every year. The only exemption is for farms selling less than $5,000 worth of organic products through direct market channels. These exempt operations do not have to submit a written farm plan but must still adhere to all other requirements of the federal organic standards. They cannot use the USDA Organic seal. The Kentucky Department of Agriculture (KDA) requires registra-

tion of organic farms based in Kentucky that claim exempt status. Those who sell products as organic in violation of federal law can be fined up to $11,000 and excluded from the national organic program for up to five years.

The KDA is the only USDA-accredited organic certifier based in Kentucky. The KDA only certifies Kentucky-based operations. It currently charges $125 per year to submit an organic crop production plan, regardless of farm size. The fee includes the required farm inspection. The KDA's fee is perhaps the lowest of any organic certifier in the country. Another eight out-of-state certifiers also certify organic farms in Kentucky. Their fees are generally higher than the KDA's, with additional fees assessed for farm inspections or by the acre.

The organic farm plan is intended to reduce dependence on off-farm inputs and synthetic substances. Most synthetics—including chemical pesticides, herbi-

cides, fertilizers, and genetically modified organisms—are prohibited entirely. This practice contributes to the popular, but inaccurate, perception that organic farming is simply farming without pesticides. Most naturally derived substances—including fertilizers and pesticides made by plants, animals or microbes—are allowed for use on organic farms, but a few are restricted or even prohibited. For example, newsprint, insecticidal soaps, and boric acid can all be used on organic land, even though they are synthetic; but arsenic and strychnine are prohibited, even though they are natural products. The USDA maintains a list of allowed synthetic substances and prohibited natural substances. Prohibited substances cannot be used for at least three years prior to harvest of an organic crop. For example, a field with no prohibited substances applied after August 31, 2014, could be ready for its first organic harvest on September 1, 2017. The 2015 and 2016 crops could not be sold as organic, but the 2017 crop could be sold as organic if it is harvested in September or later. Organic farmers maintain at least three years of management records to demonstrate that they have not used prohibited substances during that period.

The Organic Materials Review Institute (OMRI) is a useful resource for organic farmers who wish to know whether a particular product is allowed for inclusion in their organic farm plan. OMRI reviews ingredients of products marketed to organic producers, to ensure they contain no prohibited substances. OMRI-approved products can display the OMRI logo on their packaging and are added to a searchable database that can be accessed through OMRI's website.

Buffer zones are maintained around organic land to prevent contamination with prohibited substances applied to adjacent conventional land. This con-tamination is a particular concern with corn, because most conventional corn is genetically modified, and its wind-blown pollen can travel long distances, so has great potential to contaminate organic corn through cross-pollination. Organic certifiers may require larger buffer zones between organic and conventional corn plantings than they would for other crops. They will likely take relative planting dates and prevailing winds into consideration as they consider the size of the buffer needed to prevent contamination with genetically modified pollen.

Annual crops such as corn must be rotated with other crops to maintain or improve soil quality. Long rotations that include cover crops, nitrogen-fixing crops, sod-forming crops, and green manure crops are encouraged to prevent erosion and build soil quality. A simple four-year organic corn rotation might include a year of corn following three years of alfalfa. A more complex four-year rotation could have two years of alfalfa, then a year of corn followed by a winter cover crop mixture of rye and crimson clover, and, finally, summer soybeans followed by winter wheat. Either of these rotations could be certified organic, but most organic certifiers would not approve an organic farm plan calling for continuous corn, or a simple corn-soybean rotation.

Organic farmers must plant organic seed if it is commercially available. Organic seed is grown on certified organic land and is not treated with synthetic fungicides or other prohibited substances. Many varieties of organic corn seed are available, most of which are hybrids. An organic farmer can plant untreated conventional seed only if she/he can demonstrate to the certifier's satisfaction that the particular variety needed is not commercially available as organic seed.

An organic farm's plan should be designed to maintain or improve soil qual-ity without synthetic fertilizers. Regular soil testing and crop quality checks can help determine whether soils have sufficient nutrients to sustain healthy and high-yielding crops. Organic farmers often strive to maintain or increase soil organic matter content, which is an important indicator of soil quality, and feeds soil-dwelling organisms.

Sufficient nitrogen must be obtained from non-synthetic sources such as nitrogen-fixing crops, composts, animal manures (from organic or conventional livestock operations), or feather meal. If animal manure is used as a fertilizer, it must be applied more than 90 days before harvest of organic corn destined for human consumption. No pre-harvest interval applies if the corn is used for animal feed or if the manure has been properly composted according to organic requirements.

Mined materials are acceptable sources of phosphorus, potassium, sulfur, calcium, and other essential elements, provided they undergo no further processing or purification after mining, except for crushing and sieving. Since these materials can be expensive, organic farmers often try to retain locally available resources before supplementing with mineral sources. Cover cropping, composting, and manure incorporation are all useful tactics for nutrient retention and recycling on organic farms.

Understanding and following the USDA's organic standards can seem cumbersome at first, but it gets easier with time. More than 120 Kentucky operations have already been certified under the USDA's organic program, joining more than 17,000 certified organic operations nationwide. By producing organically, these farms fetch premium prices while conserving resources and promoting ecological balance and bio-diversity.

The Organic Corn Marketplace

Thomas Sikora, UK Agricultural Economics

Figure 1. Price of conventional (CME Futures) and organic corn (USDA), 2008-2014

Organic food sales in the U.S. have seen a steady rise over the last 20 years. Between 2004 and 2012, food sales climbed from $11 billion to an estimated $27 billion. Organic meat and poultry represents the fastest growing segment within the fast-growing organic industry. Because organic livestock requires organic feed, this increasing demand is one of the driving forces in the organic corn market. While the organic grain production still remains very small when compared to conventional production, more land is being transitioned to organic production. In the three years from 2005 to 2008, certified organic production of corn, soybeans, and wheat increased from roughly 200,000 acres to about 736,000 acres.

In Kentucky, the largest potential market for organic grain is the growing dairy industry in and around the state. This market is still relatively small in Kentucky, but it is growing. And even though this market is small, their demand for feed grain is not being met locally. In fact, one of the reasons that many organic industries remain small in Kentucky is the difficulty they face in sourcing the required organic inputs (such as feed corn and soybeans).

Prices

Among many possible motivating factors, farmers consistently rank high price premiums as one of the most important reasons for transitioning to organic production. Throughout the organic industry the historical price of organic grains has approximately traded at twice that of conventional prices from 1995 to 2013. On the surface, this suggests that organic simply trades at a fixed premium over conventional. But this "premium" has varied significantly. For instance, the price ratio has ranged from as small as 1 to as a high as 4.5, with most of this price-spread volatility occurring in the years since 2007 (Figure 1).

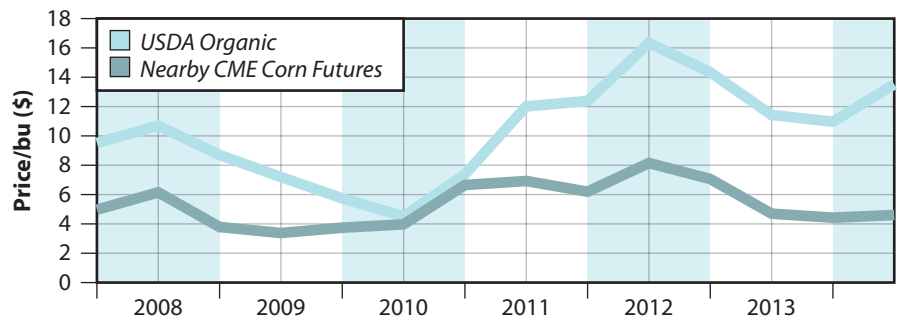This variable price spread between organic and conventional crops is economically relevant not only to existing organic producers and processors but for those conventional producers and processors considering a transition into organic agriculture. In addition, this price spread is of particular importance for the annually adjusted crop insurance plans for organic crop producers that are drafted by policymakers within the United States Department of Agriculture Risk Management Agency (USDA-RMA.)

Several years ago, it was very difficult for farmers to find accurate price reporting in the organic market. In the conventional market, you can look on your phone or computer or call your local elevator and get real cash prices. Most organic sellers had little price information, and in the early years there existed a large amount of price variability between local contracts for organic commodities. Over the last decade, however, improved price reporting by Rodale and the USDA-Ag Marketing Service has resulted in prices being posted biweekly online, and all producers now have better information on prices. While better reporting has improved seller awareness of prices, there still remains a great deal of price variability in the organic industry, especially when compared to conventional commodity prices (Figure 1).

Organic Crop Insurance
Current Status

Both certified and transitional organic farming practices have been insurable through the RMA Federal Crop Insurance Program since 2001. There were major changes for crop year 2013, however, including a premium surcharge removal for organic producers and the establishment of an organic transitional yield (T-yield) instead of being linked to a conventional T-yield.

Surcharge Removal

In March 2013, the RMA removed the longstanding 5 percent premium surcharge assessed against all organic farmers seeking federal crop insurance.

T-Yield Adjustment

Prior to 2013, organic producers insured their crops based on the conventional T-yields of their respective counties. Starting in crop year 2014, organic producers will have adjusted, organic-only T-yields that better reflect appropriate premium and expected indemnity payout levels.

Result of 2013 Changes

Starting in crop year 2014, organic producers will automatically pay 5 percent less because of the removal of the insurance program participation surcharge, and since organic T-yields will be less than conventional T-yields, the premiums associated with the lower historical T-yields will also be reduced. The bottom line is that the typical organic producer will pay approximately 15 percent less in insurance premiums and fees in future crop years.

Remaining Concerns

The biggest remaining problem exists with the RMA defining the insurance value of organic grain by linking it to its conventional counterpart. The current model simply uses a multiplier (currently 1.788 for organic corn) and derives the organic corn price by multiplying the conventional price of corn by a predetermined value. (This is the 2011 pilot program ratio based on the minimum ratios of organic to conventional prices observed from January 2007 through September 2009.)

Implications of Multiplier

Basically, the multiplier is a form of price risk that cannot be managed. For instance, if you plant organic corn when the price of conventional corn is $5.00 and the price of organic corn is $8.94 (a price difference of 178.8%), you are satisfied with a 1.788 multiplier. But during harvest, what if the price of conventional corn remained at $5.00 but the price of organic corn was now at $10.25? This reflects an actual multiplier of 2.05, not the 1.788 your premiums for revenue protection paid for. The revenue protection offered to you in this situation (where the harvest price ratio of organic to conventional corn exceeds its planting multiplier ratio) would be much less than the fair market value of your crop. Conversely, if the price of your organic corn fell from $8.94 to $8.00 while conventional corn remained at $5.00, and you received an indemnity payout on your revenue protection policy, you would actually benefit, since you would be facing an actual price multiplier of 1.6 yet would be receiving an indemnity based on a higher expected value for your crop.

Even more simply stated, at the 75 percent coverage level, an organic producer in 2012 faced an effective coverage range of 43 percent to 105 percent depending on the ratio of planting-time organic prices to conventional market prices. This multiplier risk is unmanageable through hedging and is often not seriously considered by organic and transitioning producers.

Future Work on Insurance

The RMA is currently investigating new price election methodologies which take into account the shortcomings of the above fixed-price model. This model was developed during the 2008 Farm Bill prior to the RMA having accurate price data. However, the Agricultural Marketing Service (AMS) of the USDA now reports a biweekly organic corn price both regionally and nationally. The RMA has also begun a beta testing program to better aid in price discovery by taking price reports from organic producers via the internet. It is obvious that the fixed-price methodology used by the RMA to determine the insurance price of organic corn is on its way out, and it will inevitably be replaced by an independent price for organic corn based on AMS and organic producer price reporting. The OIG report critical of the RMA for using conventional T-yields and insurance participation fees on organic producers resulted in an almost instantaneous change to those policies earlier in 2013. When the change from fixed-price to independent-price elections will occur is the unknown.

Profitability of Organic Corn Production

William Martin, UK Agricultural Economics

Is organic corn production profitable? Depending on who is asking, this question can mean two different things. One way of looking at profitability is to compare the production of organic to conventional corn: Is organic corn more profitable than conventional corn? But perhaps there are producers less interested in a comparison who would simply like to know if they can make enough profit to cover living expenses and build some savings. For the purpose of this publication we will attempt to address both of these questions.

On the surface, the equation seems quite simple. If you can sell your crop at a huge premium (often as much as twice the price of conventional corn!), how could you lose? A back-of-the-envelope calculation would tell you that $6 per bushel corn would gross $900 per acre at 150 bushels per acre. If organic corn were selling for $14 per bushel, you would see an increase in gross returns for any yield over 65 bushels per acre. This sounds too good to be true because gross returns are often misleading. Chasing prices instead of profits is never a good idea. The rest of this section will be devoted to three other factors that determine the profitability of organic corn:

- How do the costs of production compare with conventional corn?
- What are the effects of a longer rotation with fewer cash crops?
- And how much of an impact does the transition period have on profitability?

Answering these questions will help us get to the bottom of our original question: Is organic corn profitable? And how does it compare with conventional corn?

Previous Studies

Before getting into our analysis, it's worth taking a look at what other organic corn profitability studies have found.

- Iowa State University: Delate (2003) found that costs were lower for organic production as long as fertilizer costs stayed below a certain threshold. More recently, Chase (2008) concluded that a four-year organic rotation increased returns to management substantially.
- Purdue University: In 2009, Clark found that even with a yield penalty, organic corn can be more profitable than conventional corn during a (seven-year) transition period.
- Minnesota: Mahoney et al. (2001) used field trial results to conclude that an organic grain system is significantly more profitable than conventional production.

- University of Wisconsin: In 2009, Chavas concluded that, based on their field trials, organic grain and forage system was the most profitable. The trial was conducted between 1993 and 2006.
- USDA-ARS: In 2006, Archer used a simulation model based on data from a research farm in Minnesota. He compared organic to conventional cropping systems with transition and risk effects. He concluded that, even when considering the transition period and risk, organic corn production can be more profitable. This result, however, was limited to a somewhat unrealistic two-year organic rotation. When compared with a four-year organic rotation, results were less conclusive.
- USDA ERS: In a 2013 study that used ARMS data to compare the profitability of organic and conventional corn production, McBride found that price premiums cause organic corn production to be more profitable than conventional production under certain scenarios.

As is evident from the summaries above, most studies that compare organic to conventional grain production find that organic systems are more profitable. Some conclude that the system's profitability is due to lower costs and a higher premium. Others argue that costs are not significantly lower and that only a high price premium causes the organic system to be more profitable. The majority of these studies are based on university field trials. While useful, some would argue that field trial results are sometimes difficult to replicate outside of the experimental setting.

Costs

To analyze the impacts of farm costs on profitability we use empirical data from the FINBIN Farm Financial Database. The database summarizes actual farm data from thousands of agricultural producers who use FINPACK for farm business analysis. FINPACK is a comprehensive farm financial planning and analysis software system developed and supported by the Center for Farm Financial Management at the University of Minnesota. FINBIN contains farm management data from Minnesota, North Dakota, Missouri, Ohio, Michigan, Wisconsin, South Dakota, and Nebraska with Minnesota representing the largest share of farms. An ideal analysis would use local farm data, but there simply is not a large enough sample of organic corn farms in Kentucky to get an accurate picture of the system's cost structure. Nevertheless, we feel that the use of farm data gives a realistic picture of the cost-related decisions that organic producers make.

Unless otherwise noted, cost data is an average from the years 2008 through 2012. Total costs refer to total direct and overhead costs. This estimate of costs not only includes the obvious elements such as fertilizer and fuel, it also includes items such as machinery depreciation and utilities. Land rent is subtracted so that it can remain constant in our comparisons. Table 1 shows a comparison of the average total costs for organic corn producers and conventional corn producers in the sample.

Some of the difference in cost can be explained by differences in average yield. On a per-acre basis, costs such as storage, drying, and hauling are all more expensive with higher yields. Other differences, however, are due to the production practices of each enterprise. As you can see in Table 2, machinery and labor-related costs are significantly higher in organic corn production. This is not surprising since organic farms rely on mechanical cultivation to control weeds. In fact, the FINBIN data also shows that organic corn requires twice the labor hours per acre of conventional corn. More passes through the field and more labor hours will obviously drive costs higher. These cost differences, however, are outweighed by higher seed, fertilizer, and herbicide costs that a conventional corn farmer typically incurs.

To provide a better idea of how the costs of organic production can be broken down, we modified the University of Kentucky's conventional tillage corn budget. Machinery and labor estimates for organic production were adopted from the Iowa State University Organic Corn Enterprise Budget (see resources section). It is important to note that many of these expenses can vary dramatically among farms (see note about fertilizer costs). All farms are different, but this data should give an idea of how an organic corn enterprise budget compares to a conventional one (Table 3). Check out the resources section for links to budgets online where you can input information specific to your farm.

Table 2. Where costs are higher ($/ac)

From Conventional to Organic		From Organic to Conventional	
Category	Increase in Cost	Category	Increase in Cost
Fuel and Oil	$7.34	Seed	$22.47
Repairs	$8.86	Fertilizer	$60.55
Custom Hire	$5.53	Crop Chemicals[1]	$18.61
Hired Labor (direct)	$1.17		
Hired Labor (overhead)	$10.91		

[1] Compared to certified organic crop chemicals and "non-chemical crop protection"

Table 1. Total cost per acre comparison

Organic Corn	Conventional Corn
$345/ac	$450/ac

Organic fertilizer costs

There are many reasons an organic farmer may have significantly lower fertilizer costs. An increased use of cover crops and forage crops in the rotation reduces the need for external nitrogen fertilizers. In addition, many organic corn farmers are able to find a free or cheap source of manure as a fertilizer. It is important to note, however, that a farmer without these resources may find similar or even higher fertilizer costs, as organic soil amendments can often be more expensive than their conventional equivalents.

Table 3. Total costs per acre on a sample organic farm

Total Costs per Acre

Machinery Costs			Fixed	Variable	Total Costs
Plow (moldboard)			$8.90	$10.00	$18.90
Tandem disk			$3.50	$2.90	$6.40
Field cultivate			$2.40	$2.70	$5.10
Plant			$5.70	$4.90	$10.60
Rotary hoe (2x)			$3.00	$2.20	$5.20
Row cultivate (2x)			$3.80	$4.00	$7.80
Total Machinery					**$54.00**

	Quantity	Unit	Price		
Seed	0.38	bags	$200.00		$76.00
Fertilizer - manure + spread	1	ton	$50.00		$50.00
Lime - Delivered and Spread	0.5	ton	$20.00		$10.00
Drying: LP, Electric, Maint & Labor	1	gallon LP	$2.00	*Pts Remove* 3	$20.01
Crop Insurance	1	acre	$30.00		$30.00
Other Variable Costs	1	acre	$5.00		$5.00
Operating Interest	$225.00	dollars	$0.06	*# Months* 8	$9.00

Harvest		Fixed	Variable	Total Costs
Combine		$17.60	$9.90	$27.50
Haul		$4.60	$4.03	$8.63
Handle		$1.73	$2.30	$4.03
Total Harvest				**$40.15**

Labor		Hours	Rate	Total
Labor variable costs		$1.40	$12.50	$17.50
Hired Labor Overhead				$15.00
Total Labor				**$32.50**

Additional Overhead Expenses		
Taxes and insurance		$10.00
Miscellaneous Overhead		$10.00
Additional Overhead		**$20.00**

Total Operating Costs Per Acre	**$346.66**
Cash Rent Per Acre	**$175.00**
Costs + Land Rent	**$521.66**

Rotations

If you could find a way to continuously grow organic corn on the same plot of land and do so successfully and sustainably, there is no doubt that the organic system would be more profitable. Organic systems, however, require longer rotations (see production section for complete explanation). If we assume a four-year organic rotation of corn, soybeans, wheat, and alfalfa, then we are no longer interested in just the profitability of organic corn production. The new question you have to ask is: Is this rotation profitable? The question can be extended to: Is this rotation more profitable than the conventional, two-year corn and soybean rotation?

Prices

To compare systems we need to know what prices to expect. For simplicity, we use round numbers that represent an average of spot prices from 2008 to 2012 (the same period from which the cost data was taken). For organic crops, we use low-range and high-range estimates as well that will be 20 percent below and 20 percent above the spot price, respectively (Table 4).

Alfalfa prices were determined from conversations with local farmers and industry experts. Prices for alfalfa (both organic and conventional) can vary dramatically depending on quality. For example, organic dairies paid as much as $400 per ton for premium organic alfalfa in 2012. The prices we used are meant to be a conservative estimate for good quality alfalfa.

Yields

Our estimated yields are based on results of a UK field trial as well as anecdotal evidence. They are also very close to average yields from the FINBIN data. Many university field trials and the well-known Rodale Institute field trial show that organic yields increase as the farmer gains experience and eventually will match

conventional yields. While this could be the case, based on the results of the UK field trial, empirical evidence from the FINBIN data, and anecdotal evidence, we feel that this is overly optimistic. One possible reason for the difference is that organic farmers typically plant later in the season to avoid cross-contamination. Later planting reduces yield potential.

Results

To analyze the profitability of our sample rotation, we average returns to management across the rotation and then compare that to the returns to management for a traditional corn and soybean rotation. Returns to management do not include government payments in this analysis. For simplicity, we assume returns on one crop per year. We therefore assume that wheat would be harvested as grain, and the alfalfa would be established that fall.

You can see in the Tables 5 and 6 that average organic returns to management, even at the low range of prices, are higher than the conventional rotation. Organic corn carries the entire rotation with its high profit margins. One may be tempted to use these results as evidence that the shortest organic rotation possible would be the most profitable. While one may find success with many other rotations, it is important to consider the agronomic benefits that are not accounted for in a budget. Alfalfa, for instance, boosts soil fertility for the coming corn crop.

Transition Effect

One of the biggest hurdles to organic corn production is the transition process. Organic certification requires that fields do not receive any synthetic chemicals for at least three years prior to harvest. Since there is little high-quality agriculture land that meets this description in Kentucky, our budget assumes that a farmer will have to transition their land to certified organic production. Developing a comprehensive plan to manage this transition is crucial to making organic corn production a profitable enterprise. This section will provide some recommendations and a sample plan, but every farm will be different. In addition, we recommend involving your organic certifier in all stages of the planning process

Table 4. Budget price estimates

	Low Range	Average	High Range
	Price/bu		
Organic Corn	$7.20	$9.00	$10.80
Organic Soybeans	$15.80	$19.00	$22.20
Organic Wheat	$8.60	$11.00	$13.40
	Price/ton		
Organic Alfalfa	$160.00	$200.00	$240.00
	Price/bu		
Corn	$6.00		
Soybeans	$13.00		
Wheat	$8.00		
	Price/ton		
Alfalfa	$140.00		

Table 5. Organic rotation

		Corn	Soybeans	Wheat/ Alfalfa	Alfalfa	Rotation Avg.
Gross Sales	low range	$864	$456	$484	$560	$591
	average	$1,080	$570	$605	$700	$739
	high range	$1,296	$684	$726	$840	$887
Average Costs		$345	$298	$190	$250	
Land Rent		$175	$175	$175	$175	
Avg. Costs + Land Rent		$520	$473	$365	$425	
Returns to Management	low range	$344	-$17	$119	$135	$145
	average	$560	$97	$240	$275	$293
	high range	$776	$211	$361	$415	$441

Table 6. Conventional rotation

	Corn	Soybeans	Rotation
Gross Sales	750.00	495.00	622.50
Average Costs	450.00	230.00	
Land Rent	175.00	175.00	
Avg. Costs + Land Rent	625.00	405.00	
Returns to Management	125.00	90.00	107.50

(see organic certification section for more information). Make sure to talk to your certifier about buffer requirements between fields.

Many farmers assume that organic certification requires that they transition their entire business to organic production. Not only is this untrue, we find that a gradual transition is one of the best ways to maximize your profits. Another misconception is that a three-year transition period means that you will not have an organic crop until your fourth year. Three years refers to the harvest date and not the planting date. With a little planning it is possible to have a certified organic crop in the third year of the transition.

Example Transition

Starting year: Plant a crop of conventional corn. Last synthetic chemical applied in spring. Transitional wheat sown in fall, after the corn is harvested.

First year: Transitional wheat is harvested. Transitional alfalfa established.

Second year: Transitional alfalfa harvested.

Third year: Corn planted. As long as it is harvested after the date of the last chemical application of the starting year, this crop can be certified organic.

For the transition period, we assume a decline in yield due to both biological factors and a learning curve effect. Many agronomic studies have found such a decline. A study at Purdue summarized previous research and found an average transitional yield penalty for corn (14.6%), soybeans (14.9%), wheat (18.1%), and alfalfa (12.6%). See Table 7 for a summary of yields used in the analysis. These are the same yields used in the rotation analysis above.

Improper planning of the transition can have a major impact on profitability. For our analysis, we use a transition plan developed by Iowa State University (Table 8). The plan assumes the ability to divide a farm into four equal size fields. As was mentioned previously, the plan finds it to be beneficial to transition one's farm to certified organic production on a gradual basis. In this particular plan, year three is 25 percent organic, and the farm is not 100 percent organic until year six. In addition to maintaining some financial stability with some conventional crops, another advantage to this plan is that it avoids planting any corn or soybeans during the transition period. These crops would be more likely to suffer during the transition period, and the lack of an organic price premium makes them a poor choice to plant during the transition period. If the transition is properly managed, we find that an organic corn production system can be more profitable than a conventional two-year rotation with average prices (Table 9). The lower price model shows slightly lower returns over the six-year transition period (Table 10).

To make sure the results of our analysis weren't anomalous because of the input prices used, we looked at the actual prices received by organic producers over the last six years and tested the transitional plan. We also used the real cost data for each of those years instead of a running average. The only elements that stayed constant were land rent and yield. We found that if a farmer started the organic transition in 2007, their average returns would have been significantly less than our predicted returns, but they would still be higher than average returns from a conventional two-year rotation over that same period.

Table 7. Yields during transition

Crop	Yield
Corn (bu/ac)	150
	120
	102
Soybeans (bu/ac)	45
	30
	25
Wheat (bu/ac)	65
	55
	44
Alfalfa, established (tons/ac)	4
	3.5

🟦 Conventional crop
🟩 Organic crop
🟨 Transitional crop

Conclusion

This section started with a question: Is certified organic corn production profitable? Based on our analysis, we find that it *can be* profitable and that it *can be* more profitable than conventional corn production. When it comes to choosing any new enterprise, one has to consider that all farms are different and that weather or financial markets can disrupt even the best laid plans. When it comes to organic corn production, there is also a steep learning curve that must be accounted for. All that being said, the results show that this enterprise represents a potential opportunity to increase one's profits.

Farmers with limited access to land may find the results of this study particularly interesting. If you're willing to commit to the extra labor hours, the higher returns would allow a much smaller farm to be profitable than is typically the case. In their analysis of organic corn production in Iowa, the authors point out the implications of their findings for beginning farmers:

The need for fewer acres would allow the producer to enter into farming with lower capital requirements. Fewer acres also translate into a smaller machinery investment. Machinery for organic producers tends to be smaller, less expensive equipment compared to conventional producers. The much lower machinery and land investment for the organic producer would allow farmers with limited resources to attain economic goals with minimum debt. Therefore organic rotations offer beginning farmers an opportunity to gain access to farming without a debt load and risks

Table 8. Transition plan

Field	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	Corn	Soybeans	Corn	Wheat	Alfalfa	Corn
2	Soybeans	Corn	Wheat	Alfalfa	Corn	Soybeans
3	Corn	Wheat	Alfalfa	Corn	Soybeans	Wheat
4	Wheat	Alfalfa	Corn	Soybeans	Wheat	Alfalfa

🟦 Conventional crop   🟨 Transitional crop   🟩 Organic crop

Table 9. Transition returns to management per acre (average prices)

Field	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Avg.
1	$125.00	$90.00	$125.00	-$97.37	$65.00	$560.00	$144.61
2	$90.00	$125.00	-$97.37	$65.00	$560.00	$156.16	$149.80
3	$125.00	-$97.37	$65.00	$560.00	$156.16	$240.00	$174.80
4	-$97.37	$65.00	$560.00	$97.00	$240.00	$275.00	$189.94
Avg.	$60.66	$45.66	$163.16	$156.16	$255.29	$307.79	$164.78

Table 10. Transition returns to management per acre (low prices)

Field	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Avg.
1	$125.00	$90.00	$125.00	-$97.37	$65.00	$344	$108.61
2	$90.00	245	-$97.37	$65.00	$344	-$17	$104.94
3	$125.00	46.84	$65.00	$344	-$17	$119	$113.81
4	-$97.37	$65.00	$344	-$17	$119	$135.00	$91.44
Avg.	$60.66	$111.71	$109.16	$73.66	$127.75	$145.25	$104.70

that can be overwhelming. Programs and funding that are available for beginning farmers can be stretched farther in organic production than conventional.

Kentucky has an abundance of small family farms, many of which are looking for more profitable enterprises. The results of this study show that organic corn production could be a great opportunity for some of these farms.

Marketing Organic Corn

Lee Meyer, UK Agricultural Economics

Marketing organic corn is totally different from marketing conventionally produced corn, primarily because of the different market structure. Conventional corn is produced in huge quantities. U.S production was just under 14 billion bushels for the 2013 crop. While comparable production data for organic corn are not available, only 0.26 percent of the 91 million acres in corn production were certified organic in 2011. Another difference is that conventional corn is a "commodity," which means it is a generic or standardized product produced in large volumes and which can be totally described by grades and measures. With commodities, buyers and sellers do not have to be present at the market. There is also a very extensive marketing infrastructure for commodities such as corn. From a practical perspective, this infrastructure means that producers of conventional corn don't have to look far for a place to deliver their product. There are probably grain elevators close to their farms. Pricing is always complicated, but at least with conventional corn, price information is readily available from both private sources and USDA market news reports. Farmers also have extensive access to market analysis and forecasts. Finally, for conventional corn there are futures markets that enable growers to separate physical deliver from pricing. For example, producers can sell their conventional corn on the futures market at any time—even well before harvest.

In contrast to conventional corn, organically grown corn is a specialized product. And while it can be sold by grade, moisture content, etc., there is not much of a market infrastructure because of the low level of production. The bottom line is that good marketing takes a lot more effort for organic corn than for conventional corn.

It is important to understand that the market for organic corn is driven by the organic livestock products market. These are your customers. Dairy farms are the largest user of organic corn, followed by organic poultry productions (eggs and broilers). A small amount of organic corn may be used in beef production.

Most commodity corn is sold to grain elevators, who in turn sell it to users (ethanol, food processing/HFCS, feeders) or exporters. While some organic corn is sold to elevators, most is sold either directly to users or to local feed mills who supply users. So, as an organic corn producer, you will have the option of selling through one of these three outlets.

Selling directly to a user (livestock producer) has the *potential* to provide the highest return since this is the ultimate destination of your product. Direct marketing eliminates the middle man but not the services that the middle man provides. The grain is not eaten at one time, so storage must be provided to make the grain available over the whole year. Quality must be assessed and guaranteed. And, both sides must be protected from default.

An important strategy in direct sales is building a relationship with your customer. Strategic relationships can help both sides and increase total value. By honestly discussing factors such as storage, you can find solutions to potential problems. You may find that the buyer needs monthly deliveries and that you will need to provide storage but that the buyer has a truck and can provide transportation. Relationships need to be developed and proven. Both sides will look for characteristics such as reliability (which must be developed and proven over time) in addition to financial assurances that can be part of contracts.

Pricing is always an issue in direct sales. A way to simplify pricing is to use some type of formula pricing. A formula price calculates a pay price based on a publically reported price. For example, you could agree to sell your corn to a dairy farmer at $.50 less than the average USDA reported price for the past two weeks. Alternatively, you might want to agree on a price for the whole year, even though deliveries occur through the year. A longer term arrangement like this should involve some type of a contract.

Contracts, or written agreements, can be a valuable component of a direct marketing relationship. A good contract can clarify communication, avoid problems and give assurance on both sides. Longer term (multi-year) contracts can reduce risks for both sides by giving the corn seller a long-term market and the buyer a longer term supply and help with cost management. Organic Valley, a leading processor of organic milk, is trying to develop contracts between corn producers and their member milk producers with prices somewhat below current spot market prices (around $10/bu.) but still at profitable prices for corn producers.

Finding a potential buyer is not difficult. The Kentucky Department of Agriculture has a list of certified organic producers, including dairy and poultry. Each of these is a potential customer. Some already have sources of organic corn, and you may be competing with your neighbor. But others are buying feed grain for out of state and welcome the opportunity to buy closer to home and at a lower "price in the feed bunk."

Another option is to register your farm and list your products for sale on one of several internet sites. Even traditional farmers are using internet sites to help in their buying. Some examples are www.marketmaker.com (sponsored by the University of Kentucky) and www.localharvest.org. These sites are easy to

register with and will help buyers find your organic corn. And there are other ways to market your corn online. Organic Valley has a monthly trade newspaper where people can list feed for sale (http://books.dairylandprint.com/MayAOrgTrader/page2/index.html).

For farmers who would rather not deal with the issues of direct sales, selling to a feed processor might be a good option. A feed processor is similar to a grain elevator; they usually have storage and are willing to buy large quantities at harvest. Most will pay higher prices after harvest, giving you to opportunity to store and then sell at a higher price as the season goes on.

Kentucky Organic Farm and Feed, Inc. (KOFFI), located in Guthrie, Kentucky, is the one organic feed company in the state. They will bulk grain and complete dairy and poultry rations in bulk or bag. They can be reached at: (270) 265-5004 to discuss current buying options.

In theory (depending on where you are located and trucking options), you can also sell your organic corn on the "spot" market, directly to an elevator. If that fits your marketing plan, you will want to compare prices, adjusting them for transportation costs and any other marketing expenses. It's always a good idea to study the overall market. Start with the USDA Market News report. (The most current report is available online at: http://www.ams.usda.gov/mnreports/lsbnof.pdf.). As of December 2013, the price of organic feed corn ranged from $10 to $11.75. One of the problems is finding a feed mill close by and with competitive prices.

At this time, there are no known commercial grain elevators buying organic corn. There are buyers in Indiana and Illinois, but the hauling charge might be prohibitive. Still, selling to buyers in nearby states can be a back-up option in the marketing plan.

The bottom line is that while selling organic corn is different from selling conventional corn, there are numerous opportunities to enhance your returns and make a good financial return on your marketing efforts. The overall organic sector is growing, and marketing institutions (including grain elevators, market news, etc.) are sure to develop and expand, making marketing easier.

New organic grain producers and conventional farmers who are considering adding an organic corn enterprise will benefit from advanced planning. They should evaluate potential commercial (grain elevator and feed supplier) markets. They should contact potential buyers (probably organic livestock product producers) and learn about their needs. Moreover, they need to understand their cost of production so that they can know what level of selling price they'll need to be profitable.

Organic Corn Crop Management

Chad Lee, UK Plant and Soil Sciences, Grain Crops

Site Selection and Soils

Corn will grow on about any soil type in Kentucky. But corn (including organically grown corn) grows best on well-drained soils.

Since tillage is normally part of an organic corn system, soils with very little slope (0 to 2%) are preferred. Generally, soils with little to no slope are at lower risk for erosion. However, soils with little to no slope in the Ohio River Valley are generally soils near rivers and streams. These bottom fields are prone to flooding, and erosion can be a risk. Also, some of these bottom fields have higher clay content and are poorly drained. Corn can do well on poorly drained soils, but some of the crops in rotation, such as wheat or alfalfa, do not grow well on poorly drained soils.

Fields with a history of animal manure typically are high in fertility and may be ideal for organic corn systems. If soils have excessive phosphorus levels from repeated use of animal manures, corn is an excellent crop to help remove phosphorus from these fields.

Identity Preservation

Organic corn needs to be isolated from other corn fields in order to prevent stray pollen from entering the organic corn field. The farmer growing organic corn is responsible for isolation of the organic corn.

Thankfully, we have a successful example of corn isolation in the Ohio River Valley. For years, white corn has had to be isolated from yellow corn. Pollen from a yellow corn hybrid that pollinates a white corn ovary will produce a yellow corn kernel. Farmers raising white corn generally plant border rows. In general, twelve border rows are considered to be sufficient for blocking yellow corn pollen from reaching white corn plants. Farmers raising white corn will keep the harvested grain from the border rows separate from the remaining grain. Organic farmers should be able to follow a similar practice.

If the organic corn maturity is different from the neighboring corn, then the two fields may pollinate at different times and reduce the risk of contamina-tion. Also, differences in planting date may change the pollination timings and reduce risk of contamination.

Once the organic corn crop is harvested, those kernels must be kept separate from other kernels. The chapter on postharvest handling provides more details on segregation.

Crop Rotations

Around 50 B.C., the author Varro observed that legumes grown before a cereal crop improved yields of the cereal crop. He also noted that the best method was to allow the legume to get to a full seed stage and then plow it under and immediately plant a cereal. This is one of the earliest references to using a "green manure." Cereal crops such as wheat, barley, oats and rye are grasses. Corn (or maize) is also a grass. Scientists and farmers now know that a legume fixes nitrogen. If a grass crop is grown immediately after the legume, then nitrogen from the legume crop will be available for the grass crop.

Table 1. Examples of 3-, 4-, and 5-year organic crop rotations for Kentucky

Example Rotations		Year				
		1	2	3	4	5
		Crop(s)				
5-Year rotation	2 grass crops in 5 years	Alfalfa/Corn	Soybean/Wheat	Wheat/Alfalfa	Alfalfa	Alfalfa
4-Year rotation	1 grass crop in 4 years	Alfalfa/Corn	Alfalfa	Alfalfa	Alfalfa	
3-Year rotation	2 grass crops in 4 years	Corn	Soybean/Wheat	Wheat/Legume		

Studies over the past century have verified that crop rotations generally reduce diseases, insects and weeds for each crop in the rotation. In addition, crop rotations typically improve the yields of each crop in the rotation. The proper crop rotations can improve soil organic matter and soil structure. Crop rotation is absolutely critical to the sustainability of an organic cropping system. There are several options for crop rotations. In general, a legume needs to be rotated between cereals and other grass crops.

Examples of Crop Rotation

Five-year rotation: In this example, year 1 is destruction of alfalfa followed by the planting and harvesting of corn. Year 2 is the planting and harvesting of soybean followed by planting of wheat or spelts. Year 3 is harvesting of wheat followed by seeding of alfalfa. Years 4 and 5 are alfalfa forage crop. Year 6 is destruction of alfalfa followed by planting corn (two grass crops in five years).

Four-year rotation: In this example, year 1 is the destruction of alfalfa followed by planting and harvesting of corn. Year 2 is planting of alfalfa, and years 3 and 4 are alfalfa forage crops. Year 5 is destruction of alfalfa followed by planting and harvesting of corn (one grass crop in four years).

Three-year rotation: In this example, year 1 is planting and harvesting of corn. Year 2 is planting and harvesting of soybean followed by planting of wheat or spelts. Year 3 is harvesting of wheat followed by planting of a legume cover crop such as crimson clover. Year 4 is destruction of the cover crop and planting of corn (two grass crops in four years).

The crop rotation chosen also depends on the needs of the entire farming system. The five-year rotation in the example includes both corn and alfalfa, which may be very useful in dairy operations. The three-year rotation example, which includes corn, soybean and wheat or spelts may be better suited to a farm looking to sell mostly grain.

In each of these examples, a legume is grown before a grass or cereal. Over the long-term, the five-year rotation may be one of the most beneficial for soil structure. However, alfalfa requires a tremendous amount of potassium. Soil fertility in this rotation and any other rotation should be monitored to ensure adequate nutrients for each crop.

Corn Crop Management
Hybrids and Varieties

There are two basic types of corn grown in organic farming: varieties and hybrids. Corn varieties are often referred to as "open-pollinated" or as "lines". The seed of an open-pollinated corn variety has the same genetic content as the parent plants. The offspring of an open-pollinated variety generally has the same yield potential as the parents. Open-pollinated varieties are not necessarily isolated from neighboring fields of corn, so the genetic makeup of an open-pollinated seed lot may not be uniform.

Hybrids are developed by crossing the pollen from one line of corn with the silks of another line. The resulting seed is hybrid seed. Hybrid seed will produce a plant that will yield much more than either parent. A hybrid has a different genetic content than either parent, and the offspring of a hybrid plant will not produce as much yield as the hybrid seed. As a result, hybrid seed must be developed every year. A seed lot of hybrid seed should have uniform genetics.

Corn hybrids have greater yield potential and more stress tolerance than most open-pollinated varieties. As a result, open-pollinated varieties and hybrids are managed differently. If yield expectations are below 100 bushels per acre, then there probably is little difference among varieties and hybrids. If yield expectations are greater than 100 bushels per acre, then hybrids should be used.

Maturity

Corn maturities ideal for Kentucky range from about 110 to 120 days. Variations in weather and planting date can affect the actual number of days necessary for corn development, but hybrids and varieties in this range of maturities generally do best based on historical climatic conditions for this region.

Planting Date

Ideally, corn should be planted once soil temperatures are at least 50°F (10°C), there is a favorable weather forecast, and the calendar suggests early freeze risk is minimized. Most years, these conditions occur between April 1 and May 15. However, yearly weather may allow corn to be planted as early as March 25 and as late as June 1 with little impact on yield.

Generally, organically grown corn planted after June 1 will have lower yields. Later planted corn is at greater risk of damage from corn borer insects. In cases where a cover crop or green manure is allowed to grow into June before planting corn, normally, corn yield loss from late planting is greater than yield gained from the nitrogen available from green manure.

Seeding Rate

Open-pollinated lines or varieties should be seeded at about 15,000 to 20,000 seeds per acre. Corn hybrids can be seeded at 22,000 to about 30,000 seeds per acre. Better soils are suited to the higher seeding rates, while poorer soils are suited to the lower seeding rate.

Corn planted at higher populations generally does not compete better with weeds than corn planted at lower populations, unless no other weed control

practices are implemented. The seeding rate is strictly chosen to try to maximize corn yield. Better soils (and better genetics) will allow for higher planting populations.

Not all seeds in the bag will germinate. The seed tag should list a standard germination value and the percent of pure seed in the bag. The seed tag also should list any other foreign material that may be in the bag.

The following equation can be used to determine the number of live plants that can be expected from corn seed at a specific seeding rate:

$$\text{Expected population} = \frac{\text{seeding rate} \div (\% \text{ pure seed} \div 100)}{(\% \text{ germination} \div 100)}$$

For example, a seed tag may list 99 percent pure seed and 90 percent germination. If a target population is 25,000, then the calculation is:

$$\frac{25{,}000 \text{ plants/acre} \div (99 \div 100)}{(95 \div 100)}$$

$$= 26{,}580 \text{ seeds/acre}$$

Seeding Depth

Corn should be seeded about 1.5 to 2 inches deep in most soils. If the soil is dry, then a deeper seed placement of 2.5 to 3 inches deep may be necessary. Deeper placement requires very good seed quality.

Planting corn less than 1 inch deep may cause the entire root structure to be too shallow and puts the resulting plants at greater risk for falling over (also called "lodging"). Corn seeding depth should not exceed 3 inches.

Row Width

To maximize yield, corn needs to capture at least 95 percent of the light by the time the plant tassels. Generally, corn will reach 95 percent light interception when grown in row widths of 30 inches or less. Row widths less than 30 inches will capture 95 percent light interception but would hinder inter-row cultivation when needed.

Open-pollinated lines should do well in row widths of 36 inches or less. Some of the open-pollinated varieties have larger leaves, which tend to lie more horizon-

tally than some hybrids. Open-pollinated lines are grown at lower target plant populations. Open-pollinated corn lines have lower yield potential than hybrids. All of these characteristics make 36-inch rows (or less) suitable for open-pollinated corn.

Weed Control Methods

Weeds compete with corn for water, nutrients and light, and can complicate harvest. Early season weed pressure can affect corn growth and development even after the weeds are removed. Effective weed control is essential to achieve excellent corn yields, and effective weed control may be one of the more challenging practices for organic farming in the Ohio River Valley. Organic weed control methods are most effective on small weeds with shallow roots. There are more options for small annual weeds than larger weeds or perennial weeds.

Weeds that emerge with a corn crop and grow to about 4 inches in height will reduce corn yields. However, the density and species of weeds affect competition with corn and could change the removal timing of those weeds.

Johnsongrass (*Sorghum halapense*) is a perennial weed and may be the most problematic weed on organic farms in the Ohio River Valley. Removing it from fields requires multiple years and multiple weed removal practices. Failure to control this weed effectively could ruin attempts to grow all grain crops organically.

Johnsongrass can grow from seeds in the first season. The growing plant will develop roots and rhizomes. During the second season, new johnsongrass plants can grow from the rhizomes. The seedling johnsongrass is relatively easier to control than the rhizome johnsongrass. Control of this weed must be of high priority on organic farms.

While johnsongrass may pose the largest threat to organically grown crops, a plethora of weed species will attempt to compete with corn. Redroot pigweed, smooth pigweed, Palmer pigweed, common lambsquarters, common ragweed, cocklebur, and Pennsylvania smartweed are just a few of the broadleaf weeds that could be in Kentucky fields. Giant foxtail, green foxtail, barnyardgrass, fall

panicum, and broadleaf signalgrass are a few of the grass weeds. Each of these weeds has a slightly different growth habit, seed production, seed viability and competitiveness with the corn crop. There are several management tools available to help control these weeds.

Weed Removal Practices

In organic farming, the methods for controlling weeds include: rotation, cover crops or smother crops, mechanical removal, chemical removal, flaming, and hand-roguing.

Crop rotation is beneficial to the soils and can help with weed management. Different crops have different planting dates and growth habits. These differences inherently help control some weeds. This practice alone does not control weeds, but when used with other weed management practices, crop rotation is beneficial. Crop rotation also generally reduces disease and insect pressure and generally improves yields of the rotated crops.

A common **cover crop** grown for weed control is annual rye (also known as cereal rye). The rye is allowed to grow to maximum height, and the crop is mechanically crimped and flattened prior to planting. This method helps smother small weeds that germinate in the field. However, planting into a crimped and flattened matte of cereal rye increases chances for certain insects and slugs to be a problem early in the season. Almost any cover crop that has an acceptable stand will reduce early season weed pressure. The challenge with a cover crop is to control it early enough to keep it from competing with corn. Earlier removal of the cover crop reduces the risk of slugs but also reduces the smothering effect of the cover crop.

Mechanical control of weeds is probably the most common method used in organic farming. Mechanical control includes using moldboard plows, disks, field cultivators, rotary hoes, tine harrows, inter-row cultivators and other equipment that physically breaks, pulls or otherwise destroys weeds.

Several organic **herbicides** are available. Organic herbicides contain compounds such as citric acid, clove oil, cinnamon oil, and acetic acid. These herbicides will

damage any green plant material with which they contact. They generally work best on very small broadleaf weeds and do not work as well on grasses. Excellent spray coverage is necessary for excellent weed control.

Flaming puts direct heat on plants, rapidly removing water and causing the plants to wilt and die. Flaming is most cost-efficient on smaller weeds.

Hand-roguing is often the last resort in weed management. However, hand-roguing is necessary in fields where weeds are in the planted row. Hand-rouging can be effective in fields with very low populations of weeds. The old axiom of weed control is, "Never let a weed go to seed." This goal normally can only be achieved with some hand-roguing.

Before Planting

Weeds can be controlled before planting with smother crops and/or tillage. For fields that are extremely weedy, a moldboard plow may be necessary to bury seeds. Moldboard plowing can also reduce the risk of certain diseases. However, moldboard plowing increases the risk for erosion and quickly reduces soil organic matter. So, a moldboard plow should be only be used when absolutely necessary.

If moldboard plowing is not necessary, then using a disk or a field cultivator can remove weeds prior to planting. Disking generally has greater risk for compaction than a field cultivator. But, disking may remove weeds more uniformly than a field cultivator. Soil finishing implements such as a spiked harrow or a rotary hoe can help remove shallow-rooted weeds.

After Planting

Weeds can be controlled after planting and before emergence with organic herbicides, rotary hoes or tine harrows. Organic herbicides damage green plant material and do not have soil residual properties. Rotary hoes and tine harrows will remove small weeds. A rotary hoe will alleviate crusting problems. Tillage implements are more effective when the soil surface is slightly dry.

Once the crop emerges, weeds can be controlled with inter-row cultivation and flaming. Both methods generally work best on smaller weeds. Frequent, shallow passes with inter-row cultivation are preferred over fewer, deeper passes. Flaming for a single pass is more economical on smaller weeds.

After Harvest

Some weeds can be removed after corn is harvested. Fall is a great time to remove perennials such as johnsongrass from fields. Deeper tillage with a moldboard plow or disk is generally the most effective. However, fall tillage puts the soil at great risk for erosion. For this reason, fall tillage should be followed immediately with a cover crop to minimize erosion losses. Fall tillage is ideal when the soil is dry. If the soil is wet, fall tillage could result in compaction problems for the next crop.

The Weed Management System

Effective weed management is critical to maximizing yields in any corn system. Effective weed management requires the implementation of several strategies and tools. Weed management in organic corn requires multiple weed removal events throughout the year. The weed management achieved this season could have impacts for a couple of years ahead. Poor weed management this season could have impacts for several years ahead.

Fertility Management for Organic Corn Production

Edwin Ritchey, UK Plant and Soil Sciences

Introduction

Producers utilizing organic production practices face many of the same fertility concerns that conventional producers contend with in their farming operation. There are differences in the inputs that are utilized between the organic and conventional production systems. Regardless of the system implemented, they both utilize the nutrients available in the soil. Those nutrients not provided by the soil must be supplemented to provide the nutrients required by the plant to avoid limiting yield.

All farming operations should utilize a good soil fertility program to ensure that adequate levels of plant nutrients are available for plant uptake and yield. The soil fertility program should be based on sound soil sampling practices. Nutrient and amendment applications for corn production typically involve limestone, nitrogen (N), phosphorus (P), potassium (K), and to a lesser extent zinc (Zn), magnesium (Mg), and occasionally boron (B). All nutrient applications except N should be based on a quality soil sample.

Soil Sampling

The importance of a sound soil sampling program should not be underestimated and will be discussed in detail. The basic principle of soil sampling is to provide an estimation of the nutrient availability for a particular field. Soil sample extractions are designed to estimate the proportion of the nutrients that are or will become available within that crop year. The sample of soil that is analyzed in a soil testing lab represents a large area of soil, so it is critical that the sample be as representative of the area as possible. Often fertilizer recommendations for several million pounds of soil (there are approximately 2 million pounds of soil in one acre to a depth of 6 inches) will be based on one or two teaspoons of the sampled soil. For this reason soil samples should represent uniform areas that are no more than 20 acres in size. If a field is not uniform, then a smaller sampling area should be used to make sure it adequately represents the field. Avoid the areas in a field that were subjected to different management practices or anomalies within the sampled field. Some examples of areas to avoid include dead furrows and back furrows, old fencerows or homesteads that are now included in the field, areas used for

animal feeding where manure and hay accumulates, and small areas that are severely eroded. If two fields have been combined in recent years, it will be advisable to collect separate samples for each old field area and compare the samples. If the soil test results are similar, then they can be grouped in following years for sampling and management purposes. Additional information regarding soil sampling procedures can be found in the University of Kentucky Cooperative Extension Publication *Taking Soil Test Samples* (AGR-16) (www.ca.uky.edu/agc/pubs/agr/agr16/agr16.pdf).

A soil sample can be collected utilizing several different tools such as a spade, soil auger, or soil probe and collected in a clean plastic bucket. Do not use galvanized buckets since the Zn in the bucket will contaminate the sample and give misleading sample results for Zn. Remember, the fertility recommendations are only as good as the soil sample submitted to the laboratory for analysis.

There are two main times that are typically utilized for soil sample collection: fall sampling after crop harvest or spring sampling sometime prior to planting. Both times are acceptable, but there can be seasonal differences between the two sample times. For this reason, it is always best to take the samples the same time of the year after beginning the soil sampling program. Samples collected at the same time should then be observed for upward or downward trends to determine if fertility adjustments are needed.

A minimum of 10 soil cores (samples) should be collected per submitted sample and up to 30 cores for larger fields. Once an adequate number of soil cores are collected in the bucket, thoroughly mix the soil in the bucket, and then fill the sample bag or box to the amount indicated.

A representative sample should be collected to the proper depth. Sample depth is based on tillage management. For tilled soils, it is recommended to collect the soil to the depth of primary tillage (usually about 6 inches). For no-tillage managed soils or soils that have very shallow disturbance (1 to 2 inches), the recommended sampling depth is 4 inches.

Once the samples have been collected, the next step is to complete the soil test submission form. Most soil testing laboratories will ask questions such as the previous crop, the soil drainage class, or current year crop. Most university recommendations, including the University of Kentucky, are not based on yield goals. Based on numerous research studies, the yield goal method is inferior to the crop sufficiency approach. For a detailed review of the different philosophies used in making fertilizer recommendation, please refer to the University of Kentucky Cooperative Extension publication *Evaluating Fertilizer Recommendations* (AGR-151), which can be found at http://www.ca.uky.edu/agc/pubs/agr/agr151/agr151.pdf.

Sampling frequency can vary depending on the crop grown. For most crops, such as corn grown for grain, sampling every two years will be adequate. High value crops (e.g. alfalfa or vegetables) or crops that have high removal rates (e.g. silage corn) should be sampled annually.

Addition of Nutrients or Amendments

Results of the soil sample should be available within a few days of submission. The results will provide several pieces of information that should be utilized when making the nutrient or limestone application. The basic information typically includes a water (or salt) pH along with a buffer pH, and the amounts of available P, K, Ca, Mg, and Zn in pounds per acre and provides recommended amounts to add for the crop or crops being fertilized. Nitrogen (N) tests are not commonly used for making N recommendations due to the transient nature and mechanisms involved throughout and after the growing season. Soil organic matter (SOM) is often determined when a routine soil test is submitted. Although SOM can be a useful measurement for certain situations, it is not a reliable indicator of available N under Kentucky cropping conditions. Nutrient recommendations for P and K are reported in pounds of P_2O_5 and K_2O per acre. All fertilizer labels will report the nutrient analysis as a percent of P_2O_5 and K_2O that is available to the plant in a growing season.

There are two forms of nutrients: organic and inorganic. Regardless of the production system utilized, organic or conventional plants will only utilize nutrients in specific inorganic forms. Organic nutrient forms will contain carbon in their chemical structure and are not available to the plant for utilization until they are transformed into available forms. Inorganic forms are small compounds or ions that the plant can utilize. Many of the nutrients utilized in organic crop production are in compounds that must be transformed into available inorganic forms prior to the plant being able to take up the nutrients and utilize them for growth. Nitrogen is utilized in the plant as either ammonium (NH_4^+-N) or nitrate (NO_3^--N). Phosphate is utilized as orthophosphate ($H_2PO_4^-$ or HPO_4^{2-}). Potassium, Ca, Mg, and Zn are taken up in their ionic forms (K^+, Ca^{2+}, Mg^{2+}, and Zn^{2+}). Sulfur (S) is taken up as sulfate (SO_4^{2-}). Individual nutrients and amendments will be discussed in the following sections.

Conventional corn growers are accustomed to meeting their plant fertilizer needs with materials such as urea, muriate of potash, or diammonium phosphate (DAP). These materials are not permissible in organic systems, but there are alternatives which will be discussed in the following sections on nutrients. Table 1 lists a few examples of nutrient sources that are allowed and not allowed in organic crop production. Many products will have a range of nutrients, so the most common analyses were reported. There are many products available for organic crop production—far too many to include in this guide. To choose the most appropriate product, base the nutrient analysis of the products available on price per actual nutrient needed (lb of product per unit of fertilizer and its associated cost).

The Science of Plants and Nutrients

Producers need to understand the science of nutrients and plant growth to be successful. The basic principles of soil chemistry, nutrient availability, etc., are the same for organic and conventional systems. The following sections cover soil pH and fertility. Each section focuses on the management system, the basic information needed to make fertility decisions and how the chemistry and plant growth work.

Table 1. Comparisons of allowable nutrient sources, excluding manures, for organic crop production and corresponding conventional nutrients with approximate nutrient contents.
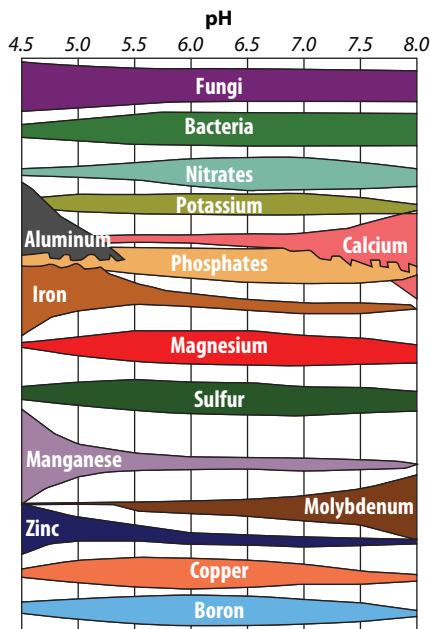
Nutrient	Allowed Organic Nutrients		Conventional Inputs	
Nitrogen	Sodium nitrate[1]	16-0-0	Sodium nitrate	16-0-0
	Blood meal	12-0-0	Ammonium nitrate	34-0-0
	Fish meal	10-0-0	Urea	46-0-0
	Feather meal	12-0-0	Anhydrous ammonia	82-0-0
Phosphorus	Tennessee Brown Rock	0-3-0	Triple superphosphate	0-45-0
	Bone Meal	3-15-0	Diammonium phosphate	18-46-0
Potassium	Sulfate of potash–mined[2]	0-0-50	Sulfate of potash	0-0-50
	Potassium-magnesium sulfate	0-0-22	Muriate of potash	0-0-60

[1] No more than 20% of the total crop requirement
[2] From nonsynthethic sources that have been mined and not processed

Soil pH and Limestone Additions

Soil pH is the most influential soil chemical property that can be managed and is referred to as the "Master Variable". Soil pH is the measure of the active acidity present in the soil. A pH can range from 1 to 14, with 1 being the most acidic and 14 being the most basic or alkaline; a pH of 7 is considered neutral. Soil pH will typically range from about 4 to 8, but most soils in the southeast will fall into the range of 4.5 to 7. There are different optimum soil pH levels, depending on the crop being grown. Soil pH determines nutrient availability, provided the nutrients are present in the soil (Figure 1). Soil pH near 6.4 is optimal for most row crops, including corn. Often the most economical method of controlling the supply of certain nutrients is by maintaining the proper soil pH.

Another pH measurement that is included in soil tests is the buffer pH. A water pH indicates what the soil pH of that sample is but does not indicate that amount of "residual acidity" present in the soil. A buffer pH indicates the amount of residual acidity and will allow for a more accurate limestone rate to be applied to the soil for the particular crop of interest. Different soils have varying amounts of residual acidity, which is largely based on the amount of clay and SOM present. Greater amounts of clay and SOM present in a soil will require greater amounts of limestone to adjust soil pH. When limestone ($CaCO_3$) is added to the soil the following reaction occurs to neutralize the acidity (H^+) present.

$$CaCO_3 + 2H^+ => Ca + H_2O + CO_2$$
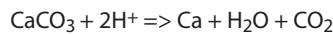
The carbonate (CO_3) present in the limestone consumes the free acidity (H^+) to produce water (H_2O) and carbon dioxide (CO_2). The Ca will remain in the soil for subsequent crop uptake and utilization as needed.

To better understand how soil and buffer pH are used to provide an accurate limestone recommendation, imagine a container of liquid with a hose inserted at the bottom of the container and connected to another container. If you remove liquid from the first container,

Active Acidity   *Reserve Acidity*
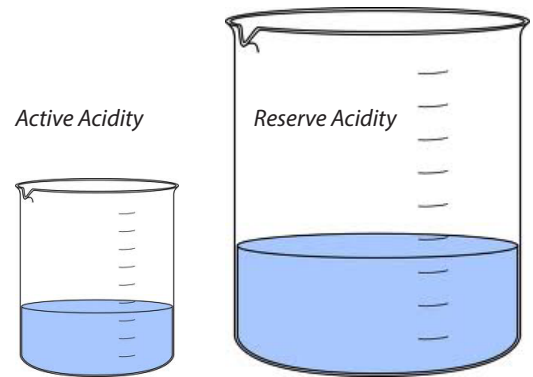
Figure 2. The concept of active and reserve acidity for determining limestone recommendations.

liquid from the second container would move into the first container until they are both empty (Figure 2). The amount of liquid that you can remove in the first container is determined by the size of both the first and second container. Since we measure the first container (water pH), we are really interested in the size of the second container (buffer pH) or the amount of acidity that will be supplied to the soil after the initial acidity is neutralized by the limestone.

The effectiveness of a limestone product to raise the soil pH is determined by two factors: the purity and the fineness of the liming material. Together these two characteristics are called the relative neutralizing value (RNV). The average RNV for Kentucky limestone is around 67 percent, but it can vary greatly. The University of Kentucky limestone recommendations are based on an RNV of 100 percent, so most limestone additions will have to be adjusted according to the RNV of the limestone source utilized. For example, if a recommended limestone rate

Figure 1. The availability of plant nutrients, toxic elements and microbial activity as influenced by soil pH. Wider bars indicate increased availability (activity).

is 2 tons per acre and the source utilized has an RNV of 67 percent, then approximately 3 tons of that material will need to be applied (2 tons/0.67 = 2.99 tons). Calcitic or dolomitic (also contains Mg) limestone are both acceptable sources to neutralize acidity for organic production. Further, any source that is able to neutralize acidity (H^+) can be considered a liming material (e.g. oyster shells).

Phosphorus and Phosphorus/ pH Interactions

There is one caveat to maintaining the proper pH in organic crop production regarding P fertilization. Phosphate is contained in animal manures as well as other sources. The plant availability of the P contained in animal manure is not greatly influenced by soil pH and is readily soluble in water. Rock phosphate is another common source of P utilized in organic crop production. The rock phosphate must dissolve and be transformed into forms that are available to the plant (orthophosphate). The dissolution of inorganic P is dominated by particle size and the soil pH. Rock phosphate will be slow to break down at a pH near 7 and is accelerated at lower soil pH levels. Maintaining a soil pH closer to pH 5.5 to 6 would be recommended if rock phosphate is used in your operation. As pH levels drop below 5.5, the availability of aluminum (Al) and iron (Fe) increase. Both of these elements will form strong bonds with P and reduce their plant availability. As soil pH approaches 7, P will form bonds with Ca, also reducing the availability of P. When utilizing animal manures as the primary P source, maintaining a soil pH near 6.4 is recommended.

Potassium

Potassium is utilized by the plant in one of the greatest amounts, second only to N. Potassium is very soluble in plant tissues and animal manures and most K additions are quickly available for plant uptake and utilization. Certain crops such as alfalfa have a high demand for K. Other crops where the total plant is harvested (e.g. corn for silage) can also remove tremendous amount of soil K. Crops with high removal rates should be monitored annually for maximum productivity.

Calcium and Magnesium

Calcium and magnesium are utilized by plants at relatively modest rates but typically are not yield limiting for row crop production in Kentucky, particularly if following a good liming program. In Kentucky, Mg is found at ample levels in most soils. Further, substantial amounts of Mg are present in the subsoil below typical sampling depths. Research conducted at the University of Kentucky determined that if soil test levels for Mg are above 60 pounds per acre for all row crops, then no yield response will be observed. If it is determined by soil testing that Mg is below 60 pounds per acre, then an Mg application (e.g. Epsom salt, dolomitic limestone, etc.) may be added to correct the deficiency.

The use of limestone without Mg present has been promoted by some in order to maintain a proper Ca:Mg ratio. Considerable research has been conducted to determine if these ratios are better at predicting yield over the availability of the Ca and Mg. Research findings indicate that the overall availability of Ca and Mg as determined by individual soil test values are a much better indicator of yield than a Ca:Mg ratio.

Zinc

Zinc is the most commonly observed micronutrient deficiency for corn production in Kentucky. This deficiency can be a factor of the amount of Zn present in the soil, soil P levels, and/or soil pH. Zinc availability is lowered as soil pH levels increase. Zinc availability is also lower when high amounts of P are present in the soil. Zinc recommendations from the University of Kentucky Regulatory Services account for these variables when determining application rates. Animal manures contain a small but usually adequate amount of micronutrients to meet crop needs.

Sulfur

Questions regarding sulfur have become more common since the amount of S emissions have been drastically reduced over the past decade. Sulfur in the soil is contained in plant residues, animal manures, and SOM in organic forms, and as sulfate throughout the soil profile. The plant available form of S is sulfate (SO_4^{2-}), a negatively charged ion. Sulfate is less mobile in the soil than nitrate but is still prone to potential leaching losses in some soils. The majority of S present in the soil is contained in SOM and deeper in the subsoil. Some private soil testing laboratories offer a soil test for sulfate-S, but the University of Kentucky currently does not test for S. Soil tests for S are not as reliable as they are for P and K due to the amount of S contained in the SOM that must mineralize into plant available forms. Further, considerable S can be below typical sampling depths that would not be accounted for in a 4- to 6-inch sample. To date, no yield responses to S in Kentucky row crops have been documented. For a more detailed discussion on sulfur consult *Sulfur Fertilization in Kentucky* (AGR-198) (http://www.ca.uky.edu/agc/pubs/agr/agr198/agr198.pdf).

Nitrogen

Nitrogen is often the most frequently limiting nutrient in crop production and is required in one of the greatest amounts. The atmosphere contains approximately 78 percent nitrogen gas (N_2) but cannot be directly used by higher plants. Leguminous plants (e.g. soybeans, field peas, clovers, vetch, etc.) have a symbiotic relationship with microorganisms that live on the plant roots (e.g. rhizobia species) that are able to convert atmospheric N_2 gas into a useable form that the plants can utilize. Nitrogen for organic crop production can be supplied by the use of legumes, animal manures, composts, other approved fertilizer sources, and a limited supply of mined mineral deposits (e.g. up to 20% $NaNO_3$). Grasses can also scavenge some of the available N in the soil profile and release it back to the subsequent crop upon termination and decomposition. However, grass species are not able to produce or "fix" atmospheric N.

Unlike most of the other required plant nutrients, no reliable soil test has been developed to make sound N recommendations. Nitrogen recommendations are typically based on response curves from numerous field research trials in different soil types and drainage classes. The University of Kentucky Cooperative Extension Service recommends N rates for corn from 50 to 200 pounds per acre depending on soil drainage class, till-

age practice, previous crop, and amount of time in undisturbed sod (*Lime and Nutrient Recommendations* [AGR-1]). Refer to Table 2 for current N recommendations contained in AGR-1.

Providing the optimal amount of N in organic production systems can be one of the most challenging aspects of fertility management. Most of the N inputs utilized in organic production must be mineralized into plant-available forms prior to being utilized by the plants. Mineralization rates are largely influenced by environmental conditions and the composition of the material being utilized, which will vary from year to year and between products. Mineralization rates typically increase as moisture levels and temperature increase, up to a point, then will begin to decrease and eventually cease. This pattern will also occur with extreme dry or cold weather.

Green manures are crops that are grown to be incorporated into the soil later/after maturity to provide nutrients (mainly N) and organic matter for subsequent crops. Corn requires a large amount of N throughout the growing season to maintain adequate growth. For this reason a legume crop is preferred prior to corn to provide a significant source of N. A good legume cover crop can provide a substantial amount of N to the following crop but is highly dependent on growth and biomass production prior to termination. Thin legume cover crops or good grass cover crops would provide less N.

Tissue analysis and measuring crop biomass provide a good estimate of the amount of N contained in a cover crop. Several representative samples throughout the field should be collected for a known area. A 3 by 3 foot square is often used to determine the amount or biomass for that area. Cut and collect all the vegetation contained in that area and dry to determine the weight of the biomass. Do this in three or four locations of the field. Then collect a small subsample from the biomass to have the tissue analyzed for nutrient content. The nutrient content of the dry biomass multiplied by the weight of the dry biomass per acre

Table 2. Recommended application of nitrogen (lbs N/A) for corn

Previous Crop	Tillage[1]	Soil Drainage Class[2]		
		Well Drained	Moderately Well Drained	Poorly Drained
Corn, sorghum, soybean, small grain, fallow	Intensive	100-140	140-175	175-200
	Conservation	125-165	165-200	
Grass, grass-legume sod (4 years or less), winter annual legume cover	Intensive	75-115	115-150	150-175
	Conservation	100-140	140-175	
Grass, grass-legume sod (5 years or more), winter annual legume cover	Intensive	50-90	90-125	125-150
	Conservation	75-115	115-150	

[1] Intensive tillage has less than 30% residue cover, and conservation tillage has more than 30% residue cover on the soil as planting.
[2] Soil drainage class can be determined from soil type.
Source: Lime and Nutrient Applications (AGR-1)

will give a good estimate of the amount of nutrients added by the cover crop.

Animal Manures and Composts

Animal manures and composts are considered complete fertilizers since they contain N, P, and K. In addition to these nutrients, they also provide secondary and micronutrients that can benefit the plant if these nutrients are lacking in the soil. Poultry litter can also influence soil pH by consuming acidity (H^+) and has a relative neutralizing value of approximately 10 percent. Lime needs will be decreased when poultry litter is used in the production system. Nutrient content and availability varies considerably between different sources (Table 3). Poultry litter has the greatest nutrient density of the common manure sources available. Conversely, beef cattle manure has a low nutrient density. This comparison does not mean that one manure is superior to

another; it just indicates that more beef cattle manure will be needed to provide the same amount of nutrients contained in poultry litter. It is always best to test the animal manure or compost available in order to apply the proper amount as required by the crop.

Incorporation of manures will also conserve the N contained in the manure. Incorporation can be accomplished by tillage or with rainfall. Approximately a half-inch of rain will incorporate the manure into the soil to reduce ammonia volatilization losses. Once in the soil, the ammonia (NH_3) will quickly convert to ammonium (NH_4^+), which is not subject to volatilization in the soil environment. As much as 50 percent of the available N can be lost to volatilization if not incorporated by either tillage or rain (Table 4). Refer to *Using Animal Manures as Nutrient Sources* (AGR-146) for a more detailed discussion on proper utilization (http://

Table 3. Average nutrient content of manures commonly used in Kentucky[1]

Animal Manures[2]	Water (%)	Nitrogen[3]	P_2O_5	K_2O
Beef cattle	80	11	7	10
Dairy cattle	80	11	9	12
Swine	80	9	9	8
Brolier litter (fresh)	20	55	55	45
Brolier litter (stockpiled)	20	40	80	35
Brolier litter (cake)	30	60	70	40
Broiler pullets	25	40	68	40
Layers	40	30	40	30
Goat	70	22	5	15
Horse	20	30	10	70

[1] All values are reported on an "as received" basis.
[2] Animal manures can vary significantly from the reported values depending on diet, storage, and handling methods. A manure test is always superior to using "averaged book values" for nutrient determination. Most soil testing labs will analyze manure samples.
[3] Plant available N can range from 20% to 80% of the total N in the year of application. See University of Kentucky Extension publication Using Animal Manures as Nutrient Sources (AGR-146).

www.ca.uky.edu/agc/pubs/agr/agr146/agr146.pdf).

Spring application of manures for corn is preferred over fall application to maximize the nutrients available, particularly N. Apply manures and compost as close to planting as possible (2 to 4 weeks prior) to maximize the N utilization and match N demands from the corn crop. If the manure is applied in the fall, a cover crop is highly recommended to retain the nutrients and reduce off-site movement of the manure and nutrients.

Manures and composts are good nutrient sources for crop production but there are additional concerns that should be addressed. The long-term use of these products can lead to excessive levels of P in the soil. There are roughly similar amounts of N and P contained in manure, but the plant demand (uptake) for P is usually much less than for N. The greater demand for N will leave a larger amount of P remaining in the soil. At high soil test levels, excess P can be lost to surrounding waters and lead to environmental concerns (eutrophication).

Manures contain pathogens that can be harmful to humans. For this reason there is a 90 to 120 day rule for uncomposted manures that applies to edible crops. This rule does not apply to cover crops or crops used as a livestock feed. If the edible portion of the crop is in contact with the ground or can be splashed with the soil, then a 120-day window from the

Table 4. Percent nitrogen from manure available to a crop for one year from the time of application[1]

Crop		Management[2]	Poultry or Liquid	Other Manures
Corn or annual grasses	spring applied	2 days or less	60	50
		3-4 days	55	45
		5-6 days	50	40
		7 or more days	45	35
	fall applied	No cover crop	15	20
		Cover crop	50	40
Small grains		Applied preplant	50	40
Pasture or hay, cool season		Applied spring or fall	80	60
Bermudagrass		Applied spring or summer	50	40

[1] Percentages are availability coefficients as compared to commercial fertilizers.
[2] Management refers to incorporation by tillage for adequate coverage or a minimum of ½ inch of rainfall unless otherwise specified.
Source: Using Animal Manures as Nutrient Sources (AGR-146)

time of application to the time of harvest should be allowed. Sweet corn for human consumption would fall under the 90-day window since there is no soil contact.

Specific regulations must be followed for a composted product to be allowable in organic crop production. Refer to the guidance standard for composting and vermicompost in organic crop production for more details (http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5090756).

Summary

Producing an organic corn crop can be challenging yet rewarding. The basics for fertilization are the same for organic or conventional crop production in that the plants need adequate levels of nutrients so that yields are not limited, and what the soil does not provide must be added in some form. The best measure of the soil fertility status is obtained by conducting regular soil testing. A good soil sampling program will ensure that plant nutrients are not limiting. Equally important, a good soil sampling program will prevent applying nutrients when they are not needed, thus reducing input costs and potential negative environmental impacts.

Additional information on fertility needs and practices can be found in the resource section of this handbook.

Harvesting, Drying and Storing Organic Corn

Sam McNeill and Mike Montross, UK Biosystems and Agricultural Engineering

Introduction

Producers transitioning from conventional to organic corn production will preserve crop value by taking on the mindset that quality is paramount. Product purity is essential when harvesting and handling any high value grain crop, including organic, non-GMO, seed, and corn for food or organic feed use. Adhering to all the steps developed for handling high quality grain after harvest will serve organic producers well as a starting point. Steps taken before, during and after harvest impact organic grain quality and ultimately value when delivered to market and processed to end products. Numerous publications on all aspects of harvesting, handling, drying and storage of conventional grain pertain to specialty crops and should be used appropriately. Specific examples include steps developed for Integrated Pest Management (IPM) and/or **sanitation, loading, aeration** and **monitoring** (SLAM). McNeill and Montross present information on harvesting, drying and storing corn in Kentucky and is a useful background reference. However, many chemicals that are widely used for conventional grain as well as in many cases the structures where it is held and the equipment used to handle it are clearly not permitted for organic corn. This chapter highlights succinct points that align with post-harvest steps for organic grain and focuses on the differences in management decisions needed for organic certification.

Pre-Harvest Chores

Sanitation is the watchword before harvest, so clean all equipment that the grain will come in contact with during

subsequent handling. This list includes combines or corn pickers, carts, wagons, truck beds, conveyors, dryers or cribs, and storage bins, so considerable time may be needed.

Use brooms and dust pans in bins and other open areas to remove debris and trash from walls and floor. Always wear a dust mask (minimal) or respirator (preferred) when working where grain dust will be generated. Vacuum equipment is preferred over blowers whenever possible to contain dust, debris, insects and trash rather than relocate/disperse it, especially in combines and storage bins.

Compounds approved to control insects in organic grain include diatomaceous earth, which may be applied in dry aeration ducts or beneath false floors prior to harvest. After the crop reaches physiological maturity (black layer) track the dry down rate in the field with a handheld moisture meter that has been calibrated with the buyer's meter. Check that all equipment is in good working condition to minimize delays once harvest begins (see pre-harvest checklist for organic grain producers). Combines that are properly adjusted and operated will reduce harvest losses to a minimal acceptable level (3 to 5%).

Harvesting

Schedule harvest from different fields based on crop maturity and lodging potential. Under ideal conditions (no insects or mold problems in the field and sunny days with no/low rainfall), corn can be left in the field to dry to 16 percent (shelled corn) or 18 percent moisture (ear corn). Under normal conditions (low insect or mold problems and intermittent showers), harvest at moisture levels that match the farm's ability to dry the crop in a timely manner. Early research has shown harvest losses to be minimal when corn is between 23 to 26 percent moisture. Thus, for a large crop that would take several weeks to harvest, farmers with adequate drying capacity would want to harvest through this range to minimize field and machine losses. Under stressful conditions (high insect pressure, mold or aflatoxin potential, or pending inclement weather), prepare drying equipment for maximum capacity and begin harvest in when corn is 26
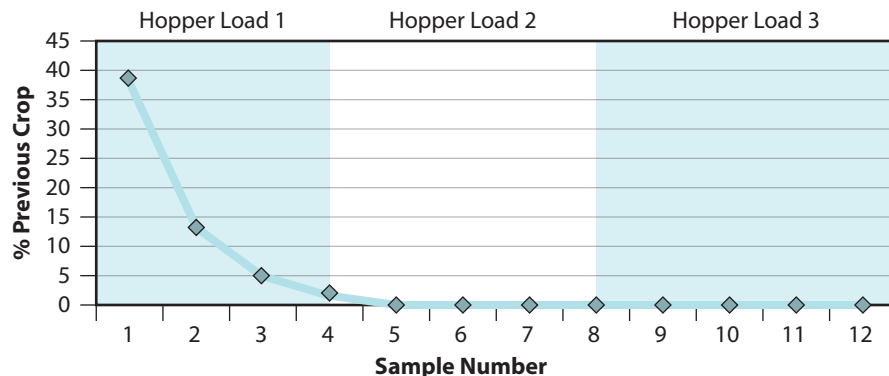

Figure 1. Grain purity from combine hopper samples during harvest

percent moisture or above. Then match harvest to the amount of grain that can be dried and cooled in 24 hours.

Border rows of organic corn should be harvested first to flush the combine of previously harvested crops. Agricultural engineers at Iowa State University described their results of thoroughly cleaning a conventional combine between fields of identity-preserved (IP) grain. They showed that three combine tank loads were adequate to purge the machine and assure acceptable purity (Figure 1).

An alternate method to assure grain purity between different crops is to thoroughly clean out combines, but this is a time consuming and laborious chore. The same team of agricultural engineers at Iowa State collected data on this task. They recorded the location and amount of residual grain and material other than grain (MOG) found when cleaning two

popular combines (Figure 2). Significant differences were observed in the total amount collected between the two machines and between locations of each unit. Most residual material was found in the rock trap in both combines, followed by the header, grain tank, unload auger and feeder house (Case combine), or the grain tank and header (John Deere). Material in the cleaning area was less than 5 pounds for both machines.

Drying

Field drying is the first step toward sustainable grain crop preservation. Typically, the harvest decision is often made on prevailing weather and crop conditions with the expectation that corn kernels will lose between half and three quarters of a point of moisture on a sunny day in August and September. Thus, corn can dry in the field from 25 to 20 percent moisture in seven to ten days of good
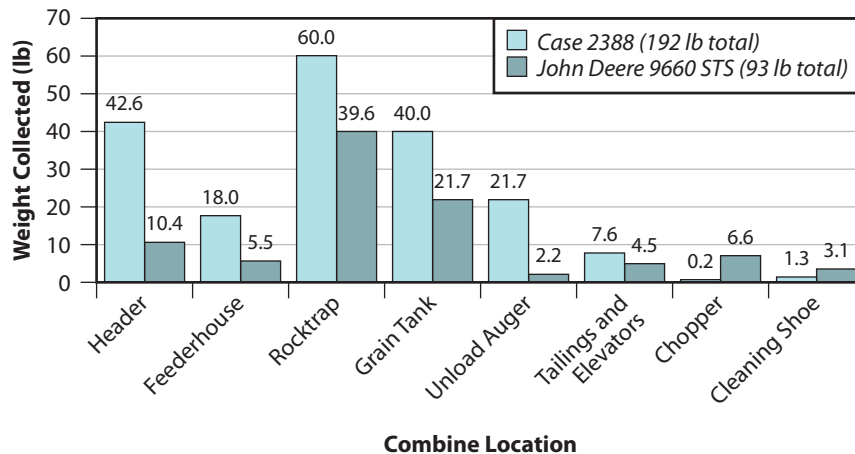

Figure 2. Corn and material other than grain (MOG) collected when cleaning two popular combines in Iowa

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drying weather. Under ideal conditions harvest losses can be manageable and the crop may be dried entirely in the field or harvested at 18 percent and placed in a bin or crib. The value of organic corn motivates producers to carefully consider when to begin harvest and to weigh the economic trade-off between field drying (and associated potential losses) and heated air drying (and cost) when needed.

Ear Corn

Corn that will be harvested and stored on the ear should be allowed to dry in the field as long as weather is favorable and stalk strength is adequate. During field dry-down, be aware that moisture in the cob is much higher than the kernel, as shown in Table 1.

If drying in a typical wooden crib with a rectangular cross-section (8 to 10 feet maximum width) or in a round wire mesh crib (12 to 15 feet max. diameter) harvest should begin when the kernel moisture is no more than 20 percent from fields where insect and mold damage is minimal. During harvest, be sure that husks are removed as much as possible without generating too many loose kernels, and minimize stalk pieces, weed seeds or plant fragments and other foreign material that can interfere with airflow once it is placed in the crib. If field and weather conditions remain favorable, delay harvest until corn kernels dry to 18 percent. Otherwise, if corn is above 20 percent moisture, make arrangements to provide mechanical ventilation in the crib to speed drying and protect the crop from damage.

The rate and extent of drying depends on weather conditions. Kernel moisture will approach the equilibrium levels shown in Table 2 after sufficient exposure to the corresponding environment. Average monthly temperatures in Kentucky during the fall range between 70ºF in September to 50ºF in November, while the average relative humidity will be between 30 percent during a bright sunny day to 90 percent or higher during the night and on cloudy, rainy days.

Crib drying is slower than field drying with the same weather conditions, but kernel moisture will usually reach 15 percent moisture within a few weeks of favorable weather. Once dried to 15

percent or less, mold growth and associated potential mycotoxin production will stop. However, any mycotoxins that are brought in from the field will remain, and managers must guard against conditions that could favor subsequent mold growth during storage.

Shelled Corn

Under ideal conditions cornstalks remain strong and corn is free of insect and mold damage in the field. In this case, harvest can be delayed until kernels dry to 20 percent moisture and shelled corn can be dried without heat at airflow rates of 3 to 2 cubic feet per minute per bushel (cfm/bu) within 8 to 12 days, respectively. Note that this scenario is within the allowable storage time for corn that is less than 70 degrees (Table 3). However, at higher temperatures some spoilage may

occur from mold spores that are inherent on kernel surfaces.

Under normal conditions (some lodging and pest or weather pressure) heated-air dryers may be needed to preserve the crop and should be sized to dry corn to 16 to 17 percent within 24 to 48 hours after harvest. Corn can be cooled in the dryer or transferred hot into storage bins where fans run continuously to cool it to the average outdoor temperature within 30 hours (0.5 cfm/hot bu). Under stressful conditions corn should be dried with heated air to 16 percent and cooled within 24 hours after harvest. For bin dryers, grain depth can be reduced to increase airflow for faster drying, or more bins can be converted to dryers to increase capacity when needed.

Loewer et al. observed from a collection of field studies in the Midwest

Table 1. Moisture content of corn kernels and cobs during field dry-down

Kernel moisture %	10	13	15	20	25	30
Cob moisture %	9	13	18	33	45	52

Source: American Society of Agricultural and Biological Engineers (ASABE).

Table 2. Equilibrium moisture contents of yellow corn at typical temperature and relative humidity levels observed during harvest in Kentucky.

Temp.	Relative Humidity, %							
	30	40	50	60	65	70	80	90
40	9.9	11.5	12.9	14.5	15.3	16.2	18.3	21.3
50	9.4	10.9	12.3	13.8	14.7	15.5	17.6	20.5
60	8.9	10.3	11.8	13.3	14.1	15.0	17.0	19.9
70	8.4	9.9	11.3	12.8	13.6	14.4	16.4	19.4
80	8.0	9.4	10.8	12.3	13.1	14.0	16.0	18.8

Source: ASABE.

Table 3. Allowable storage time (days) for aerated shelled corn before losing 0.5% dry matter

Temp.	Corn Moisture, %wb						
F	16	18	20	22	24	26	28
35	1144	437	216	128	86	63	50
40	763	291	144	85	57	42	33
45	509	194	96	57	38	28	22
50	339	130	64	38	26	19	15
55	226	86	43	25	17	13	10
60	151	58	29	17	11	8	7
65	113	43	22	13	9	7	5
70	85	32	16	10	7	5	4
75	63	24	12	8	5	4	3
80	47	18	9	6	4	3	3
85	35	14	7	5	3	3	2
90	26	10	5	4	3	2	2

Source: ASABE Standard D535.

Table 4. Cost of harvest losses (5%) and heated air drying (energy only and dryer ownership) at different yield levels for organic corn valued at $10.00/bu with equivalent LP gas price of $1.50/gallon

Harvest loss: 5.0%							
Standing Yield (bu/ac)	Harvest Loss (bu/ac)	Harvested Yield (bu/ac)	Value of Losses ($/ac)	Drying Cost ($/ac)		Return to Drying ($/ac)	
				Energy	Total	Energy	Total
100	5.0	95.0	50	21	26	29	24
150	7.5	142.5	75	32	39	43	36
200	10.0	190.0	100	42	51	57	48

that harvest losses for corn are generally lowest when grain moisture is between 24 and 28 percent. However, grain at this high moisture level should be dried with heated air to below 17 percent moisture within 24 to 48 hours after harvest to arrest mold growth and potential mycotoxin development. Otherwise, it should be left in the field for further drying, but yield losses from, weather damage, stalk deterioration and/or wildlife may be costly.

To weigh the trade-offs of drying costs with field losses, a spreadsheet has been put together to help producers make an informed decision for their operation. The situation is highly impacted by corn and energy prices, which can change quickly, so producers put in their selling price for corn, anticipated level of harvest losses for the season, yield potential, and price of LP gas (or equivalent price for natural gas). An example at three yield levels for organic corn at $10 per bushel, harvest losses at 5 percent, and LP gas at $1.50 per gallon is shown in Table 4. For 150 bushels per acre, the value of corn left in the field is $75, the cost of drying energy is $32, and the cost to own and operate the dryer is $39 per acre. Thus, the returns to the organic corn enterprise are $43 if the dryer has already been paid for or $36 per acre if not. This spreadsheet is available on the BAE website so farmers can enter their own harvest losses and prices for grain and energy (http://www.bae.uky.edu/ext/Grain_Storage/calculators.shtm).

Consider cleaning corn after drying as it is transferred to storage bins. This practice will remove trash and broken kernels, which can interfere with uniform airflow. Mold-free material removed by the cleaner can be fed or sold to organic livestock farms. If mold is present, it should be tested for mycotoxins prior

to feeding to determine if it is suitable and, if so, which animals can tolerate the levels that are present.

Corn should be thoroughly cooled below 60°F as soon after drying as possible to reduce mold and insect activity and further maintain storage life. It is not too unusual for nighttime temperatures to fall in this range during September in Kentucky, so farmers should look for these opportunities to run aeration fans and begin the cooling process. Temperature cables are recommended in all bins of high value grains and can be used to track drying or cooling fronts easily and remotely.

Storage

The allowable storage time for shelled corn with aeration before losing 0.5 percent of dry matter is shown in Table 3. Note that corn above 20 percent moisture has a relatively short storage life during late summer conditions in Kentucky when average daily temperatures are near 70 degrees. Also note that a 10-degree reduction in grain temperature nearly doubles the storage life for most conditions. For these reasons, natural air drying is more limited in Kentucky than in production regions to our north where cooler temperatures prevail.

Safe storage of all grains is based on the fundamental relationship of moisture exchange between individual seeds and the surrounding air, which is driven by the vapor pressure gradient (from a high concentration to a lower concentration). For this reason, when wet grain is placed in a dry environment moisture is transferred from the grain to the air until the gradient is zero (equilibrium condition). The equilibrium moisture content for corn at different temperatures and relative humidity conditions is shown in Table 2; use these values to estimate

the extent of drying when exposed to a given condition in the field or storage bin for a sufficient amount of time, which largely depends on temperature. Keep in mind that *Aspergillus flavus*, the fungus that produces aflatoxin, prefers conditions above 80°F and 80 percent relative humidity, so avoid corn moistures that are found in this range after harvest. Research at the University of Kentucky has shown that under optimal conditions, aflatoxin levels can double in six to ten hours, so quickly drying and cooling mold-damaged corn is especially critical to minimize losses in grain quality.

Most all mold species prefer a warm, humid environment (relative humidity above 65%) and grain near the wall of storage bins in Kentucky will be near the average outside monthly temperature (80°F). Primarily for these reasons, yellow corn that will be held during the summer months in Kentucky should be dried to at least 13 percent moisture so that the surrounding air will remain dry enough to retard mold growth (<65% in Table 2). Organic corn that will be sold before spring and is in good condition at harvest can be dried to 15 percent moisture, cooled to 60°F within a few weeks, then to 45°F within a few months to establish a safe storage environment (humidity <65%).

Loading, aeration and **monitoring** (LAM) are remaining watchwords during storage of all grains. Dry, clean corn will store well if storage conditions throughout the grain mass remain stable. After **loading** a bin, a grain peak will form, which creates deeper grain in the center and more resistance to airflow than the grain along the wall. Thus, the first step after loading a bin is to remove the center peak and either level the grain by hand (preferred method) or form an inverted cone (compromise method) to provide more uniform airflow throughout the

bin. If leveling by hand with shovels, be sure to lock out and tag out the switch on the unloading auger motor before entering the bin. It is also recommended to wear a climbing harness and dust respirator for personal protection when working in a confined space.

To further preserve dry corn, it should be cooled along with the outside air in the fall. In Kentucky, average monthly temperatures for September, October, November and December are 70, 60, 47 and 37, respectively. Thus, **aeration** fans should be operated once a month beginning in October to cool stored grain to within 5 to 10 degrees of these levels. In addition to temperature cables, aeration controllers are also suggested so fans can be operated automatically (often when managers are away or asleep) and adjusted to match average outside temperatures.

Cover fan openings with a tarp, heavy plastic or sheet metal after thoroughly cooling the grain to prevent unwanted, wind-driven air movement through the bin. Remember that grain is a good insulator, so once cooled it will remain stable. However, it's a good idea to look inside the bin once every two weeks during fall aeration and once a month during the winter to check for any leaks or moisture build-up that can lead to hotspots and spoilage.

Monitoring grain is the last SLAM watchword and the last line of defense for protecting grain quality during storage. Handheld moisture meters, temperature probes, grain sampling tubes (triers), and insect pit, dome or hanging traps are all used together to monitor grain condition and mold or insect activity. This approach requires that someone enter the bin to collect grain samples, which are usually transferred to a farm shop or office where they're sieved, inspected and analyzed for changes in quality. Keep in mind that although temperature cables remotely monitor conditions deep in the bin where handheld probes cannot reach, and because grain is such a good insulator, hotspots far from temperature sensors go undetected. This underscores the need for going to the trouble of climbing on top of the bin and checking grain condition, especially for high value crops such as organic food- and feed-grade corn.
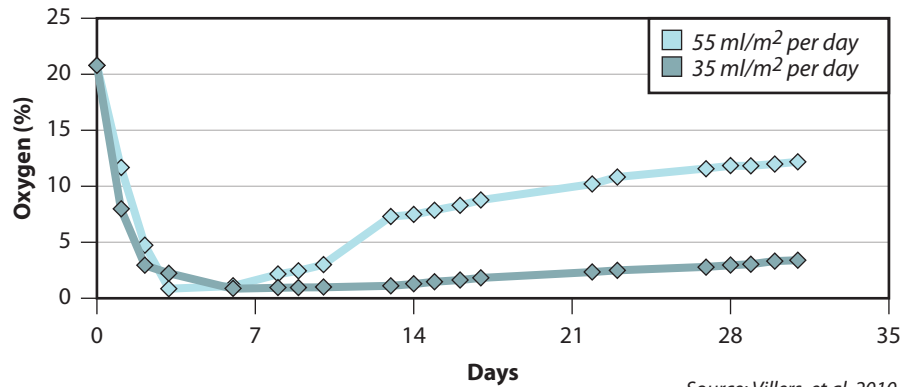
Figure 3. Changes in oxygen levels with time (days) in storage for hermetic bags with different permeability ratings

Stored grain insects often become active in the top of the bin following spring warm up when temperatures in the top grain surface become favorable for their activity (>60º F). Thus, pit traps can be used to monitoring insect activity and should be checked every week after mid-March.

Damaged corn should be checked once a week until grain temperature and other conditions in the bin or crib are stable. Cloth respirators (minimal protection) or half-face respirators (better protection) should be worn to protect lungs from exposure to dust and mold spores during inspections. Look for any changes in the grain both on the surface and below the surface. If conditions don't change after three consecutive inspections and temperatures below the surface are 50 degrees or lower (usually by mid-November), inspect every two weeks. Reduce inspections to once a month after temperatures throughout the bulk fall below 40 degrees (mid-December). If small hot spots develop, carefully open the pile to fully expose the area for rapid cooling. If large hot spots develop, move a portion of the pile to another location to spread it out and reduce further heating. If extensive mold damage is found during storage, mycotoxin levels may increase so corn should be checked before feeding. See *Aflatoxins in Corn* (ID-59) for guidelines on the levels of aflatoxins for different animals, and check with an animal scientist for specific questions on feeding once the level of contamination is known.

Hermetic Storage

Hermetic storage is an ancient storage method that has been used recently to store organic corn in developing countries, even in tropical environments, and is successful as long as the container remains airtight. This method works on the principal that the inherent microbial and/or insect populations that are present on seed surfaces at harvest consume oxygen and produce carbon dioxide during respiration. This progresses fairly quickly even at moderate temperatures (Figure 3) and the available oxygen is depleted, which basically causes the organisms to suffocate. Hermetic storage (commonly called "grain bags") has been widely used to store conventional corn and soybeans in Argentina, Africa, India and many other countries and to a limited degree for conventional corn storage in the U.S., including Kentucky. However, the wildlife population renders this storage method undesirable in large open areas where little protection can be provided. In contrast, hermetic storage can be an affordable and effective storage option for organic corn on a farm or warehouse scale.

Carbon Dioxide

A variation to hermetic storage is to pump carbon dioxide directly into airtight bins to kill any insects that might destroy the crop. In order to effectively do this, the levels of carbon dioxide in an enclosed space must increase from the normal .0004 percent to 40 to 60 percent. These levels can be extremely dangerous during the fumigation process

if the proper protection is not worn. One should not enter a storage area which may be over 5 percent carbon dioxide without a self-contained breathing apparatus (SCBA). Canister masks will NOT protect workers from lethal levels of carbon dioxide.

Advantages of this type of storage include no residue on the corn afterwards, although there is debate as to whether or not the flavor may change slightly. This system works well for facilities that can support closed-loop fumigation as well as afford the expenses that go into assuring the storage units are in fact airtight. It is also important to note when purchasing carbon dioxide that the laws for its usage vary by state. In some states it may be considered a restricted use pesticide, which means it is only registered for use on certain crops at specific locations.

Thermal Treatment

Residual insect populations in aeration ducts and the plenum area of grain bins can be controlled by holding high temperatures (>120ºF) in these areas for a sufficient amount of time (>30 min). This technique has been used on both small (lab) scale and large scale (in flour mills) as an alternative to chemical fumigation. Insects will not develop a resistance to this treatment, and workers don't have the risk of applying fumigant tablets or pellets in an area where moisture could be present. However, considerable labor may be required to remove perforated duct covers or floor sections to have access to the area(s) needing treatment.

Ozonation

Closed-loop ozone generators have been used to displace oxygen in stored grain, in part as an alternative to chemical fumigation for controlling insect populations. Successful field trials with organic corn, popcorn, and conventional corn were conducted by scientists at Purdue University in 2005. They found that an ozone concentration of 50 ppm held for three days effectively controlled maize weevil, red flour beetle and larvae of Indian meal moth that were placed 0.6 m below the grain surface and in the plenum area. Moreover, the milling quality of organic corn and popping volume of popcorn were not affected.

Biological Controls

Beneficial insects have been studied as an alternative to chemical use for stored grain in the U.S. and Europe. Entomologists have established which predators control specific insects, the mode of host recognition, environmental conditions preferred, their application rate and interval, and physical range of effectiveness within the grain mass. In addition to avoiding chemical residues and providing a safe working environment, other advantages include the avoidance of chemical resistance by the target pest and lower cost.

Safety

Grain handling equipment inherently generates considerable levels of dust in the immediate areas where grain is transferred. Specific locations on the farm are in the grain receiving area, as grain moves between conveyors, is moved out of or into trucks or gravity wagons, and is dropped into feed and storage bins. Workers often need to be near these areas to monitor flow, clean spills, prepare feed or perform other chores. Repeated exposure to grain dust at low levels can irritate breathing passages and at high levels can create an asthma-like reaction. For these reasons, workers should protect themselves from dust exposure at all times. Unfortunately, this is rarely practiced, but the effects of dust exposure are cumulative and can have life changing effects on workers who may have or may develop an allergic reaction to dust.

Resources

Organic Farm Planning under the USDA's National Organic Program

Kentucky Department of Agriculture Organic Marketing Program. http://www.kyagr.com/marketing/organic-marketing.html.

Organic Materials Review Institute. https://www.omri.org/.

USDA National Organic Program. http://www.ams.usda.gov/AMSv1.0/nop.

USDA National Organic Program. About the National List. http://www.ams.usda.gov/AMSv1.0/NOPPetitioned-SubstancesDatabase.

The Organic Corn Marketplace

AMS National Organic Grain and Feed-stuffs Report. Bi-weekly price report for nine grain and bean commodities as well as alfalfa prices by quality grade. http://www.ams.usda.gov/mnreports/lsbnof.pdf.

Mercaris. Up-to-date, accurate information on organic and non-GMO markets. Online trading platform (currently being developed) allows buyers and sellers to meet and trade physical commodities. Fee-based subscription service. http://www.mercariscompany.com/.

Office of Inspector General, USDA, Organic Crops Audit Report. The complete report on the evaluation of the RMA and how organically produced crops were managed within the Federal Crop Insurance Program. http://www.usda.gov/oig/webdocs/05601-0006-KC.pdf.

RMA Price Discovery (Beta). Individual, projected, and historical prices, and projected and historical price volatility. http://prodwebnlb.rma.usda.gov/apps/PriceDiscovery.

RMA Questions and Answers Page, 2013 Crop Insurance Changes. Detailed discussion and examples on how the new organic T-yield incorporation will affect organic and transitional producers via lower-cost premiums. http://www.rma.usda.gov/pubs/rme/2013q&a.pdf.

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The Profitability of Transitioning to Organic Grain Crops in Indiana. http://www.agecon.purdue.edu/extension/pubs/paer/2010/february/alexander.asp

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