Brix manipulation for reducing pest pressure: Literature Review

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EXECUTIVE SUMMARY

In the past several years a number of products have come on the market claiming to raise plant Brix levels. In addition to the nutritional/taste benefits of "high-Brix" crops one of the reported advantages of raising Brix levels is fewer pests and diseases (e.g. http://www.goodearthgardenschool.com/gegs/archives/2009/09_June_15_High_Brix_gardens.pdf). The objective of this study was to review the scientific evidence regarding high-Brix crops and pest levels. For our review we focused on insect pests. In our review we found no studies that directly studied the impact of manipulating plant Brix level on insect levels. Only one study, published in a non-peer reviewed report, examined the impact of Brix on pest levels in the field, and found no relationship. Similarly, in our evaluation of Brix manipulations on potatoes we have found no consistent relationship between Brix levels and aphid counts.

Fundamental to the idea of high-Brix crops is the optimal balance of key nutrients via foliar and soil feeding. We examined the impact of several of these key nutrients on pest pressure and did find that this was an area of active research. The impact of nitrogen on plant-feeding insects is well known – excess nitrogen leads to increase insect populations. For the other nutrients unfortunately the relationship between nutrient levels and pest incidence is less clear. For example, phosphorous, calcium and magnesium levels have all been shown to either increase or decrease insect feeding as levels of the nutrients are manipulated. Potassium on the other hand seems to have a consistent trend towards lower pest pressure with increasing potassium input. Several studies have proposed that examining individual nutrients is too simplistic and that it is the combined impact of nutrients that affects insect feeding. This type of idea is consistent with the high-Brix concept of optimal mineral balance. We also interviewed two American practioneers of high-Brix crops who were able to provide details regarding their specific management programs and anecdotal evidence of the impact of increasing foliar Brix levels on pest pressure.

In summary, while our review did not find any support for the idea that high-Brix crops lead to less pest pressure, we did find that many of the individual nutrients manipulated in "high-Brix" programs have been shown to have impacts on pest levels. Although there is support in the literature that a balance of nutrients is necessary to minimize pest pressure, a Brix-reading on its own is likely too simplistic to fully encompass the complex mechanisms mediating nutrient-plant-insect interactions. Growers are encouraged to conduct their own on-farm trials if using high-Brix products – a suggested list of considerations for such a trial is included in the report.

INTRODUCTION AND OBJECTIVE

Brix is a measure of soluble solids in plant sap. Anecdotal reports suggest that manipulating nutrition status to produce "high-Brix crops" results in lower pest pressure on crops (see http://www.westonaprice. org/farming/nutrient-dense.html). The theory behind high-Brix crops is that plants with a 12-point or higher refractometer reading have a high nutrient content and are attacked by fewer pests. Accordingly, high-Brix readings can be produced by adding specific nutrients to the soil prior to planting, and by maintaining sap pH of 6.4 throughout the season through foliar application of Ca, Mg, K, or Na to raise pH, or phosphates or sulfates to lower pH (http://www.crossroads.ws/ CRActive/ PikeAg.htm).

> "**Brix mix -** A fertilizer formulated to increase the brix (sugar content) of growing vegetables, trees and vines, flowers, herbs, and ornamental crops. By raising the brix levels in plants, a farmer can increase yields and reduce insect and fungus attacks. Maintaining a high brix level helps the crop deal with adverse climactic conditions that can cause stress, and thus a lower yield. The brix scale, which represents the percentage of sugar by weight in a solution, was invented in the late 1800s by Austrian scientist Adolph F. Brix." *From the Earthbound Organic website http://www.ebfarm.com/WhyOrganic/library/Glossary.aspx*

As the quote above from Earthbound Farms indicates the idea of manipulating Brix to achieve better pest control is well known among organic growers. However, there has been recent interest in this concept among BC growers, in part because products are now on the market claiming to promote high-Brix readings in crops. The objective of this project is to review the scientific literature (Part I) on the impact of Brix (or nutrient) manipulation on plants and their pests. For this review we focused on insect pests. In addition to a literature review we also interviewed researchers and practitioners (Part II) working in the field of plant nutrition/health and pest response, to determine their experience with the high-Brix approach to crop protection. This review concludes with a summary discussion of our findings.

PART I: LITERATURE REVIEW

1.0 Methods

To conduct the first part of the review, scientific literature was searched systematically using three article databases, Agricola, Biological and Agricultural Index Plus, and Web of Science. A sample of search terms and resulting number of articles is listed in Table 1.

Table 1. The number of scientific articles resulting from entering search terms in Agricola, Biological and Agricultural Index Plus, and Web of Science search engines. Numbers in brackets indicate the number of articles relevant to this study in cases where not all articles were applicable.

Search Terms	**Agricola**	**Biological and Agricultural Index Plus**	**Web of Science**
Brix and Insect	12 (3)	0	0
Brix and Insect and Soil	0	0	0
Brix and Arthropod	0	0	0
Brix and Hemiptera	1 (1)	0	0
Brix and Homoptera	1 (1)	0	0
Brix and Aphid	1 (0)	0	0
Brix and Whitefly	1 (0)	0	0
Brix and Feeding	4 (1)	1 (0)	0
Host plant and Homoptera and Soil	10	1	0
Host plant and Homoptera and Fertilizer	10	10	0
Soil fertility management and Host plant and Homoptera	0	0	1
Soil fertility management and Host plant and Insect	0	2	10
Soil management and Host plant and Insect	3 (2)	10	49
Host plant quality and Fecundity and Insect	13	11	0
Host plant quality and Fecundity and Insect (plant-insect relations)	4	0	0
Phloem and Homoptera and Nutrient	6	0	0
Phloem and Homoptera and Mineral	0	0	0
Phloem and Homoptera and Fertilizer	2	0	0
Osmotic and Homoptera and Fertilizer	0	0	0
Osmotic and Homoptera and Soil	0	0	0
Osmotic and Homoptera and Soil Fertility	0	0	0
Chemical constituents of plants and Homoptera and Soil	2	0	0
Chemical constituents of plants and Homoptera and Fertilizer	3	0	0
Chemical constituents of plants and Homoptera	46	0	0
Whitefly and fertilizer	13	1	0
Aphid and fertilizer	58	19	0
Hemiptera and Fertilization	6	1	0
Hemiptera and Plant fertilization	0	0	0
Magnesium and Insect and Host plant	2 (1)	0	10

Table 1 illustrates that very few (4) studies were found studying the relationship between plant Brix levels and insect feeding. The vast majority of studies examined plant chemistry in conjunction with insect feeding (chemical constituents of plants and Homoptera), or the impact of fertilizers or specific nutrients on insects (soil management and host plant and insect; aphid and fertilizer; magnesium and insect and host plant). Articles about soil fertility fell into two categories; studies that looked at the impact of organic management and amendments, i.e. a multi-nutrient approach, and those that evaluated the impact of specific plant nutrients on insects. This review will first discuss the findings of studies evaluating a multi-nutrient approach. Second the impact of specific nutrients on pest populations will be examined.

2.0 Organic Management and Amendments: Multi-nutrient Approach

From our review of the literature we found two approaches to amending multiple nutrients simultaneously for improved plant performance: Brix and mineral balance hypothesis.

2.1 Brix levels and insect pests

Four studies were found that studied Brix levels in conjunction with insect levels. Three of the four studies examined the impact of feeding damage by sucking insect pests (Homoptera) on Brix levels, i.e. the plants response to insect feeding (Madaleno *et al.*, 2008; Jones *et al.*, 1998; Mercader and Isaacs, 2004). The fourth study (Mayse 1996) examined insect response to plant Brix levels, consistent with the objectives of this study. Working in grapes Mayse (1996) examined the relationship between foliar Brix levels and leafhopper (*Erythroneura* spp.) counts. Samples were taken from five organic and three conventional vineyards from June to October for two years, measuring leaf Brix and leafhopper populations. Comparisons were made between leaf blade vs. petiole samples, leaf age, field location, and impact of time of day on Brix readings and leafhopper counts. Despite such attention to detail, their findings did not show any relationship between plant-Brix level and pest populations in either the organic or conventional field sites. In six of the eight vineyard sites examined, leafhopper populations either went up or did not respond in a predictable manner as leaf Brix readings went up (Mayse, 1996). This is the opposite response to what is claimed in the high-Brix literature – as Brix goes up pests go down. However, in a later interview Mayse suggests that the relationships between grapevine nutrition status and populations of leafhoppers and other pests may be more complex and involve more factors than can be predicted by Brix levels alone (Mayse in Anonymous, 1997).

A preliminary study of aphid populations on potato leaves yielded similar results to Mayse (1996) (E. S. Cropconsult, unpublished data). We sampled leaf Brix, and aphids associated with the sampled leaf, weekly from July to August in 11 organic potato fields in 2008 and 2009. We compared Brix and aphid levels on new vs. older leaves, three different potato varieties, and by field, as well as changes with crop age. In July we found a weak to moderate relationship between leaf Brix and aphid populations in 6 of the 11 fields, with 12-31% of variation in aphid counts being explained by Brix levels (Table 2). In the remaining 5 fields the relationship was negligible, with the co-efficient of variation (R^2) ranging from 0-9%. The relationship was much weaker in August, with 7 of the 11 fields having less than 2% of variation in aphid counts explained by Brix. However it is interesting to note that in 11 of the 12 fields aphid counts were either neutral to or went down with increasing Brix level, and in only one case did aphid populations go up with increasing Brix. This would suggest that there may be some association between components of plant sap and insect feeding, however as suggested by Mayse (1996) Brix levels may be too simple a measurement to explain or predict the relationship between insect feeding and plant nutrient status.

Table 2. Relationship between Brix score and aphid density. Correlation coefficients closer to 1.0 have stronger relationships.

Variety	Field	Correlation co-efficient (July & August)	Correlation coefficient (July only)	Correlation coefficient (August only)
Yukon Gold	Blair SW	0.065	0.13	0.0035
	Blair NE	0.021	0.16	0.017
	Home	0.055	0.08	0.089
	Woods	N/A	0.311	N/A
Gem Russet	Trim	0.0041	0.096	0.011
	Bhullar E	0.017	No aphids	0.024
	Manning N	0.00006	0.086	0.0023
	Dawson NW	0.06	0.12	0.02
Redsen	Tilbury 6	0.0012	0.19*	0.032
	Manning S	0.0153	0.082	0.0071
	Homestead	0.0002	0.221	0.0004

* Correlation after removal of a single outlier.

2.2 Mineral Balance Hypothesis

Numerous studies have examined the impact of organic management or amendments as part of a holistic approach to manage pests with all of these studies examining soil amendments as the route to optimizing plant health. Examples of studies that demonstrate lower pest pressure on crops grown in soil with organic amendments include those using waste vermicompost (Arancon *et al.*, 2007), raw cow manure mixed with sawdust (Alyokhin *et al.*, 2005), and fresh or composted dairy cow manure (Phelan *et al.*, 1996). In their work with European corn borer Phelan *et al.* (1996) determined that growing corn in organically farmed soil led to less corn borer egg-laying than in corn grown in conventionally managed soil (Phelan *et al.*, 1995). From this result they generated the mineral balance hypothesis - organically managed soil supports better plant health through buffering soil pH, moisture, and mineral nutrients (Phelan *et al.*, 1995). This hypothesis gained further support through work with Colorado potato beetle (Alyokhin *et al.*, 2005). Manure application decreased beetle density in plots, and 40-57% of the variation in beetle density was accounted for by leaf mineral concentrations (Alyokhin *et al.*, 2005). Leaf boron in particular was 2X higher in plots treated with manure than in plots treated with conventional fertilizer (Alyokhin *et al.*, 2005). In none of these studies, however, was Brix level included as a measure of plant response to different amendments.

The mineral balance hypothesis is similar to the high-Brix approach in that the goal is to obtain an optimal balance of nutrients in the plant and thus optimize plant yield and reduce pest pressure. However, an important difference between the mineral balance hypothesis and the high-Brix approach is that the Brix approach uses a combination of both soil amendments and foliar feeding to obtain optimal plant nutrient status. In contrast, the mineral balance approach the focus is on amending the soil in order to achieve a more sustained and optimal release of nutrients for plants to subsequently utilize (Phelan personal communication). The mineral balance hypothesis does not appear to hold however in all studies examining organic soil amendments, e.g. Boiteaue *et al.* (2008) and Karungi *et al.* (2006a and 2006b) both found higher pest levels on crops grown in soil with organic amendments (poultry fertilizer and composted kitchen wastes) than chemical fertilizers.

3.0 <u>Impact of Individual Nutrients on Insect Feeding</u>

The nutrients commonly managed in a Brix program are phosphorous (P), potash or potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). In Brix program inputs of ammonium- and nitrate-form nitrogen (N) are also carefully managed. However a large body of research has been generated on the effects of nitrogen fertilizer on insect populations, and it is generally accepted that increasing plant tissue nitrogen levels increases pest pressure (e.g. Jahn *et al.*, 2005; Cisneros and Godfrey, 2001; Jauset *et al.*, 2000), so nitrogen will not be covered in this review. Instead we will focus on studies of phosphorous, potassium, magnesium, and calcium as these are the most commonly studied nutrients in terms of impact on insect pests and the nutrients commonly manipulated in order to produce high-Brix crops. Results of the review of these four nutrients are summarized in Table 3.

3.1 Phosphorous and Potassium

Phosphorous (P) and potassium (K) are key elements in traditional fertilizers and are known to be major contributors of plant health. The effects of these inputs on insect pests have been shown to be variable (Table 2). In the case of whitefly feeding on sweet potato, Skinner and Cohen (1994) found that as P levels decreased, whitefly oviposition on sweet potato leaves decreased as well. In petunia Jansson and Ekbom (2002) found that as P fertilizer levels increased, aphid (*Macrosiphum euphorbiae*) development time shortened, and the adult lifespan and number of offspring increased. Both of these studies (Skinner and Cohen, 1994; Jansson and Ekbom 2002) suggest that higher phosphorous levels are associated with higher insect levels. However studies of the woolly adelgid (*Adelges tsugae*) on hemlock (Pontius *et al.*, 2006), and potato leafminer *Liriomyza trifolii* (Facknath and Lalljee, 2005) show the opposite. Hemlock species associated with low colonization success by *A. tsugae* had higher levels of foliar P (Pontius *et al.*, 2006). Similarly, high foliar P levels lowered the number of *L. trifolii* feeding punctures on potato leaves, and resulted in smaller pupae and adults (Facknath and Lalljee, 2005).

For potassium the majority of studies demonstrate that increasing foliar K levels can reduce insect pressure (Facknath and Lalljee, 2005; Myers *et al.*, 2005; Myers and Gratton, 2006; Walter and DiFonzo, 2007). This finding is in agreement with a compilation of studies by the International Potash Institute (cited in Amtmann *et al.*, 2008). In 63% of the studies, higher K levels were associated with lower levels of insect and mite infestations. For example, for leafminer *Liriomyza trifolii* in potato, increases in foliar K due to fertilizer application lowered the number of feeding punctures, survival, and size of pupae and adults (Facknath and Lalljee, 2005). Myers *et al*. (2005) found that the soybean aphid produced more nymphs and had higher rates of population increase on field-collected leaves showing K deficiency symptoms than on healthy leaves. In a follow-up field study these authors found that aphid population growth rate was negatively correlated with foliar K, i.e. as leaf K increased, soybean aphid population growth decreased (Myers and Gratton, 2006). Plants receiving the lowest K fertilizer rate showing a 60% higher *A. glycines* net reproductive rate, and nearly double the peak aphid abundance compared with medium and high K plots (Myers and Gratton, 2006). A study by Walter and DiFonzo (2007) paired K-deficient and K-sufficient sampling sites and compared aphid population on plants. Under high aphid pressure, *A. glycines* density was 50% higher in K-deficient areas, whereas there was no difference under low aphid pressure (Walter and DiFonzo, 2007). In a K-deficient field, plants that did not receive K fertilizer had more than 3x the number of aphids by the end of the study (Walter and DiFonzo, 2007). In addition, aphids produced nymphs at an earlier age than in fertilized plots (Walter and DiFonzo, 2007).

Amtmann *et al.* (2008) provide a potential mechanism to explain the relationship between K deficiency and increased insect attack. K deficiency results in reduced synthesis of proteins, starch, and cellulose, and increased accumulation of lower molecular weight compounds such as amino acids, nitrate, soluble sugars, and organic acids. These lower weight molecular compounds are more easily utilized as nutrient sources by sucking insects. So in other words, K deficiency on it's own may not correlate with higher insect attack, but the subsequent impact of K deficiency on plants, makes plants more readily attacked by sucking insects. Low K fertility was associated with high foliar levels of the amino acid serine and higher aphid infestations (Walter and DiFonzo, 2007).

3.2 Magnesium (Mg)

The impact of soil or foliar Mg on insect damage or population growth has been shown to have either a positive or neutral (no response) effect on insect performance (Table 3). Studies conducted with crop wastes found that soil Mg was significantly higher in plots amended with crop wastes than conventional NPK plots, and that soybean aphid infestation levels on bean plants was also significantly higher (Karungi *et al.*, 2006). Higher levels of Mg have also been shown to favor reproduction and shortened development time for silkworm, and increased oviposition for adelgids (Amwack and Leather, 2002). In contrast, a study with raw cow manure and sawdust amendments found that leaf Mg levels were significantly lower in manure + sawdust plots than synthetic fertilizer plots, however Colorado potato beetle populations were not significantly affected by Mg status – neutral effect (Alyokhin *et al.*, 2005).

3.3 Calcium (Ca)

In studies of hemlock species showing varying levels of resistance to *Adelges tsugae* infestations (Pontius *et al.*, 2006), foliar Ca levels explained 23% of the variability in infestation levels; species with naturally higher foliar Ca were associated with lower insect infestations. Similarly, calcium levels on the surface of aphid-resistant *Nicotiana* spp. (tobacco) leaves were 10-100X higher than those on leaves of susceptible species (Harada *et al.*, 1996).

In studies with organic amendments, however, the situation was similar to Mg, i.e. calcium had either a positive or neutral effect on insect performance. Bean plots amended with crop wastes had higher soil Ca levels and higher aphid infestations (Karungi *et al.*, 2006), while potato plots amended with cow manure had significantly lower foliar Ca levels, but no significant correlation between Ca and beetle densities (Alyokhin *et al.*, 2005). Studies summarized by Amwack and Leather (2002) similarly found a positive effect of Ca on reproduction and development time for silkworm *Bombyx mori* (Thangavelu and Bania, 1990), or a neutral effect for Ca on Western spruce budworm *Choristoneura occidentalis* (Clancy and King, 1993).

Table 3. Summary of investigations into the role of soil fertility and/or foliar nutrient content in insect infestations.

	Negative impact on pest population (i.e. nutrient level goes up, pest level goes down)	**Positive impact on pest population** (i.e. nutrient level goes up, pest level goes up)	**Neutral effect on pest population**
P	*Adelges tsugae* on hemlock (Pontius *et al.*, 2006)	Whitefly on sweet potato (Skinner and Cohen, 1994)	
P	*Liriomyza trifolii* on potato (Facknath and Lalljee, 2005)	*Macrosiphum euphorbiae* on petunia (Jansson and Ekbom, 2002)	
K	*Aphis glycines* in soybean (Myers *et al.*, 2005)	*Macrosiphum euphorbiae* on petunia (Jansson and Ekbom, 2002)	Yellow sugarcane aphid on kiyuku grass (Miyasaka *et al.*, 2007)
K	*Aphis glycines* in soybean (Myers and Gratton, 2006)	*Adelges tsugae* on hemlock (Pontius *et al.*, 2006)	
K	*Aphis glycines* in soybean (Walter and DiFonzo, 2007)		
Mg	*Choristoneura occidentalis* (Western spruce budworm) (Clancy and King, 1993 in Amwack and Leather, 2002)	*Aphis fabae* in bean (Karungi *et al.*, 2006)	*Leptinotarsa decemlineata* in potato (Alyokhin *et al.*, 2005)
Mg		*Bombyx mori* (silkworm) (Thangavelu and Bania, 1990 in Amwack and Leather, 2002)	Elm leaf beetle in elm (Bosu and Wagner, 2007)
Mg		Galling adelgid (McKinnon *et al.*, 1999 in Amwack and Leather, 2002)	
Ca	*Adelges tsugae* in hemlock (Pontius *et al.*, 2006)	*Aphis fabae* in bean (Karungi *et al.*, 2006)	*Leptinotarsa decemlineata* in potato (Alyokhin *et al.*, 2005)
Ca	*Myzus persicae* in tobacco (Harada *et al.*, 1996)	*Bombyx mori* (silkworm) (Thangavelu and Bania, 1990 in Amwack and Leather, 2002)	*Choristoneura occidentalis* (Western spruce budworm) (Clancy and King, 1993 in Amwack and Leather, 2002)

3.4 A combination effect?

While there is a trend towards lower pest pressure with adequate or higher K levels, and lower Mg levels, overall there is no consensus from scientific studies as to whether a specific nutrient has a positive, negative, or neutral impact on pests. However a few studies have suggested that it is the combined impact of nutrients that is the critical factor when determining impact on pest levels – a suggestion that is similar to what is proposed by the high-Brix theory. For example, Miyasaka *et al*. (2007) suggested that sugarcane aphid injury was greatest when a large imbalance of foliar N to K existed. Several of the above studies (Facknath and Lalljee, 2005; Pontius *et al.*, 2006; Myers and Gratton, 2006) also found strong associations between foliar P and Mg, foliar N, K, and Ca, and foliar N, P, K, and S, respectively. However, we could not find any studies where the combined impacts of these minerals together on insect pests were examined.

Another explanation of the discrepancies among studies is the role of that many minerals play as components of plant defensive compounds rather than constituents of plant sap (phloem). In some cases, plant defensive compounds may be characteristic of the species of plants being tested. For example, in studies of aphid-resistant tobacco plants the high Ca levels on the leaf surfaces were in the form of the defensive compound $CaCl_2$, which was found toxic to be aphids (Harada *et al.*, 1996). This compound was not present in the susceptible species, and no other Ca or chloride compounds isolated killed or repelled aphids in the study (Harada *et al.*, 1996). So the higher level of Ca associated with aphid resistance was not present in the sap but on the leaf surface. Similarly, *Medicago truncatula* plants showing resistance to feeding by beet armyworm *Spodoptera exigua*, lost this resistance when they were modified to stop producing a layer of calcium oxalate crystals in a sheath around their vascular tissues (i.e. structural location of Ca rather than in the sap), which caused abrasion and wear to *S. exigua* mouthparts (Korth *et al.*, 2006).

Part II: KNOWLEDGE REVIEW

In addition reviewing the scientific literature we also interviewed researchers and practitioners who were identified through their work on the reviewed scientific studies or via the internet (Table 4). All researchers and practitioners were contacted by phone, but only Dr. Phelan, Dr. Skow, and Reggie Destree were available for interviewing. Each researcher was asked to summarize their understanding of the concept of high-Brix crops, or associated theories, to provide examples of how a program to manipulate Brix levels could be implemented and to give field examples of the success of the high-Brix approach. Their comments are summarized below.

Table 4. Contacts for Brix or crop nutrients knowledge review.

Contact Person	Company/ Affiliation	Phone/email	Comments
Kip Green	Biologically Integrated Vineyard Systems Project	Phone: 559-866-5632 Email: ktgrnacres@cs.com	-Worked with Dr. Mark Mayse on study of Brix – leafhopper interaction in vineyards
Dr. P. Larry Phelan	Professor of Entomology, Ohio State University	Phone: 330-263-3728 phelan.2@osu.edu	-put forth mineral balance hypothesis, role of organic matter in soil biological buffering
Dr. Dan Skow	Owner,	Phone: 507-235-	-studied under Dr. Reams, who

	International Ag Labs	6909 Fax: 507-235-9155 http://www.aglabs.com/ index.html	developed Brix/insect resistance concepts -do Brix consulting -most widely cited company relating to Brix
Amigo Bob Cantisano	Owner, Organic Ag Advisors; Heaven and Earth Farm	Phone: 530-292-3619 Fax: 530-292-3688 orgamigo@gmail.com	-well-known organic agriculture consultant in California and Western USA -mentioned in Mayse article as putting out high-Brix brochure
Mark Marino	Earthbound Farm	Phone: 831-625-6219, ext 16 http://www.ebfarm.com/ index.aspx	-organic farm that mentions Brix manipulation on website
Reggie Destree	Crop Consultant, Dramm Company's organic fertilizer division	Phone: 608-467-2438 Email: reggieveg@charter.net	-conducted a Brix study on beans and soybeans -also farms

<u>Summary of interview with Larry Phelan (Professor of Entomology, Wooster, Ohio):</u>

Dr. Phelan is a proponent of the mineral balance hypothesis, which is similar in some ways to the concept of high-Brix crops, although the focus is primarily on manipulations to the soil rather than foliar feeding of plants. He suggests that in general mineral balance can be maintained by keeping the carbon:nitrogen (C:N) ratio at about 25:1, although for each crop the ratio is slightly different. At higher carbon levels an active detrital food web is supported, which in turn increases the biological activity of the soil. Greater biological activity in the soil provides, according to Phelan, a slower and more sustained release of N and the other soil nutrients. In addition to regulating the release of nutrients from the soil, in his work Phelan has also shown that soil microbes help "turn-on" plant defensive pathways prior to disease or insect attack. In their work, Phelan's team use standard soil tests to optimize ratios and nutrients. As researchers they use petiole testing to obtain information on plant nutritional status and to make correlations with insect levels, but not for making adjustments via foliar feeding.

Phelan recommends using animal or plant manures to get high carbon and nutrients. Dairy manure is better than other types because it has more minerals and carbon, but Phelan emphasized using locally available manures. As poultry manure is very high in N but low in C, sawdust or straw can be added to it to increase C:N ratio (and other nutrients) and improve biological activity. In his interview, Phelan also stressed the importance of crop rotation and the impact that rotation has on promoting a diverse soil microbial community. Evidence to support the mineral balance theory comes from several systems. For example in corn Phelan showed that fewer corn borer eggs were laid on plants grown in soil that had been managed organically versus corn grown in conventionally managed soil. In tomatoes, egg laying by whiteflies was reduced when plants were fertilized with compost versus ammonium nitrate. Phelan has also examined the impact of different methods of manipulating C:N - adding sugar, straw, sawdust – on soybean yield. While adding sugar significantly increased soil respiration and lowered nitrate levels initially, this effect wore off over time. In contrast adding straw and sawdust had more sustained effect, with N released slowly by microbial community.

Summary of interview with Dan Skow (International Ag Labs, Fairmont, Minnesota):

According to Dan Skow, keeping sap Brix levels up does help to keep insect and disease pressure down but it takes time. He recommends that soil Ca: Mg ratios should be maintained at a 7:1 ratio. At lower soil Ca: Mg ratios plants will need higher N inputs, which will increase insect pressure. Further, Skow suggests that growers keep soil P: K ratio at approximately 1:1. In Skow's experience imbalances towards higher K result in more insects and diseases. Skow also recommends that the soil oxidation reduction potential (ORP) should be between 24-28. Skow recommends an overall nutrient manipulation goal of maintaining plant tissue N, Ca, and K in 1:1:1 ratio throughout season. Skows company offers DVD based courses on their program.

In order to achieve these optimal ratios, Skow uses the following steps:
1) an initial Morgan soil test to make P recommendations (This test is only done at certain labs because it is less efficient than standard soil tests – Skow has the Morgan soil test done by the LaMont Chemical Co.)
2) an initial soil oxidation reduction potential (ORP) test
3) add potassium sulfate, gypsum, limestone, soil inoculants, humates to amend soil initially
4) add P (8-19-3) in seed row with seed, liquid 32 or 28% side-dress, calcium nitrate or liquid sulfur to raise phosphate in plant tissue based on petiole sampling
5) do petiole tests to determine what minerals to foliar feed with (N, Ca, K)

Summary of interview with Reggie Destree (Dramm Company, LaCrosse, Wisconsin)

According to Reggie Destree sap pH in healthy plants should be between 6.2-6.5. However, sap Brix should be in a range specific to the crop (e.g. in potato foliage Brix should be about 5 or higher, in corn should be 8-9). A lower than optimal sap pH indicates, to Destree, that there is a Mg, Ca, K, or Na deficiency. Similarly, a higher than optimal sap pH indicates K or N deficiency. In addition to sap pH and Brix, Destree also measures sap electrical conductivity (EC). Again the optimal EC range is specific to the crop (e.g. in potato foliage should be about 1200, in peas should be 1000-1200). Destree also added that it is important to keep phosphate levels in correct range. In his experience if all of these parameters (sap pH, sap Brix, sap EC and phosphate) are in the correct range there should be few or no aphids. As an example he discussed studies conducted in soybeans and dry beans in Michigan, Illinois and Wisconsin which showed aphid counts of 0-10/plant associated with leaf sap Brix of 9.5 and sap pH of 6.2. In contrast a leaf sap Brix of 5.7 and sap pH of 5.3, was associated with aphid counts of >3500/plant (Destree study cited by Jay Cayman, accessed at: http://list.msu.edu/cgi-bin/wa?A2=ind0703&L

=mich-organic&P=1996).

An example of a potential program for organic potatoes was discussed. Destree suggested the following steps and products, sold by his company, that he would recommend based on testing of soil and/or plant sap. All readings are done using hand-held meters

1) pre-plant incorporation of P, K, Ca, Mg, S, or micronutrients (as needed)
2) Fertilizer liquid “starters” on seed-piece: AER SP-1, Drammatic E (includes kelp, fulvic acid and energizer), AER K-Sulfate
3) N applied with planting (AER AgriBoost O, Dramm ONE)
4) K top- or side-dresses, or foliar applications.

As the plant grows Destree would also recommend organic foliar plant nutrients to maintain plant health and stabilize plant sap pH (examples of products used include Dramm One Plant Food, Neem, AER AgriBoost O, K-Sulfate).

SUMMARY

The objective of this review was to find support for the claim that manipulating plant Brix levels to produce high-Brix crops results in reduced insect pest pressure. A review of the scientific literature did not reveal any studies demonstrating that foliar feeding for manipulating plant Brix levels resulted in lower insect pressure. Only one study, a survey in grapes, examined if there was a relationship between foliar Brix and pests; the study found no relationship. Similarly, field data collected from potato fields in Ladner, BC does not indicate a relationship between Brix-levels in plant foliage and aphid counts. Several studies and experts suggest that Brix-level alone may not be a sufficient predictor of insect attack on plants.

The rationale behind high-Brix crops is that foliar feeding of multiple nutrients is necessary in order to maintain the optimal nutrient balance necessary to reduce insect feeding. Unfortunately, most scientific studies examining the impact of plant nutrient status and insect feeding rarely examine more than one nutrient at a time. Indeed a review of the studies examining individual nutrients suggests that for most nutrients – with the exception of potassium – manipulation can result in positive, negative or neutral impacts on pest populations depending on the insect-plant combination. Several studies suggest that the balance of nutrients may be the more critical factor determining insect feeding, rather than the concentration of any one nutrient. However, we found no studies experimentally testing this idea.

Local growers wonder if the claims that soil amendments and foliar feeding in order to raise plant Brix will result in reduce pest pressure. Our review of the literature indicates that there are no studies that specifically address this question. Although several practioners of the high-Brix approach have anecdotal reports of efficacy, again third party studies are lacking. In other words, there is no objective evidence to support or refute the idea that manipulating plant Brix levels will have a subsequent impact on pest levels. We suggest that growers interested in the high-Brix approach conduct their own on-farm trials to test whether products 1) raise Brix levels and 2) compare pest levels on treated and untreated crops. As a minimum guideline for such trials we recommend that growers

> 1) Focus on a single crop that experiences moderate pest pressure and foliar pests are easy to find (e.g. leaf lettuce)
> 2) Have treatments isolated from each other, e.g. with a buffer of bare soil between treated plants as some of the nutrient manipulations are to the soil
> 3) Follow general guidelines regarding randomization, replication and control (for useful guidelines to on-farm studies see the "On-farm Research Guide" Prepared by the Organic Farming Research Foundation (Santa Cruz, CA) http://ofrf.org/grants/on-farm_research_guide.pdf)
> 4) Take accurate counts of pest incidence prior to application of Brix modify products and at regular intervals subsequently
> 5) Plots should be big enough that pests don't "spill over" into adjacent treatments
> 6) A forum for sharing and compiling the observations of individual growers is also recommended so that growers can share experiences and ideas.

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