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Research: Vacuum

A Summary of Research to Improve Vacuum in Maple Tubing Systems

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Sap exudation from maple trees is driven by the gradient in pressure from the inside to the outside of the tree. Under certain weather conditions (fluctuations above and below the freezing point of water) a dynamic period of tree pressure can be observed (Heiligmann *et al.* 2006, Chapeskie and Staats 2006). In most cases, the greater the difference in pressure, the greater the volume of flow produced. It has long been recognized that lowering the pressure in tubing by using vacuum pumps will increase sap yield (Laing *et al.* 1962, Blum and Koelling 1968). For every additional inch of mercury (Hg) difference in vacuum, there is a corresponding increase in yield of approximately 5-7% (Wilmot *et al.* 2007, Perkins *et al.* 2012), with no significant change in sap chemistry or tree wounding (Wilmot *et al.* 2007). Therefore maple producers generally attempt to reduce the pressure in their tubing system as much as possible, and strive to quickly detect and fix leaks to maintain the vacuum at these high levels.

A problem in maple tubing systems that affects achieving maximum vacuum at the taphole is commonly thought of as a lack of "vacuum transfer." In actuality, the opposite is true. The difficulty is caused by the inability to move air (originating from leaks or from gases produced by trees) out of the system rapidly. During flow, the tubing system contains a combination of liquid (sap) and gases. When separate, air and liquid will each flow at very different rates, with air moving much faster than liquid. Liquids are largely incompressible, whereas gases in the tubing system can expand or contract depending upon the pressures involved. Because of this property, air cannot be transferred optimally through mixed gas/liquid systems. The slow movement of air out of the tubing system increases pressure locally within the tubing system, resulting in reduced (less negative) vacuum levels, and consequentially, lower sap yields. In addition, junctions (tee and wye fittings), sags, leaks, slope changes, ice and debris build-up, and other factors impart friction and turbulence or blockages which affect the smooth flow of air and liquid in mainline, however these problems are either transient or controllable to some degree. Proper design, layout, installation, and maintenance of tubing systems can help ensure that liquid can move freely along the bottom of the mainline pipe and air is evacuated rapidly across the top, greatly minimizing most negative consequences in mainlines. However the internal diameter of 5/16" lateral line systems is small enough that slugs of air and sap are intermingled, which results in poor (slower) air removal. In addition, the small diameter of fittings in 5/16" lines (compared to mainline) results in higher internal friction affecting both air and liquid movement.

To combat these problems, dual-conductor systems were developed to separate air and liquid in mainlines.

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This improved air transfer and allowed good vacuum levels to be achieved to the ends of the mainline system, but didn't address the vacuum transfer limitations of the lateral/drop line system. The result was that producers moved towards shorter lateral lines with fewer taps per lateral. Although this improved vacuum transfer and sap yield to some degree, it did not address the inherent limitations of the smaller tubing system containing both liquid and gases.

The following research program was conducted at the University of Vermont Proctor Maple Research Center over several years to explore a variety of methods to potentially increase sap yields from tubing systems through modifications of the lateral/dropline portion of the sap collection system.

Methods

All of the research described was conducted in the "Martin Block" sugarbush section (encompassing approximately 24 acres) at the UVM Proctor Maple Research Center in Underhill Center, Vermont, in the sap flow seasons from 2010 to 2015. A light thinning was performed in the summer prior to the first tapping. Trees averaged 14.2" in diameter at breast height (dbh) at the beginning of the study and had not been previously tapped. Average slope was 20.4%. The sugarbush was divided into twelve plots containing approximately 65-70 trees each, for a total of about 820 trees in the study. This allowed the study of four different experimental treatments (including the control) most years with three replicate plots for each treatment. The specific treatments examined varied by year and are detailed below. Each plot was serviced by a ¾" mainline connected to a Busch vacuum pump through a custom releaser equipped with a counter, which was calibrated to record the sap volume each time it dumped. Releaser tallies were recorded once or twice daily during every flow period over each season, standardized to sap yield (gallons sap per tap) for each plot, then averaged by treatment. Analysis of variance was used to assess differences by treatment. Due to the low sample size (three replicates), these results should only be viewed as screening studies to identify treatments showing promise.

All trees in all treatments were tapped within the same week each year. Only one tap per tree was used regardless of tree size. New spouts were used each year. If new tubing was installed for one treatment, new drops were placed in all other treatments to maintain a similar level of sanitation across all treatments. Droplines were the same length across all treatments each year.

Treatments

Treatments used during the five years of study are shown in Table 1. From 2010-2014, four treatments were examined each year with three replicate plots per treatment. In 2015, two treatments were compared, with six replicate plots per treatment.

Treatment A was designed to represent a standard "best practices" (Control) tubing installation (Heiligmann et al. 2006), with standard 5/16" laterals and droplines averaging five taps per lateral. All remaining treatments were experimental. The specific treatments examined varied by year. Treatment B was very similar to the control treatment, except that each 5/16" lateral line serviced only one tree (one tap per lateral with a 5/16" tubing system).

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Treatment C was similar to Treatment B, with the exception that there was no lateral line. Instead, ¾″ mainline was run to each tree, a ¾″ saddle and the 30″ of 5/16″ tubing served as the dropline. Treatment D (Figure 1A) utilized a custom-made stub-spout combination made of ½″ PVC mated to a clear-straight polycarbonate spout that would allow sap or gases to flow out of the spout into the large open space of the chamber, thereby allowing better separation of liquid and gases temporarily. Treatment E (Figure 1B) utilized custom-extruded ½″ polyethylene tubing and nylon fittings (tees and stubby) for both lateral and droplines in an attempt to allow sap to run across the bottom of the tubing and gases to flow across the top, similar to what should occur in the typical mainline. Treatment F (Figure 1C) utilized a custom extruded dual-conductor 5/16″ line connected to a customized stubby. One conductor of the dual-line had a tactile ridge molded in so that the wet and dry line could always be identified correctly. The top line was used as a dry-line with the bottom serving as a wet-line. The internal configuration of the custom-built stub-by allowed air to flow predominantly to the rear of the stubby and out the dry-line, while sap would flow chiefly though the wet-line. Treatment G consisted of commercially-made 3/16″ lateral line and 3/16″ droplines. No effort was made to optimally re-tube the plots specifically for the 3/16″ system. The treatment consisted only of simply replacing the previous lateral lines with 3/16″ lines regardless of slope or number of taps on a lateral line.

In most years, vacuum was continuously measured and recorded at the ends of the last lateral lines (next to spouts) on each experimental plot using Keller-Druck LEO recording vacuum gauges (2010-2013) or the Smartrek wireless vacuum monitoring system (2014-2015). In general, the changes in sap yields closely reflected differences in vacuum achieved, so these results are not presented.

Results

All treatments produced good sap yields each year of the project, with a low of 19.7 gal sap/tap across all treatments in 2012 and a high of 35.1 gal sap/tap, averaging 27.1 gal sap/tap for

Treatment	2010	2011	2012	2013	2014	2015	Average Change[3]
A. CONTROL 5 Taps per Lateral	31.5	27.4	18.1	33.6	23.6	23.3	na
B. 1 Tap per Lateral	32.1	28.1	18.4	34.1	24.8		2.5%
C. Mainline to Each Tree	30.7	25.6	20.4	34.3	25.7		3.0%
D. Chamber Stubby	29.1						-7.6%
E. 1/2″ Lines		27.1					-1.1%
F. Dual-5/16″ Conductors			21.9[a]	38.5[a]	27.7[a]		17.7%
G. 3/16″ Lines						25.5	9.4%
Annual Average Sap Yield	30.9	27.1	19.7	35.1	25.5	24.4	na

[3] Average % change from Treatment A – Control.

Table 1. Experimental treatments and sap yields (gallons of sap per tap) in Martin Block section in Underhill Center from 2010 2015. Direct yield comparisons should only be made within a given sap flow year (column). Average change in sap yield due to each treatment is shown in the right-most column. Letters after sap yields indicate a significant difference in yield compared to the control treatment.

the six seasons of study.

Table 1 provides sap yields for each treatment within each year. Because each sap flow season was different, only values within a single column (year) should be directly compared. In general, most treatments showed only minor, non-significant effects on sap yield. Over the five years tested (2010-2014), Treatment B (*one tap per lateral*) produced a 2.5% increase in sap yield compared to Treatment A (*five taps per lateral – Control*). Similarly, Treatment C (*Mainline to each tree*) produced a 3.0% increase over the control during the same time period. Treatment D (*Chamber Stubby*) was tested only in 2010 and produced 7.6% less sap than the control, mostly due to an inability to get a leak-tight seal between the polycarbonate straight-through spout and the bushing used to mate the spout to the ½" PVC chamber. Thus this was not a good test of the concept, but more of a problem in translating the concept to a workable, functional prototype. Treatment E (*½" lateral lines*) appeared to be a very promising candidate in our modeling studies, however the approach proved to be very problematic in the field, producing slightly (-1.1%) less than the control treatment during the one year (2011) it was tested, providing a good illustration of the importance of field testing ideas. Dual-conductor lateral and drop lines (Treatment F) produced significant increases in sap yield averaging 17.7% over each of the three years of study (2012-2014), which included a poor year, a very good season, and an average yield season. Treatment G (*3/16" Laterals and Drops*), which was tested only in the 2015 season, produced a 9.4% improvement in sap yield.

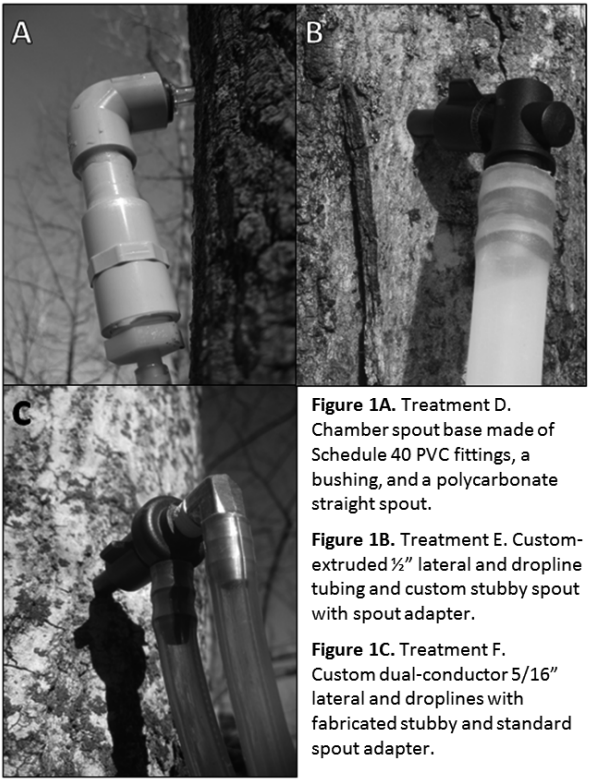

Figure 1A. Treatment D. Chamber spout base made of Schedule 40 PVC fittings, a bushing, and a polycarbonate straight spout.

Figure 1B. Treatment E. Custom-extruded ½" lateral and dropline tubing and custom stubby spout with spout adapter.

Figure 1C. Treatment F. Custom dual-conductor 5/16" lateral and droplines with fabricated stubby and standard spout adapter.

Discussion

Simple changes such as installing only one tap per lateral or running mainline to each tree can result in slight increases in sap yield, however the additional cost of implementing these strategies is prohibitive.

Due to problems in implementation, it is impossible to judge whether separating the liquid and gas using a chamber-type stubby or spout design would be worthwhile, although it most likely

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would not result in substantial changes because any effect would be transient, and air and liquid would eventually both have to transit the same small diameter line.

The use of ½″ lateral lines showed promise in the lab, but in the woods, the increased weight of sap in the ½″ laterals caused the lines to sag when full of sap, thus providing areas for the sap to pool and reduce effective gas transfer. When these areas subsequently froze, they blocked all transfer of air or sap until those areas melted. Melting took longer because of the larger diameter of the ice dam created and because the tubing was a light, translucent white color and likely did not absorb as much solar radiation compared to the blue 5/16″ line in the other treatments. Had the tubing been suspended on wire like mainline, it may have shown better results, however this would raise the cost of installation tremendously, rendering the approach unviable.

Despite the positive and consistent increase in sap yield resulting from the use of dual-line 5/16″ tubing, the additional anticipated expense makes this approach profitable only when yields are 0.5 gal/tap or better AND bulk syrup value is high or a producer is selling directly into the retail syrup market or making value-added products from the syrup produced. Given the recent drop in bulk syrup prices, this approach is not likely to be adopted despite the high yields achieved.

Although the treatment did not achieve statistical significance due to low sample size, the use of commercially available 3/16″ tubing and fittings produced a 9.4% increase in sap yield.

Four things are critically important to consider in determining the proper strategy to pursue. The vacuum level in the mainline was already very high due to the pump, averaging about 25.5″ Hg. This left very little room for improvement due to natural gravity vacuum. Second, the installation of 3/16″ tubing was not optimized in any way, but was installed merely as a replacement for the 5/16″ tubing that was previously installed in this area. Even a slight level of optimization (running the tubing further downhill, adding more taps per lateral) would likely increase the vacuum level even further. Third, the low cost of implementation of 3/16″ tubing compared to the other approaches in this study was very attractive. Using 3/16″ tubing is no more expensive than using 5/16″ tubing. In a normal 3/16″ tubing installation, less mainline is used, thus the approach is likely to be even less expensive, making the net profit per gallon of sap higher than other approaches. Finally, the other methods examined all involve new products or methods that would require some (or considerable) adjustment on the part of maple producers. Using 3/16″ tubing is a very easy transition to make for those used to 5/16″ vacuum tubing (Wilmot 2014).

In summary, only the dual-line experimental treatment and the 3/16″ tubing treatments show any reasonable amount of promise as approaches to increasing yield. While the dual-line system produced higher net yields, the 3/16″ tubing method is considerably more economical in terms of producing a reasonable net profit for the cost of achieving the added sap yield.

Although on the surface it might seem paradoxical that we can solve the problem of poor vacuum transfer by using a smaller tubing line, the answer lies in the fact that 3/16″ tubing generates vacuum not by allowing the passage of air out of the system quickly, but by using the weight of the sap in the small diameter line to generate vacuum within the 3/16″ lines themselves. Therefore, the additive effect of pumped vacuum in the mainline system and natural gravity vacuum in the 3/16″ lines means that we achieve the highest vacuum in the area we want it the most – at the taphole.

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