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The Effect of Vacuum on Walnut Sap Flow

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by Mike Rechlin, Kate Fotos, Christoph Herby, and Mat Cabral

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North Mountain Campus: 400 Road Less Traveled, Franklin, WV 26807 USA | Ph: 304.358.2000 | www.Future.Edu & www.Future.Org

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INTRODUCTION

The use of either artificial vacuum with a pump and releaser on 5/16-inch sap lines or, more recently, natural vacuum on 3/16-inch sap lines with adequate slope has been well documented in the maple industry (Perkins, 2010, Wilmot 2007, Wilmot 2014). Every 1-inch Hg vacuum applied to maple lines above 15 inches results in a 5-7% increase in sap yield. High vacuum systems typically apply 24-26 inches Hg, more than doubling maple sap production. Vacuum use, which increases the pressure gradient inside to outside the tree, is especially effective during days when sap flow would normally be marginal.

Far less is known about sap flow and vacuum in black walnut (*Juglans nigra*). Black walnut and maple are anatomically and physiologically very different trees. Maple is a diffuse porous hardwood and walnut is classified as semi-ring porous (Panshin and Zeeuw, 1970). Whereas maple sap flows in the spring due to the buildup of stem pressure, the pressure developed in walnut trees is presumed to be a combination of stem pressure and root pressure (Ewers, et.al, 2000). Sugar maple, also called hard maple, is an extremely hard wood whereas black walnut is a relatively soft wood. These differences suggest that what is known about vacuum in maple may not hold true in black walnut.

The only published work on black walnut sap flow and vacuum was done by Mike Ferrell and Ken Mudge (2014). In their study, they found that, of four trials, the one with vacuum applied to the lines produced the lowest volume of sap per tap. In their paper, they commented that theirs was a preliminary investigation and needed replication. During the 2019 sap flow season, Future Generations University conducted studies, funded by the West Virginia Department of Agriculture through a Specialty Crop Block Grant, on walnut and sycamore sap flow. This work indicated that walnut sap would not develop a natural vacuum in 3/16-inch lines, presumably due to the high volume of gasses in the sap lines, but that the rate of sap and tree gas flow through 3/16-inch lines could be markedly increased by the application of relatively low levels of artificial vacuum (Rechlin and Fotos, 2019).

Interest in black walnut sap and syrup production is growing, as evidenced by the recent formation of a Black Walnut Syrup Makers Group Facebook page. This new interest is fueled by a growing market for specialty tree syrups, including bourbon barrel aged maple syrup, herb infused maple syrup, walnut syrup, and walnut blended maple syrup. Specialty markets have developed to where the 2020 bulk price for West Virginia walnut syrup this past season was between $150 and $250 per gallon. Retail walnut syrup and blended maple walnut prices are far higher. This market potential, providing the possibility of developing a walnut tree syrup industry in the Central Appalachians, along with observations from our 2019 preliminary studies, provided the impetus for this 2020 work.

Our objective in this 2020 study was to revisit walnut tree sap flow and to determine whether vacuum applied to sap collection lines would substantially increase the production of walnut sap. Along the way, we made some somewhat startling and troublesome observations and formulated a next generation of questions that need to be answered to allow a viable walnut syrup industry to develop.

STUDY #1: ELTON BOWERS WALNUT AND MAPLE SUGARING OPERATION, PENDLETON COUNTY, WV

STUDY DESIGN AND RESULTS

Two research lines, upper line "A" and lower line "B," were laid out along a stream in the bottom of a hollow (Figure 1). Both lines (3/16-inch tubing with 5/16-inch drop lines) had 20 taps, with 12 trees on the A line and 11 trees on the B line. Sap from both lines ran by gravity into 5-gallon food grade buckets.

Figure 1. Elton Bower's Study Site

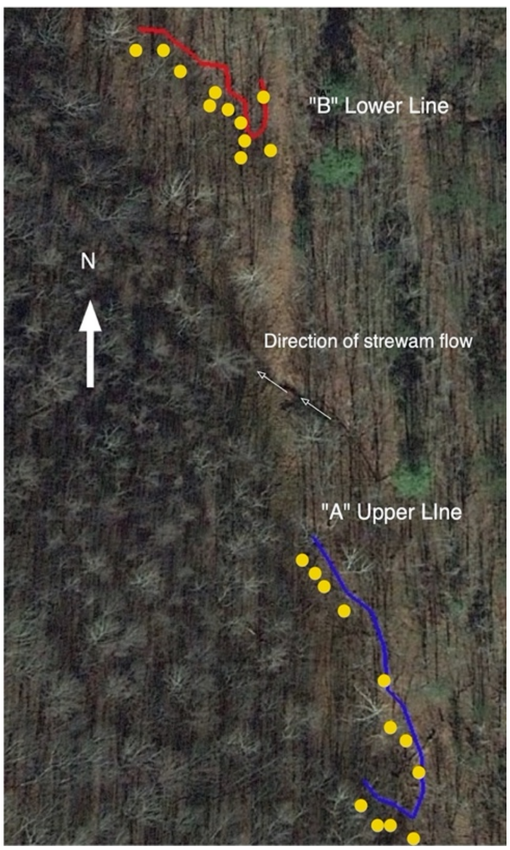


Table 1. Research line tree summary descriptions

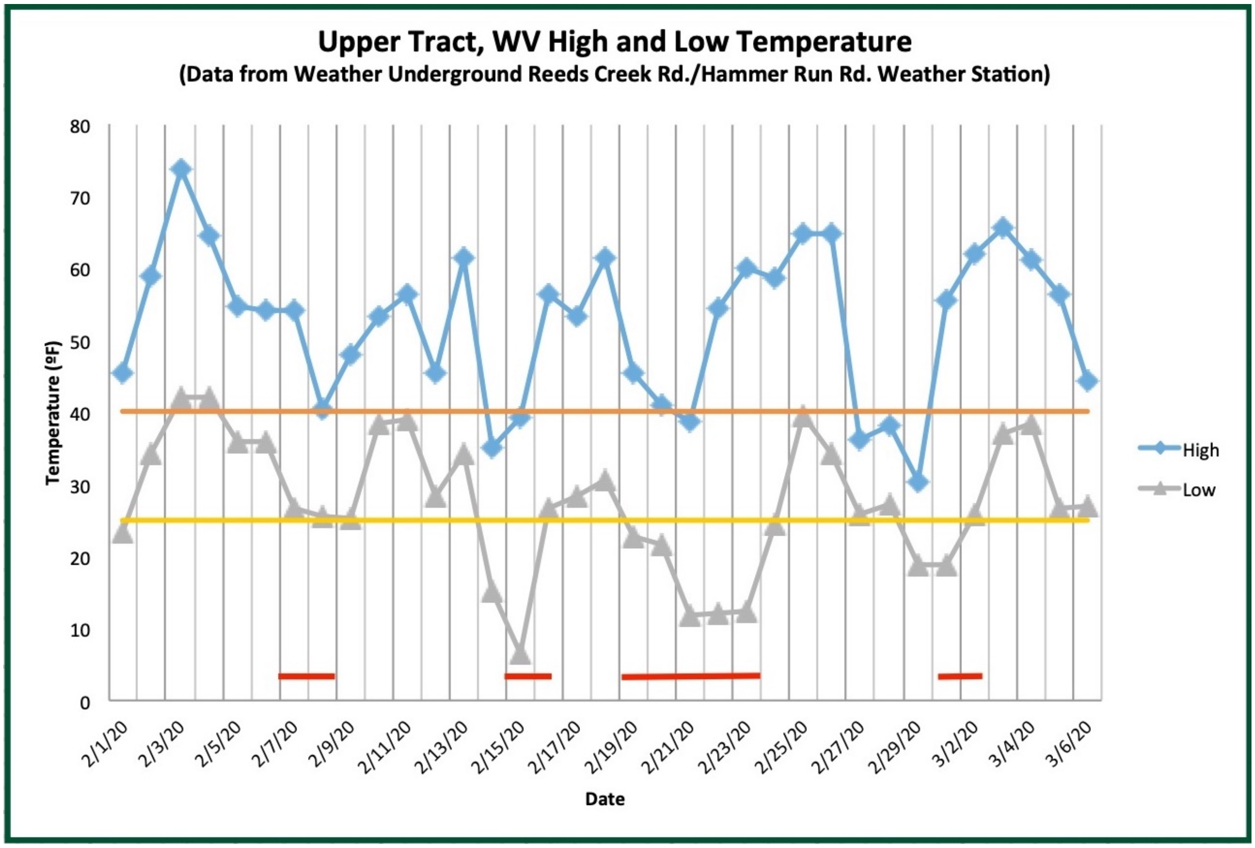
Tree summary descriptions	Avg. DBH inches	Total Basal Area ft. sq.
"A" Upper Line Trees	10.2	5.8
"B" Lower Line Trees	11.8	8.7

The trees on both lines were in similar sites and were relatively similar in size, with the exception of one 16-inch DBH tree on line "B," bringing up the average diameter and Basal Area of that line (Table 1).

A positive relationship between tree Basal Area and sap flow (bigger trees, more Basal Area, more sap flow) has been shown in maple but not in walnut. In walnut trees, sap flow has been positively correlated with thickness of the sapwood layer (Naughton, 2006). The sapwood in walnut trees is comprised of a relatively set number of annual rings (FPRL, 1976). The thickness of the sapwood is influenced more by the growth rate of the trees than their absolute size, meaning that a younger, faster growing tree could have a thicker sapwood layer than an older, slower growing tree and would be expected to yield more sap.

Trees on both lines were tapped on February 7th, with measurements taken from February 9th to March 4th. During that time, there were four periods with weather conditions conducive to good sap flow. Horizontal red lines on the Figure 2 indicate these. Good sap flow periods are defined by temperatures dropping to the mid-20 degrees Fahrenheit at night followed by highs reaching into the 40's. It should be noted that Elton's operation is in a shaded, cool hollow, where temperatures are routinely expected to be below those registered at the Upper Tract weather station.

Figure 2. Temperature fluctuations at Upper Tract, WV, near Elton's sugaring operation



Sap was collected from both lines at close to the same time and measured to the nearest 0.25 quarts. In five of nine collections under gravity flow, the upper line "A" out produced the lower line "B". Three times the lower line out produced the upper line, and one time they had the same rate of flow (Table 2).

Table 2. A comparison of sap flow between the upper "A" line and the lower "B" line under gravity flow.

Date	"A" Upper Quarts	"B" Lower Quarts	Relative flow	Tally of relative flow
2/9	13	14.5	U<L	U> L - 5
2/10	13	7.1	U>L	U< L - 3
2/12	5.5	5	U>L	U=L - 1
2/17	22	22	U=L	
2/18	10.25	7.75	U>L	
2/20	2.25	1	U>L	
2/22	1.75	2	U<l	
2/23	2.75	2	U>l	
2/24	13	13.75	U<L	

Vacuum was then applied to line "B" with a Shurflo DC diaphragm pump, and sap collected from both lines over recorded time intervals. During the eight study runs, the vacuum averaged eight inches, ranging from 1-inch to 14-inches. The 14-inches of vacuum were obtained after talking with Mike Bisbee of Mountain Maple and installing a recirculating line to keep the diaphragm moist. It held at that level for one day, dropping back to 8-inces the next day. The results are shown in Table 3.

Table 3. Sap flow on "A" line, gravity flow, and the "B" line with vacuum

Date	"A" Upper	"B" Lower	Elapsed Time	"A" Upper	"B" Lower
Units	*Quarts*	*Quarts*	*Hours*	*Qts/Hr*	*Qts/Hr*
2/12	0.06	2.0	5.88	0.01	0.34
2/18	3.25	6.25	6.42	0.51	0.97
2/23	1.0	4.0	4.00	0.25	1.00
2/24	7.0	10.0	6.50	1.08	1.54
2/25	3.0	5.5	7.97	0.38	0.69
3/1	1.0	3.0	7.06	0.14	0.42
3/2	2.5	4.0	5.60	0.45	0.71
3/4	6.0	10.0	47.40	0.13	0.21
Total	23.81	44.75			
Average				0.37	0.74
Statistics		"A," " B" t-test, p-value = 0.038			

DISCUSSION

In Figure 2, we have identified four good maple, freeze/thaw sap flow periods of multiple days each. Data in Tables 2 and 3 show that sap flow increased during each of these periods and then dramatically decreased by March 4th. Tap holes on both research lines were providing good sap flow between February 9th and March 2nd, giving us a 23-day sap flow season. It is worth noting that Elton's maple stand, located in the same valley, was tapped earlier and ran later, with a 42-day season.

Table 2 shows that without vacuum, the upper "A" line out produced the lower "B" line in 5 of the 9 days measured. Table 3 shows a reversal of that trend, with vacuum the "B" line out producing the "A" line in all eight runs. The average flow rate of 0.74 qt./hr. on the "B" line under vacuum was double the 0.37 qt./hr. production of the "A" line on gravity flow.

STUDY #2: HIGHER VACUUM TRIALS

With the statistically significant ($p = 0.038$) increase in sap flow under low vacuum on the 20-tap research lines at Elton's, we wanted to run a trial on a larger tubing system and see how sap flow would respond to higher vacuum levels. After searching in vain for a vacuum pump and releaser that we could use for a week late in the sugaring season, Mat "the sugar bug" Cabral offered to bring his DeLaval 76 dairy pump, capable of pulling up to 20 inches of vacuum, and electric releaser up from Virginia Beach. Matt drove up with his equipment, and we set up a trial on March 2nd at Elton's operation, followed by a set up on March 3rd at Tonoloway Farm in Highland County, Virginia.

ELTON BOWERS HIGHER VACUUM TRIAL: PENDLETON COUNTY, WV

On March 2nd, we connected Mat's equipment to 109 walnut taps on 3/16-inch lateral lines without a mainline. This was a different tapping area from the upper and lower research lines reported on above. These trees were tapped on February 8th. From 2/9 – 3/2 they had yielded a total of 172 gallons of sap or 1.6 gallon of sap/tree. Through most of the season, they had been connected to a Mountain Maple Surflo diaphragm pump and controller. However, we were never able to keep vacuum, making it basically a gravity flow collection system. The nights of March 1st and 2nd both had good freezes followed by daytime temperatures in the 60's, which should have initiated a good sap run.

We ran Matt's pump from mid-morning to 4:30pm and only collected 1.5 gallons of sap. This was, in our minds, a dismal failure. We had expected to get a lot more sap. However, we added to our knowledge of these systems as the day proceeded. Operating the vacuum pump, Matt made the following observations:

- When pulling 20-inches Hg at the pump, the pump was struggling; belt slipping, RPM of the engine fluctuating, and vacuum pump not catching up to the engine. When the engine was backed off to provide only 15-inches at the pump, it worked better. When brought back up to 18, it began struggling again.

- When backing the engine off, the vacuum dropped immediately. Whereas, on past uses, it took time for the vacuum level to readjust.
- The pump seemed to burn an excessive amount of oil.

This collection system was set up with 3/16-inch lines running to a star saddle manifold on a short (1 foot) 3/4 -inch piece of mainline tubing. Mat's conclusion was that the short main did not provide enough vacuum buffering to modulate the pump changes and that the lack of gasses available to be drawn through the short main and the 3/16-inch laterals was overworking the pump.

Near the end of the day, we clamped off all but the longest lateral and began leak checking up the line by isolating each spout, clamping it off above, and then tightening that spout. In every instance the spout had vacuum leaks and tightening raised the vacuum in the line below the clamp from between 3 and 5-inches Hg to 17-inches. Matt noted that some of the spouts looked as if they had backed out of the tree by up to 1/4-inch. This was our first indication that the spouts we were using (7/16-inch nylon maple spouts) were not holding in the trees.

TONOLOWAY FARM HIGHER VAC TRIAL: HIGHLAND COUNTY, VA

Unlike Elton Bower's Farm, walnut tapping at Tonoloway Farm was not part of a pre-designed research project. This is the second year that Christoph and Lauren Herby have been producing and selling maple syrup. Most of their tapping had taken place on a neighbor's land. They were interested in expanding their syrup operation and, although lacking a maple resource, Tonoloway Farm has plenty of walnut trees. Given the high price of walnut syrup ($150-$250/gallon bulk), they decided to give it a try. During the 2020 sap flow season, Christoph and Lauren put in 628 maple taps and a total of 417 walnut taps. In the walnut stand, they put in 1,200-foot of 3/4 -inch mainline, running 3/16-inch lateral lines with 5/16-inch drops and 7/16-inch CDL maple spouts. Christoph's system was also equipped with a Sureflo diaphragm pump and Mountain Maple controller.

Table 4. Tonoloway Farm 2020 tapping

Species	Number of Taps	Date Tapped	Collection system
Walnut	20	2/7	Buckets
Walnut	297	2/18	3/16 tubing
Walnut	100	3/2	3/16 and 5/16 tubing
Maple	628	2/7-2/14	3/16 tubing

***Note**: This system was designed based on the best information available (and there was not much) through internet searches, the 2019 preliminary walnut sap flow study conducted by Future Generations University, and discussions with anyone they could find who had tried tapping walnut trees. During most of the season, Christoph's system was only able to maintain an at-the-pump vacuum level of 1- to 2-inches Hg. After our success with raising the vacuum to 14 in Hg on our "B" research line at Elton's site, Christoph plumbed in a similar recirculating line and eventually got his at the pump vacuum up to 9 inches Hg*.

We arrived at Tonoloway Farm just after noon on March 3rd. Unlike at Elton's, there was a good sap run in progress. When we arrived, his diaphragm pump was not on. I walked up the first lateral and read the gauge at 5.5-inches. This indicted that a natural vacuum was developing in the 3/16-inch lines. However, having the required 30 feet of elevation change, the natural vacuum would be expected to be closer to 24 inches were it on a maple line. As Matt was setting up his equipment, we turned on the already installed diaphragm pump, and the end of line gauge reading jumped to 7.5 inches. With the DeLaval dairy pump operating at 20-inches Hg at the pump, the end of line gauge read 10.5 inches.

We ran the pump from 1:22pm to 3:10, an elapsed time of 1.8 hours, and collected 33 gallons of sap, for a flow rate of 18.3 gallons/hour. During the previous 45 hours without vacuum artificial Christoph collected 275 gallons.

Table 5. Higher Vacuum Sap production

Elapsed Time (Hrs)	Gallons Sap Collected	Gal/hr.
1.8	33	18.3
45	275	6.1

To get an idea of sap flow with and without vacuum, we marked off a 4-foot section of lateral line and repeatedly measured the speed of the gas bubbles with and without the pump running. Without vacuum, gas bubbles were moving along the line at the rate of 0.4 feet/second. After the application of vacuum and a period of adjustment, the gas was moving at the rate of 1.3 feet per second.

While there, Christoph commented on the number of taps with vacuum leaks he was finding in his walnut stand, confirming what we saw the previous day at Elton's. After our day at Tonoloway Farm, Christoph continued collecting walnut sap until March 9th, giving him a 21-day season. He also continued to fight taps backing out of trees to the point that he had to daily tighten a good number of his spouts. Christoph estimates that 25% of his spouts had to be tightened each day to maintain vacuum. He also noticed that the problem did not seem to be related to a nighttime frost; the spouts just backed out of the trees.

DISCUSSION

By either measure, sap collected or rate of flow in the lines, Christoph's collection system showed that vacuum increases sap flow. However, without a controlled study, it is impossible to say by how much. At Elton's, 8 inches of vacuum doubled sap flow. At Christoph's, higher vacuum (20 inches in the mainline but only 10.5 on the end of the first lateral) tripled both measures. However, the measured flow rate of 18.3 gallons/hour really can't be compared to the 6.1 gallons/hour because the 45-hour collection period included nights where the sap flow would have naturally decreased. Positively showing a tripling of flow would require conducting a controlled study similar to the "A" and "B" lines at Elton's.

We showed at Elton's that the application of low levels of vacuum can double the rate of sap flow. We showed at Christoph's that raising the vacuum further causes more rapid movement of sap gasses through the lateral lines. What needs to be seen is if that correlates to an increased volume of sap flow. Increasing vacuum on walnut could just be pulling more gas out of the tree relative to sap. Or, the large pores of the semi-ring porous walnut could, with the application of vacuum, be allowing quicker access to sap further away from the tap hole.

IMPLICATIONS FOR A WALNUT SYRUP INDUSTRY

Through our studies, we estimate a seasonal average gravity sap flow of 2-gallons of sap per tap. This is way under the expected 10 gallons of sap per tap for maple. However, if we could triple that 2-gallons with artificial vacuum, it would produce a seasonal average of 6 gallons of sap. Of course, that number will vary dependent on the numerous environmental factors influencing sap flow in any given year. That's not a lot of sap, but if Christoph's 417 taps all produced 6-gallons, he would have collected 2,502 gallons of sap. Assuming a Brix of 1.4 (average Brix measured at Tonoloway) and using the "modified rule of 86" it would take 62 gallons of sap to make a gallon of syrup. His 2,502 gallons of sap would then convert to 40.3 gallons of syrup. Selling at a bulk price of $150/gallon the operation would have brought in $6,045.

For comparison, with maple under high vacuum you can assume 20 gallons of sap per tap. If Christoph had 417 maple taps, he would have brought in 8,340 gallons of sap. That's a lot more sap. Assuming an average Brix of 1.5 Brix, it would take 58 gallons of sap to make a gallon of syrup. His 417 maple taps could then have made 144 gallons of syrup. Selling at the bulk price of $22/gallon it would have brought in $3,168.

Walnut syrup production, although having a low per tree sap yield, is starting to look like a good venture, which is why Christoph is interested in expanding to 1,000 walnut taps next year.

However, for this to be a viable venture, we need to solve the problem of spouts backing out of the trees. Having to leak check and reset spouts every day is not feasible at any scale. We need to design a spout that seals and stays put in order to scale up walnut tree tapping.

The second issue to be looked at is the application of higher levels of vacuum. In addition to measuring the sap flow increase with end line vacuum at 10.5 inches, what would it be if we could tighten the system and get the level close to 24 inches?

Finally, to move a walnut tapping industry forward, we need to figure out the best time to tap the trees. Walnut trees build up pressure due to stem pressure with a presumed physiological mechanism similar to maple, but also due to root pressure, similar to birch. Birch sap flows towards the end of the maple season and beyond. So, should you tap walnut trees like maple or like birch? Our work this year indicates that walnut has a shorter sap season than maple, 23 days at Elton's as opposed to his 42 days for maple. With the shorter sap flow season, it becomes increasingly critical to get the timing right.

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PICTURES

Mat Cabral and Kate Photos installing a vacuum pump at Elton Bowers sugaring operation.

Christoph Herby with a tank full of walnut sap

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