USDA SARE ON-FARM RESEARCH

BLACK WALNUT SAP VACUUM STUDY

The Tonoloway Black Walnut Vacuum Study

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EXECUTIVE SUMMARY

The purpose of this project is to advance the technical understanding of harvesting black walnut tree sap for processing into walnut syrup, which presents a viable economic and environmental opportunity in the Southern Appalachians. The pinch point lies not in consumer demand, but in supply and production efficiency. A major technical challenge with walnut syrup production lies in harvesting of walnut tree sap.

To gain concrete insights on the transmission of vacuum in the use of maple tubing systems for harvesting black walnut sap, this study took vacuum measurements along the length of three tubing systems: 3/16" on gravity vacuum, 3/16" with mechanical vacuum, and 5/16" with mechanical vacuum. Vacuum measurements were taken at 56 points across 6 sap lines representing two of each configuration being studied. Repeating data collection four times during the course of the sap harvest season, several noteworthy patterns emerged.

- 3/16 lines with high vacuum do not effectively transmit vacuum up the line, although the vacuum may be beneficial to keep sap moving on low-flow days. An interesting phenomenon is seen in which vacuum levels climb near the top of the line, showing the "hybrid effect" of capillary/gravity vacuum overcoming friction losses on long lines with substantial elevation gain.
- 5/16 lines are highly effective at transmitting vacuum up the lines, with virtually no vacuum loss throughout the study.
- Under the right circumstances, 3/16 gravity lines have potential to exceed the vacuum levels created with mechanical pumps, but this may be contingent on ideal line layout with significant elevation drop and minimal rises.

While the limitations of the study make it difficult to declare a singular "winner" for the best system to use when tapping black walnut trees, there are several takeaways that may be helpful to syrup producers. Under the right circumstances, 3/16 gravity lines can compete and even outperform mechanical systems with both 5/16 and 3/16 tubing. This makes them a good candidate for small scale operations, or installation of lines in areas that would be difficult to set up a vacuum pump. 5/16 vacuum systems are the most effective at consistently delivering pumped vacuum to the taps. However, 5/16 lines are more challenging to install because they do not tolerate any elevation rise, and they are also more difficult to check for leaks because sap flow is less visible. 3/16 lines on high vacuum are not effective at fully delivering high vacuum far up the lines. However, the "hybrid vacuum" effect does increase higher up the lines with significant elevation gain. It appears that the use of any pump, even if it is not high vacuum, helps to draw sap from the lines and reduce stagnation.

Further study would be required to develop definitive recommendations for the burgeoning walnut syrup industry. A definitive study would combine this newfound understanding of vacuum patterns with measurements of sap yield on the same lines (ideally at the level of individual taps, but line totals would also provide valuable insight). Nonetheless, the present research provides a new understanding of how vacuum is transmitted through a walnut sap line, providing evidence for syrup producers making decisions about the best tubing systems for their particular topography, scale, budget and equipment.

1 - BACKGROUND

The purpose of this project is to advance the technical understanding of harvesting black walnut tree sap for processing into walnut syrup, which presents a viable economic and environmental opportunity in the Southern Appalachians. Syrup from black walnut trees (Juglans nigra) demonstrates significant market potential, as walnut syrup producers throughout the country sell out of their product with retail prices substantially higher than maple syrup. The pinch point lies not in consumer demand, but in supply and production efficiency. This illustrates an opportunity for maple syrup producers to diversify while opening an opportunity for other forest landowners to value black walnut trees beyond their timber potential.

Meanwhile, the maple syrup industry suffers negative impacts of climate change. As winters become warmer, the conditions for sap harvest occur earlier and for a shorter duration (US Forest Service 2018). This impact is most strongly felt in the southern range of maple syrup production in the Appalachians, notably Virginia, North Carolina and Tennessee, where maple syrup production is limited to locations with high elevation and colder winters. In Virginia sugar maple is found in only 35 counties, while black walnut is found in all the state's counties (US Forest Service 2020). Meanwhile, the natural range of black walnut trees extends further south and west, with millions of tappable trees throughout the Southern SARE area.

A major technical challenge with walnut syrup production lies in harvesting of walnut tree sap. Initial studies at Tonoloway Farm show that walnut trees produce one quarter to one third as much sap as maple trees when tapped according to maple industry standards.

Like maple trees, walnut trees yield more sap when negative air pressure (i.e. vacuum) is applied to the tap. In early 2020, Tonoloway Farm contributed to research showing preliminarily that black walnut trees respond favorably to vacuum, similarly to maple trees (Rechlin et al. 2020). However, walnut trees release substantially more gas into the tubing system. It is presumed that this is related to the semi-ring-porous structure of walnut trees, versus the diffuse-porous structure of maple trees. In practical terms, this means there is more air in the tubing and a presumably weaker transmission of vacuum up the line. While the maple syrup industry trends towards natural vacuum systems that draw sap through capillary action in 3/16" tubing, 5/16" tubing systems use mechanical vacuum created by a pump. It remains unclear if walnut sap can be harvested most efficiently with 3/16" gravity systems or 5/16" mechanical systems.

To gain concrete insights on the transmission of vacuum in 3/16" and 5/16" sap lines, this study took vacuum measurements along the length of three tubing systems: 3/16" gravity vacuum, 3/16" with mechanical vacuum, and 5/16" with mechanical vacuum (5/16" tubing does not work with gravity vacuum because the larger diameter does not allow capillary sap flow). Knowing the actual level of vacuum delivered to the tap will remove one of the major questions about sap flow in black walnut trees: how to get the most sap from each tap. With that said, the scope of this study is limited to vacuum measurements along the length of sap lines and does not include measurement of sap flow from each corresponding tap. These findings may be interpreted with reference to previous studies of black walnut sap yield with varying vacuum conditions (Rechlin et al. 2020) in addition to Tonoloway Farm's own sap harvest records from the 2022 season.

Tonoloway Farm is uniquely suited to conduct this type of research because it is the largest producer of black walnut syrup in North America, with several high-density stands of black walnut numbering more than 2000 trees and good access for tapping. The slopes are conducive to testing both natural and mechanical vacuum systems, while Tonoloway Farm's experience in producing maple and walnut syrup provides background for producing tree syrup according to industry standards. The farm is open to the public as a demonstration site for forest farming. In addition, with a new production facility opened in 2022 it can accommodate training and visitor events and outreach programs.

2 - METHODS

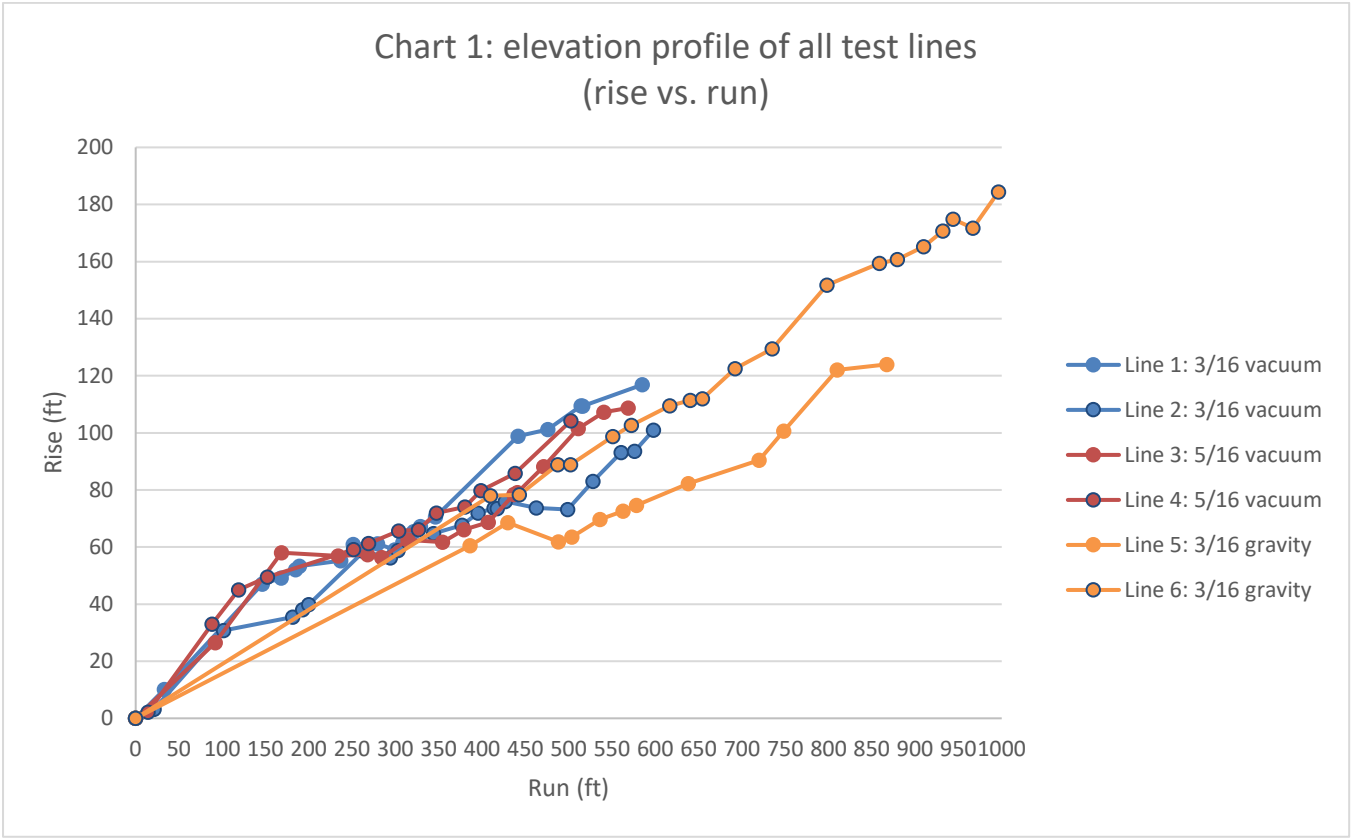
Six new sap harvest lines were set up at Tonoloway farm for the 2022 harvest season, representing two lines under three different configurations:

- 3/16 lines with mechanical vacuum pump
- 5/16 lines with mechanical vacuum pump
- 3/16 lines with gravity/capillary flow, no mechanical vacuum

The vacuum lines were connected to a ¾" mainline with a Bosworth double-diaphragm vacuum pump at the bottom of the mainline, capable of producing 18+ inches of vacuum on a tight network. While these lines were part of a larger sap collection system for Tonoloway Farm's commercial harvesting of walnut sap, the test lines were isolated with ball valves

so that vacuum could be directed exclusively to the test lines during data collection. While all lines had significant elevation rise, the 3/16" lines without a vacuum pump were installed at a location with the most elevation gain (100+ feet) to allow observation of the capillary/gravity vacuum effect.

Figure 1: sap lines at the Tonoloway Farm research site



Drop lines and taps were installed along the lines consistent with practices of black walnut syrup tapping: 1 tap on small trees less than 16 inches diameter at breast height (DBH), two taps on trees 16-20" DBH, and up to 3 taps on trees larger than 20" DBH. These standards allow for more taps than maple standards, accounting for the faster growth rate of black walnut trees, and correspondingly faster recovery at the site of tapping. Trees were numbered and labeled with

metal tree tags. At every other tree, a tee and drop line was placed to allow for vacuum data collection. This line was kinked and connected to the peg on the tee to prevent the leaking of sap or entry of air that might compromise the vacuum (Figure 2). The trees on all test lines were tapped on the 16th of February, 2022. On four days during the sap harvest season, vacuum measurements were taken using a vacuum gauge (Figure 3) at every other tree on the six test lines, providing 56 data points each day. Prior to collecting data each day, lines were checked for leaks and taps were re-seated in their holes if any evidence of leaking was apparent: hissing sounds near the tap or abnormal bubble patterns on 3/16 lines.

Figure 2: Vacuum dropper when not in use

Figure 3: Vacuum gauge on a 3/16" gravity line

A professional site survey was conducted to record precise elevation and GPS coordinates of the study lines and individual tree/tap locations. In Figure 4, below, the four vacuum lines appear on the left (southern) side, while the two gravity lines appear on the right (northern) side of the walnut stand. Detailed site surveys are included in Annex.

Figure 4: Surveyed sap lines at Tonoloway Farm

Data collection days were chosen to reflect varied weather and sap flow conditions:

February 17th: Heavy sap flow on first day after tapping. Daytime temperature reached 48F after freezing two previous nights. Mechanical vacuum directed exclusively to study lines.

February 26th: Moderate sap flow. Daytime temperature reached 40F after one night below freezing. Mechanical vacuum directed exclusively to study lines.

March 7th: Light sap flow on vacuum lines, moderate flow on gravity lines. Temperatures approaching 50 without a recent freeze. Mechanical vacuum directed exclusively to study lines.

March 15th: Late season, low sap flow on all lines. High temperature of 55F after a light overnight freeze (low 31F).

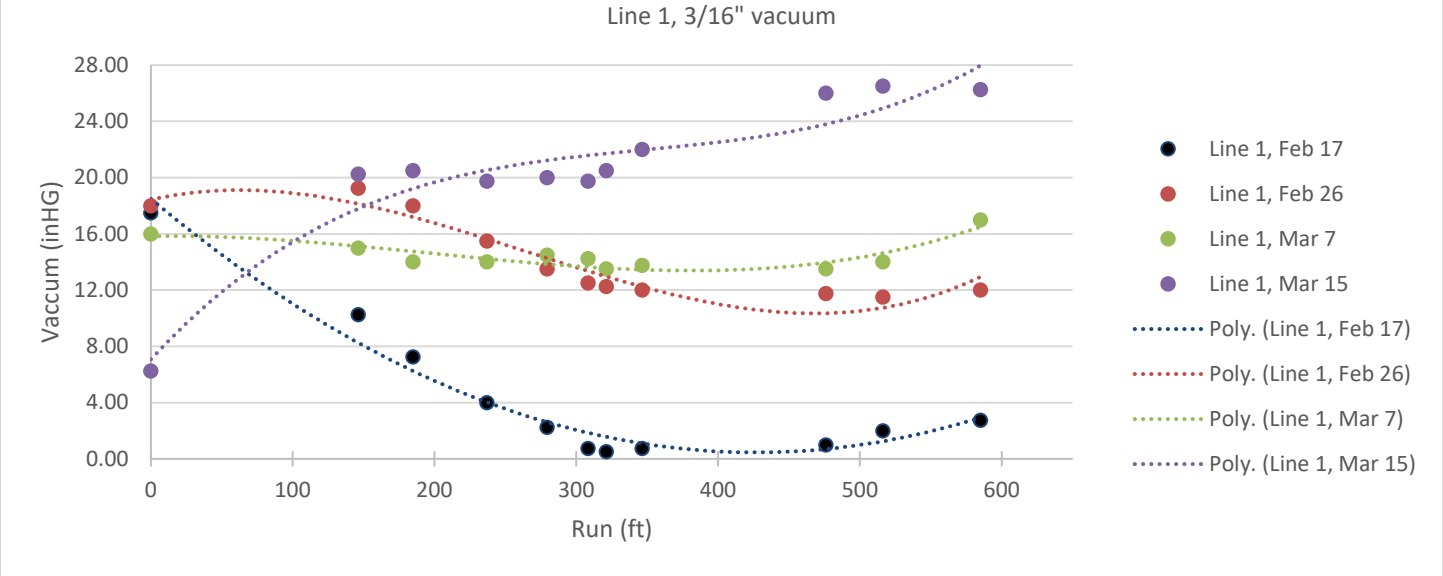
Sap flow was assessed qualitatively based on visual observation (speed of flow, ratio of sap to air in the lines) and rate of sap accumulation in collection tanks. **Mechanical vacuum was directed to all lines in the network by leaving ball valves open, reducing vacuum in the mainline to 6.25 inHg**. This was done on purpose to simulate conditions on a lower vacuum system, as might be achieved by a cheaper Sureflo diaphragm pump that is commonly used by smaller producers.

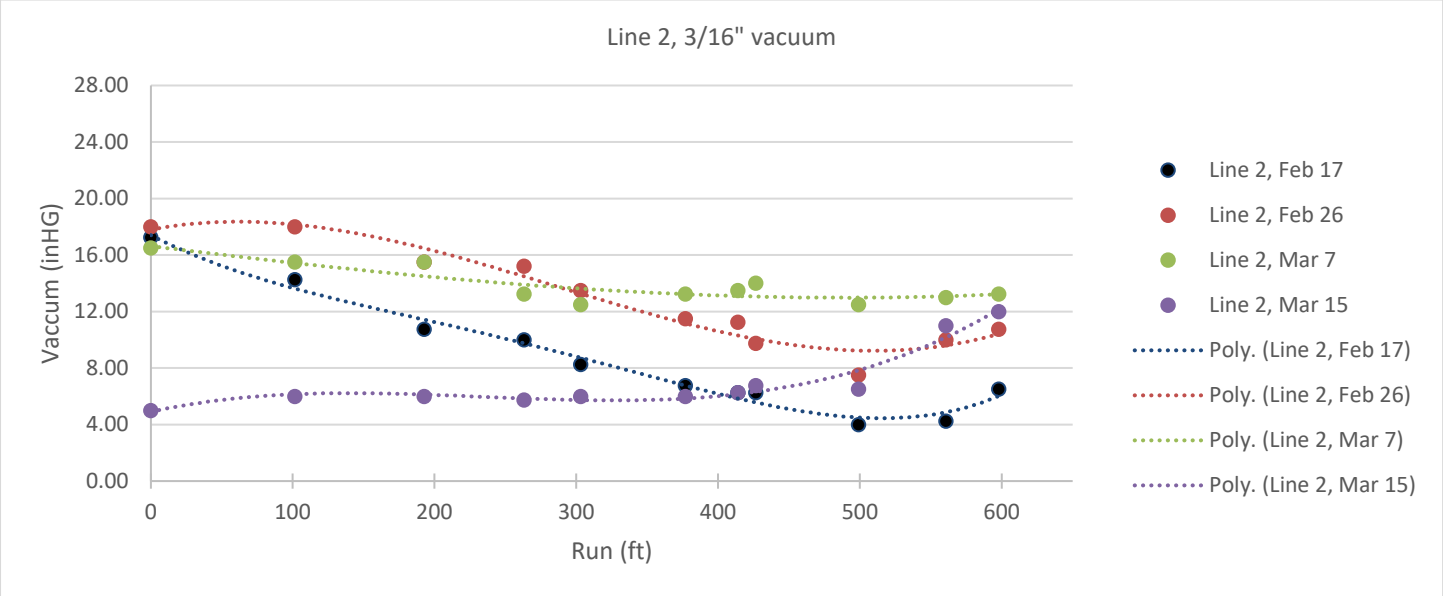
Figure 5: Sap transfer from a collection tank to the haul tank. A vacuum pump can be seen on top of the collection tank, powered by the red generator next to the tank.

3 - RESULTS AND INTERPRETATION

3.1 Results by Line Type

3/16" vacuum lines

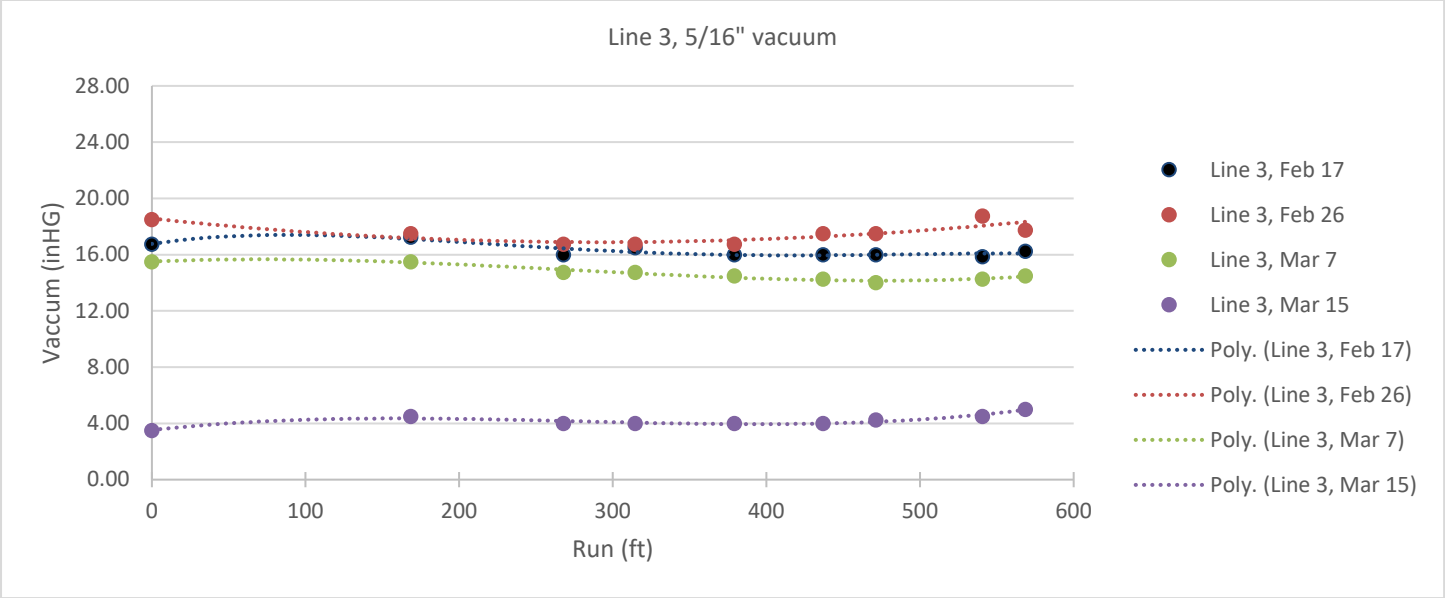


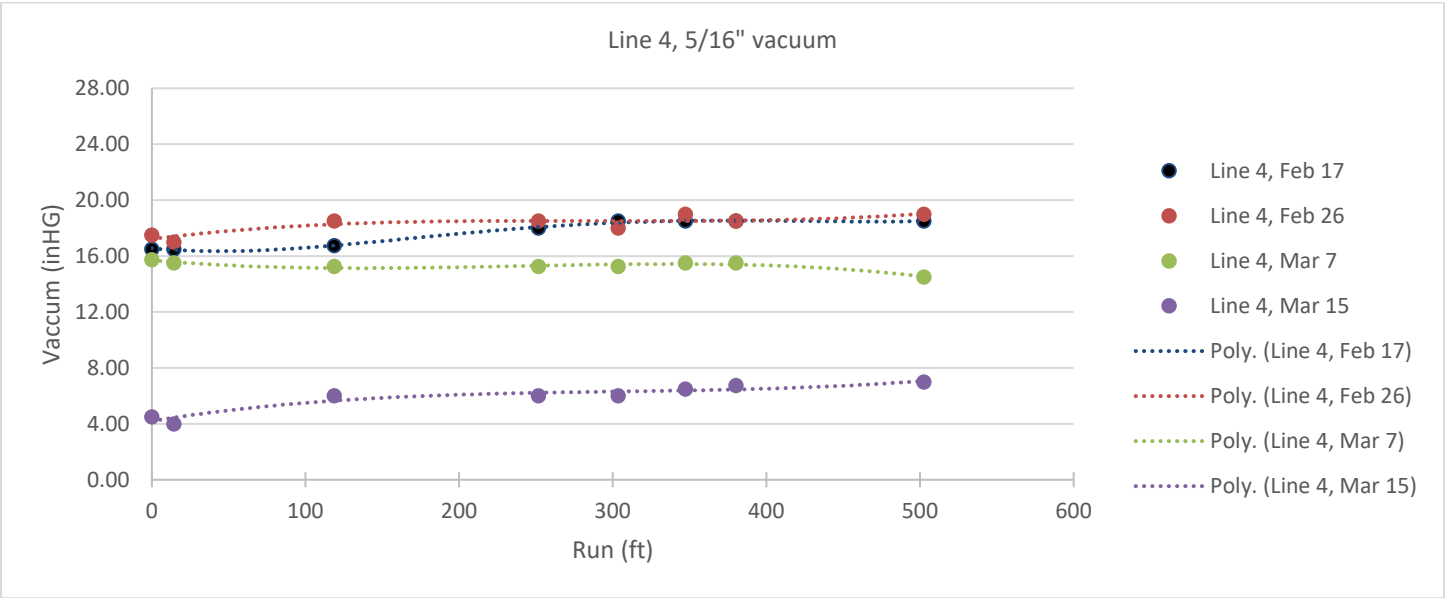


Observations & Interpretation: On 3/16" lines with high vacuum (Feb 17, Feb 26, Mar 7) vacuum begins high closest to the mainline and decreases gradually. This was also observed visually, as the pulsing motion of the diaphragm pump can be seen on lower taps and fades into continuous smooth flow further up the lines. The decrease in vacuum may be attributed to friction loss, as well as the capillary flow in 3/16" lines; there is no air space above the sap to transmit vacuum up the line. With relatively higher volumes of gases present in walnut sap lines compared to maple, the "pulling" effect appears to be limited and does not carry far up the lines, as gases are generally more compressible/expandable than liquids. Towards the top of all lines, there is a subtle but noticeable increase in vacuum. This may be attributed to the "hybrid" effect of 3/16" lines on vacuum: taps near the top of the lines benefit from gravity/capillary vacuum, as the weight of the sap further down the line increases vacuum at higher taps. Notably, on March 15th when vacuum was reduced to 6.25 inches, there did not appear to be much vacuum loss and the gravity effect was more pronounced, particularly on line 1. Throughout the season, the 3/16" lines on vacuum did not

appear to yield as much sap as other lines in the system; perhaps the impact of vacuum “sucking the taps dry” and drawing in more gases through the tree tissue.

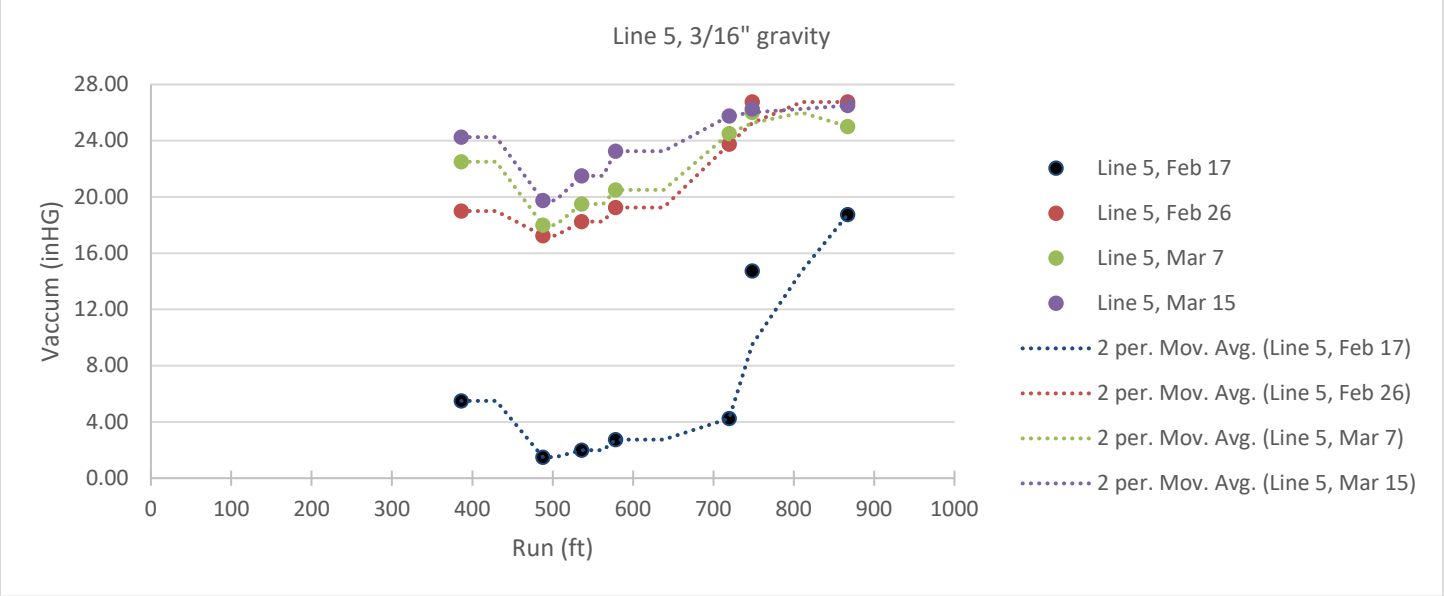
5/16” vacuum lines

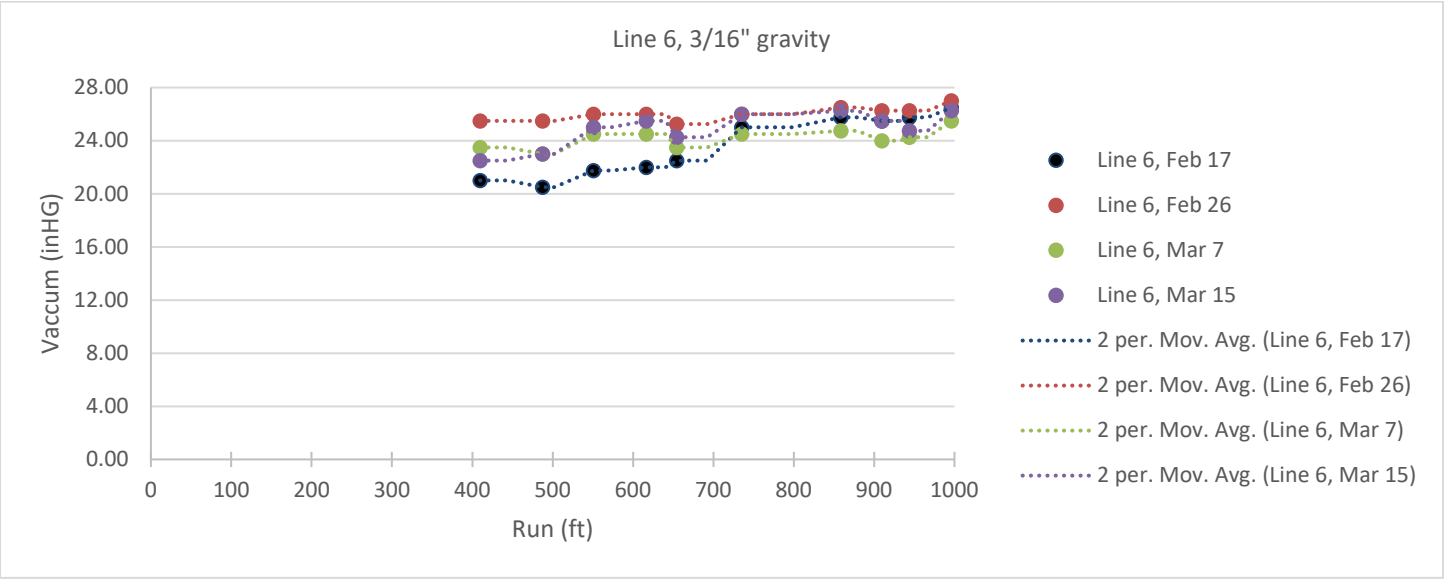




Observations & Interpretation: 5/16” lines transmitted high vacuum throughout the length of the test lines, yielding nearly flat linear vacuum patterns. This applied equally to high vacuum and low vacuum tests. The only day that capillary flow was observed in the 5/16” lines was on March 15th. This can be noticed in the corresponding graph on line 4, where a gradual increase in vacuum readings may be attributed to gravity vacuum.

3/16" gravity lines



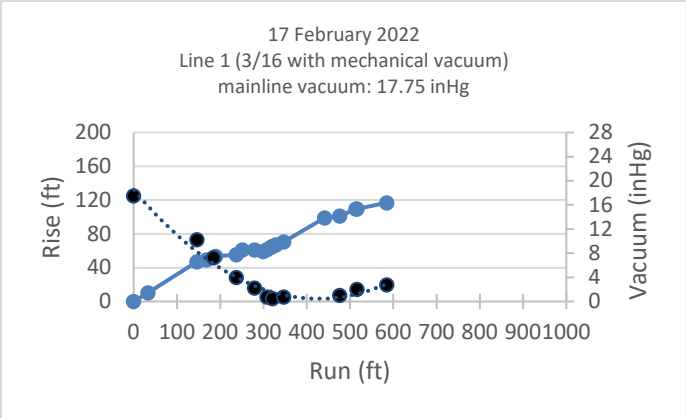


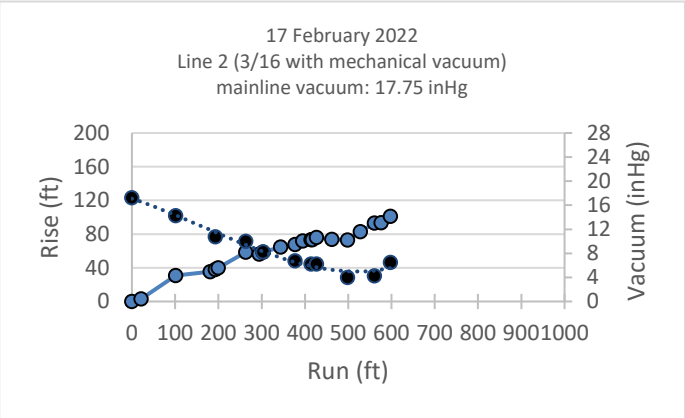
Observations & Interpretation: The highest vacuum levels in the study were consistently found on the 3/16" gravity lines. Both of these test lines were consistently full of sap throughout the season, with visibly less gas and moving at a slower rate than the lines with mechanical vacuum, but with significantly higher vacuum readings. Under certain circumstances, these lines achieved vacuum readings approaching 28 inHg, the upper limit for vacuum in any system due to atmospheric pressure normally varying between 27 and 28 in Hg at the site's elevation of 2800 feet above sea level. There are two notable anomalies in the first graph, representing line 5. There is a consistent dip at tree number 22, located roughly 490 feet from the beginning of the line. This pattern is consistent with an undetected leak, which often occurs when a tap hits hollow or porous wood; no hissing can be heard because air enters unimpeded through the inside of the tap. The second anomaly can be seen on February 17th on line 5: there was a leak at tree 127, located 638 feet from the beginning of the line. The leak could not be repaired at the time of data collection because the required tool was not on hand. The data therefore shows a drop at that tap, followed by a gradual increase in vacuum for taps above the leak. It is noteworthy that a leak in the gravity system "corrects" itself on taps above the leak, while this phenomenon is impossible on a purely mechanical vacuum system reliant on transmission of vacuum up the line beyond the leak. While this study did not measure sap flow, Tonoloway Farm harvest records show that these two lines with 64 taps produced an astounding 13 gallons per tap during the study period, compared with 2.9 gallons per tap for all other 1200 taps on a combination of 3/16 gravity, 3/16 vacuum and 5/16 vacuum lines. Interestingly, the sugar content on these lines averaged 0.5 brix, while the rest of the farm averaged 1.1 brix for the season. Still, accounting for low brix, these two lines produced nearly twice the sugar of the rest of the farm.

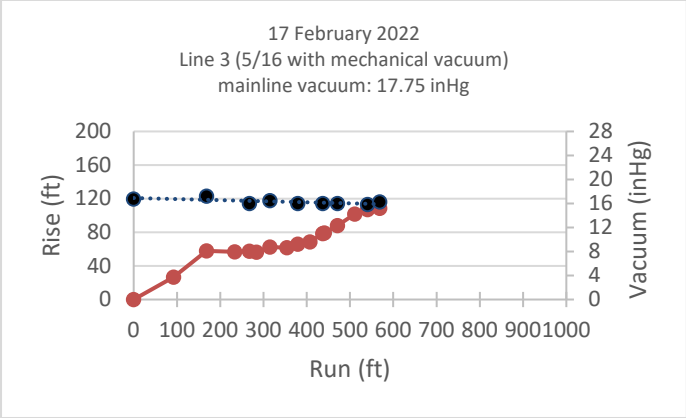
3.2 Results by date

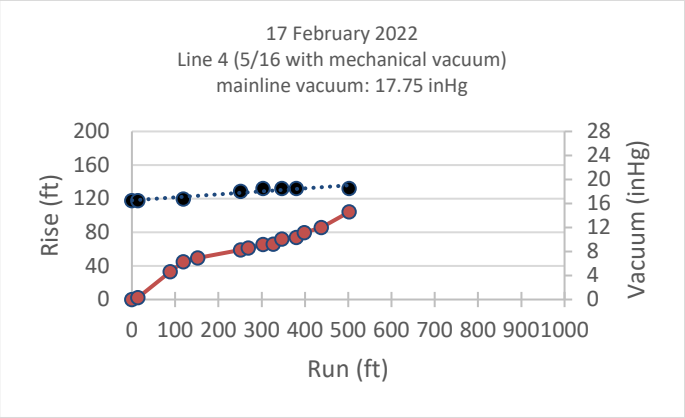
Solid lines show sap line profiles vs. elevation (left X axis), dotted lines show vacuum (right X axis).

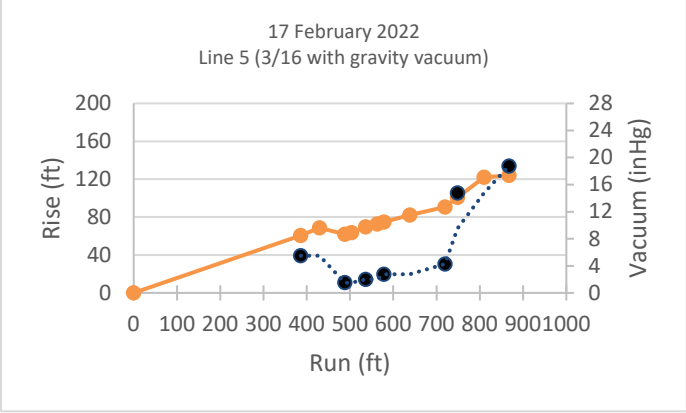
Graphs are included here to illustrate trends. Full data set and larger scale graphs in Annex.

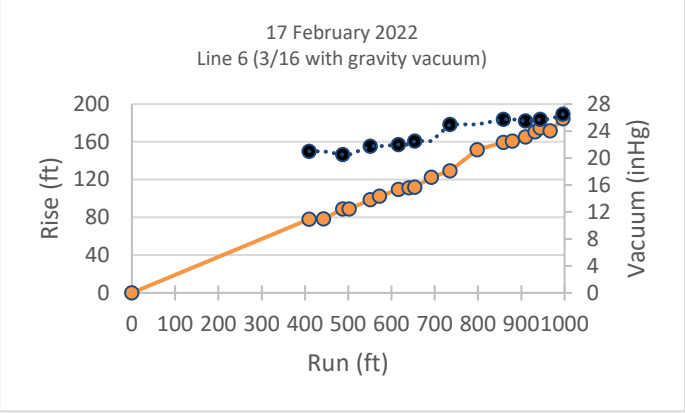






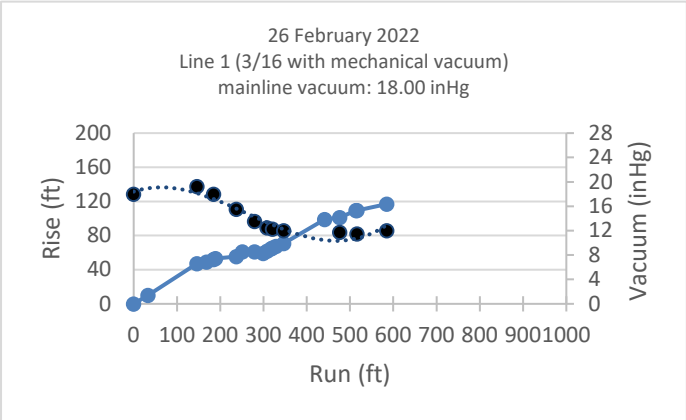


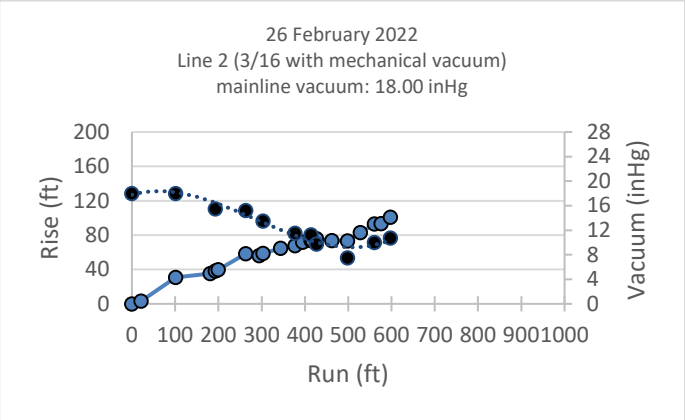


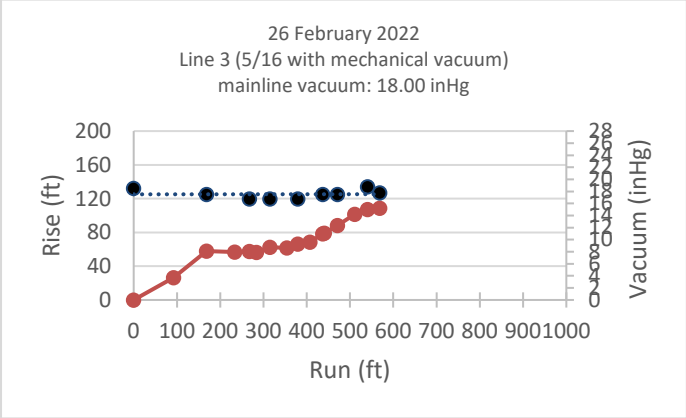


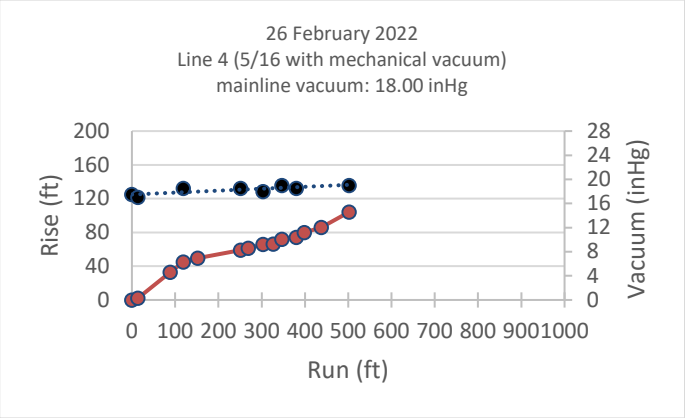
Observations & Interpretation: February 17th was the first day after tapping and heavy sap flow was observed. Daytime temperature reached 48F after freezing the two previous nights. Mechanical vacuum was directed exclusively to the study area, with vacuum on the mainline measured at 17.75 inHg. Lines 1 and 2 (3/16 vacuum) show a relatively rapid decline in vacuum traveling up the line, with a slight rise at the top, presumably due to gravity-vacuum hybrid effect. Lines 2 and 3 (5/16 vacuum) show a nearly flat vacuum readings, indicating consistent transmission of vacuum up the line. Line 5 shows a leak 638 feet up the line, while Line 6 shows the highest vacuum readings collected that day, approaching 28 inHg at the top of the line.

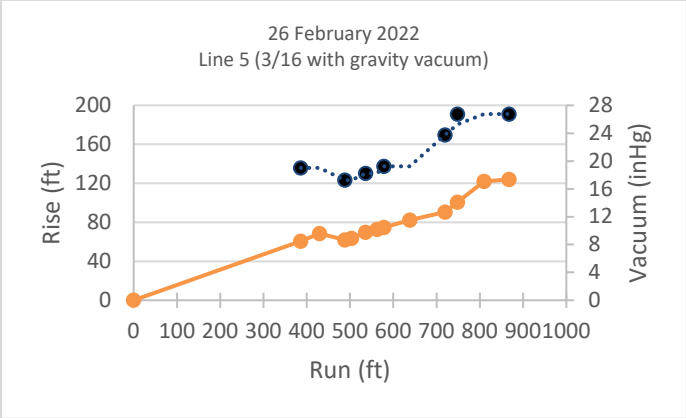
Solid lines show sap line profiles vs. elevation (left X axis), dotted lines show vacuum (right X axis).

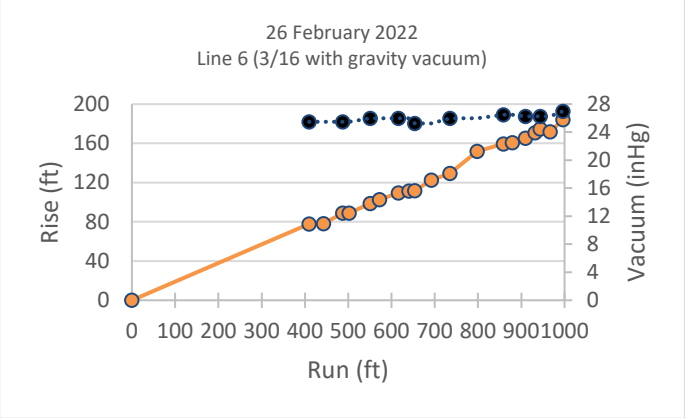






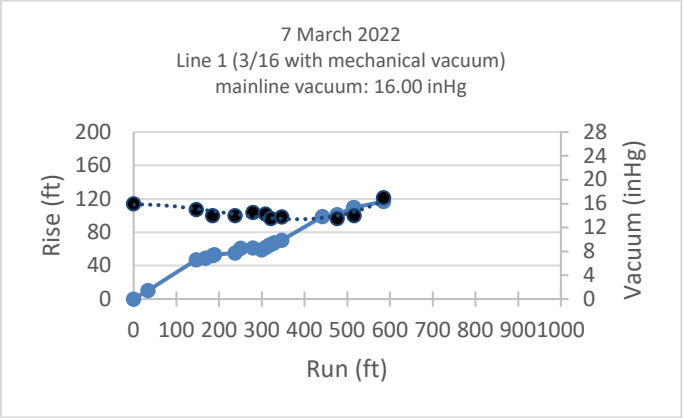


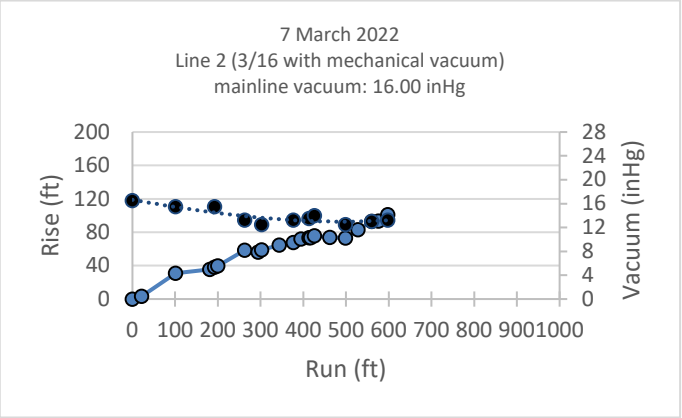


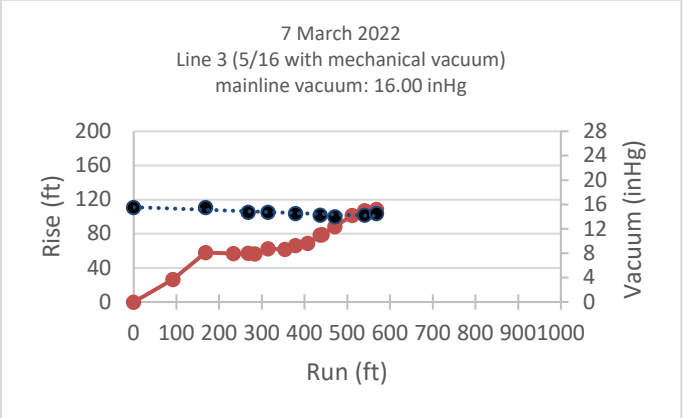


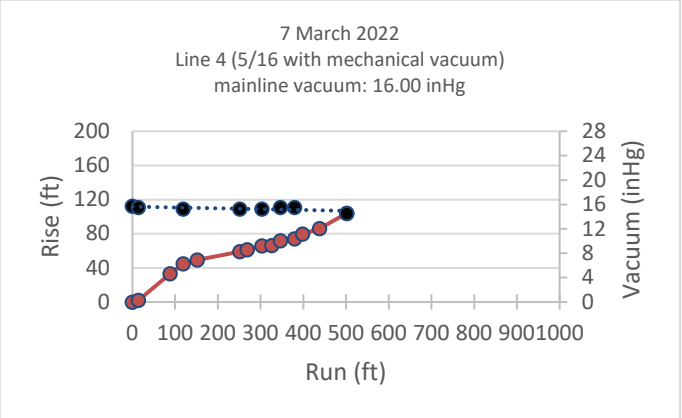
Observations and Interpretation: February 26th was a day of moderate sap flow, as daytime temperature reached 40F after one night below freezing. Mechanical vacuum was directed exclusively to the study area, recorded at 18.00 in Hg at the mainline. On lines 1 and 2 (3/16 vacuum) the decrease in vacuum was not as dramatic as on February 17th, with all but one reading keeping above 8 in Hg. The “hybrid effect” rise in vacuum was once again noted at the top of lines 1 and 2. Lines 3 and 4 (5/16 vacuum) maintained the same consistently high vacuum as was previously observed. Line 5 (3/16 gravity) shows a dip at the leaky tap, followed by a consistent rise to very high vacuum at the top, while line 6 (also 3/16 gravity) maintained high vacuum across all measurements.

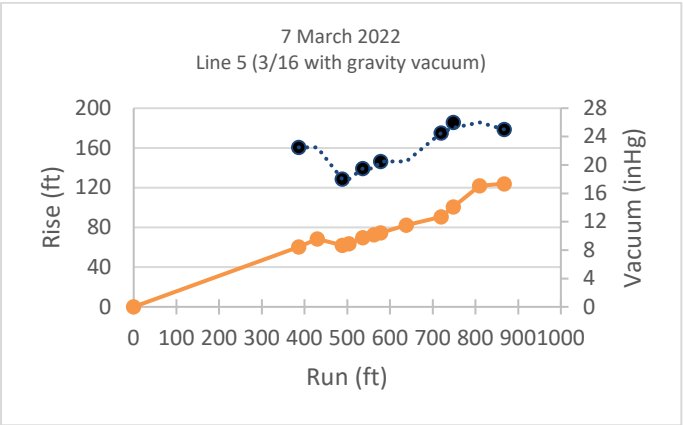
Solid lines show sap line profiles vs. elevation (left X axis), dotted lines show vacuum (right X axis).

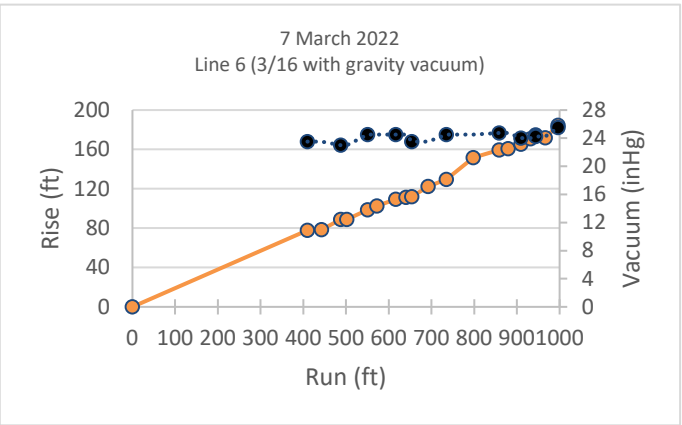






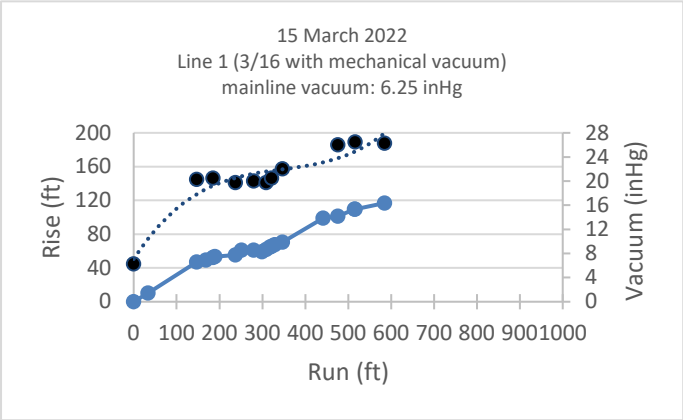


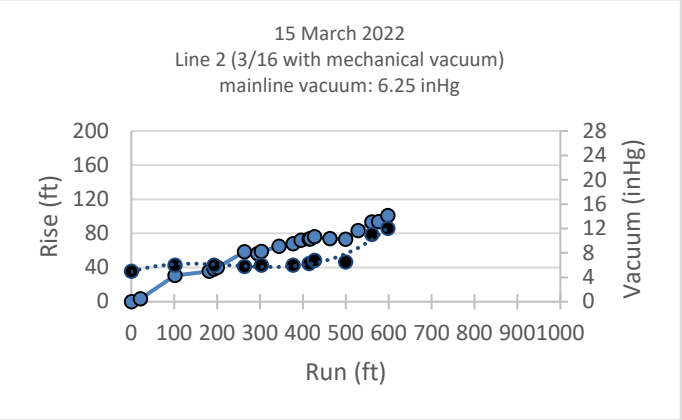


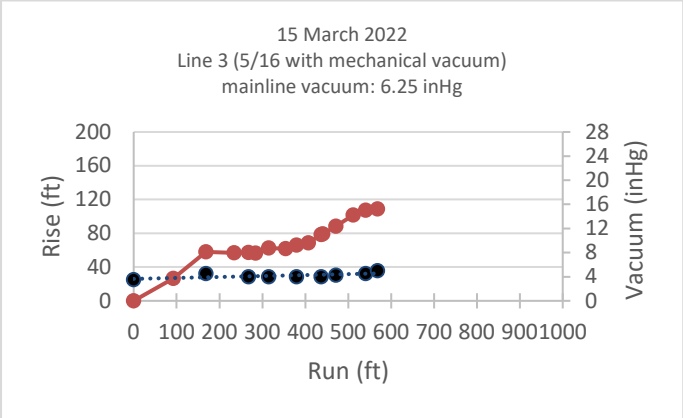


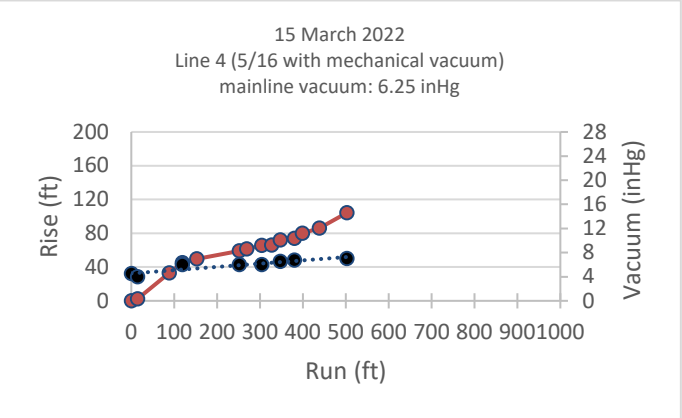
Observations and Interpretation: March 7th was a day of light sap flow on vacuum lines, with moderate flow on the gravity lines. Temperatures approaching 50 without a recent freeze. Mechanical vacuum was directed exclusively to the study lines with a reading of 16.00 inches at the mainline. It is worth noting the trend of decreasing vacuum at the mainline from February 17th to March 7th. As sap flow decreases and taps begin to "dry up", it appears that the vacuum pump struggles to maintain high vacuum due to the increase in gases entering lines through tap holes. There were no other indications of leaks observed nor evidence in the data for this date on lines with mechanical vacuum. For lines 1 and 2 (3/16 vacuum), the decrease in vacuum along the line is much less dramatic than was seen on previous dates. Lines 3 and 4 (5/16) maintain the same nearly flat transmission of vacuum up the line. Lines 5 and 6 repeated the pattern that was previously seen, while continuing to yield more sap than other lines throughout the network. On this day, it was observed that certain gravity 3/16 lines not included in the study struggled to move sap past rises in the sap lines. While the test lines were almost entirely downhill, other lines included small rises that are a notable feature of 3/16 lines. With sap flow slowing down this late in the season, the sap near the bottom of the lines did not create enough gravity vacuum to draw sap over small rises in the lines. This phenomenon wasn't seen on 3/16 vacuum lines, indicating a potential advantage to hybrid 3/16 systems with mechanical vacuum.

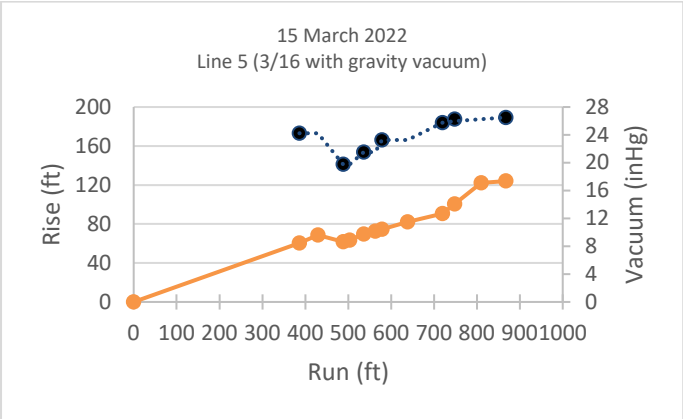
Solid lines show sap line profiles vs. elevation (left X axis), dotted lines show vacuum (right X axis).

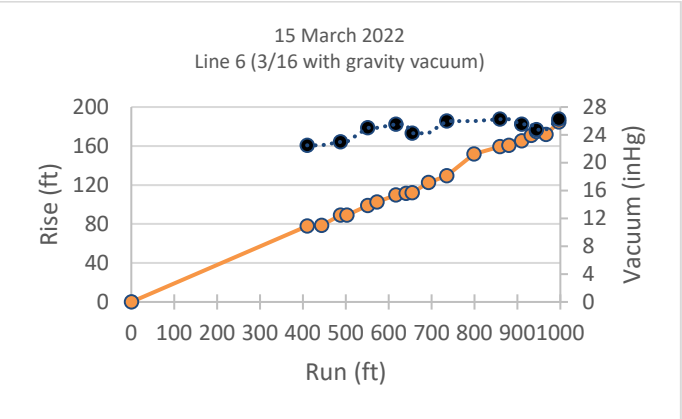












Observations and Interpretation: Having seen a consistent pattern emerge in the first three data sets, the research team decided to reduce mechanical vacuum on this last day, March 15th. With sap flow slowing in all lines, the weather provided another opportunity for sap harvest with weather reaching 55 after a mild overnight freeze of 31 degrees. All the study lines continued to have sap flow, although the farm harvested roughly 1/3 as much sap on this day as had been harvested earlier in the season. To simulate a lower-pressure vacuum system, the ball valve was left open, directing vacuum to a larger network of 542 taps in addition to the 115 taps on the four study lines for mechanical vacuum. With this configuration, the vacuum measurement at the mainline was 6.25 in Hg. On lines 1 and 2 (3/16 vacuum) there was no decrease in vacuum going up the line. In fact, vacuum increased due to gravity/capillary effect. Interestingly, capillary flow was also seen on 5/16 lines on this day with a pattern of increasing vacuum on Line 4, even though the sap volume was quite low. This could be attributed to slower overall movement through the lines (lower vacuum at the pump) or perhaps changing consistency of the sap at this late point in the season. It is also worth noting that the syrup produced from this late-season sap was sour-tasting and nearly unpalatable.

3.3 Weaknesses of the study

There are several factors that weaken the conclusions of the study, most of which were impossible to mitigate during this project.

1. This study only considers variations in vacuum along the sap lines. While it is established that higher vacuum yields higher sap flow, we have no direct correlation in this study. After all, syrup producers ultimately benefit from large sap harvests, regardless of vacuum. The observations on 3/16" vacuum lines that the lines may have been "sucked dry" might put into question the benefits of high vacuum on 3/16 lines. Although it was beyond the scope of the current research, further study comparing vacuum to sap yield will help determine the best combinations of line selection and vacuum configuration.
2. The topography of the location and the existence of other sap lines for Tonoloway's commercial syrup production limited the site selection for new study lines. This led to the decision to install the 3/16" gravity lines at a different location from the vacuum lines, where there was more elevation gain between the collection tank and the top of the lines. While this exaggerated the effect of capillary vacuum, making the trends easier to observe, it is not a true "apples to apples" comparison with the vacuum lines which did not have as high of elevation gains from the mainline to the highest tree.
3. The presence of additional tees on the lines for vacuum measurements causes increased friction, slowing the flow of sap down the lines and reducing the transmission of vacuum up the lines. While unavoidable by the design of this research, it is worth acknowledging the possible impact caused by the additional tees required for the study.

4 - CONCLUSIONS

4.1 Vacuum trends

In comparing the three vacuum-line configurations, clear patterns emerged:

1. 3/16 lines with high vacuum do not effectively transmit vacuum up the line, although the vacuum may be beneficial to keep sap moving on low-flow days. An interesting phenomenon is seen in which vacuum levels climb near the top of the line, showing the effect of capillary/gravity vacuum overcoming friction losses that presumably reduced the mechanical vacuum.
2. 5/16 lines are highly effective at transmitting vacuum up the lines, with virtually no vacuum loss throughout the study. The longest line in this configuration was 36 taps on 16 trees over a length of 570 feet.
3. Under the right circumstances, 3/16 gravity lines have potential to exceed the vacuum levels created with mechanical pumps, but this may be contingent on ideal line layout with significant elevation drop and minimal rises.

4.2 Lessons learned

While the limitations of the study make it difficult to declare a singular "winner" for the best system to use when tapping black walnut trees, there are several takeaways that may be helpful to syrup producers. These are informed primarily by the vacuum readings from this study, combined with observation, limited sap harvest data, and experiences from 4 years of black walnut syrup production at Tonoloway Farm.

- Under the right circumstances, 3/16 gravity lines can compete and even outperform mechanical systems with both 5/16 and 3/16 tubing. This makes them a good candidate for small scale operations, or installation of lines in remote locations where it may be difficult to set up a vacuum pump. It is important that these lines have significant elevation drop to function properly, and their performance seems to decrease with even small rises in the lines.
- 5/16 vacuum systems are the most effective at consistently delivering pumped vacuum to the taps. We can't conclude decisively that this results in higher sap yields, but certainly increases the likelihood that all available sap will be harvested. However, 5/16 lines are more challenging to install because they do not tolerate any elevation rise, and they are also more difficult to check for leaks because sap flow is less visible. Given how important it is to check for leaks when harvesting black walnut sap, and the higher cost of 5/16 tubing, Tonoloway Farm has opted to use 3/16 tubing on future sap line installations.
- 3/16 lines on high vacuum are not effective at fully delivering high vacuum far up the lines. However, there is an interesting phenomenon of "hybrid vacuum" in which the influence of mechanical vacuum gradually decreases while gravity/capillary vacuum increases higher up the lines. It appears that the use

of any vacuum pump, be it high (10+ inches of Hg) or low (5-10 inches of Hg) does have a beneficial impact of preventing stagnation by “pulling” sap out of the lines.

Further study would be required to develop definitive recommendations for the burgeoning walnut syrup industry. A definitive study would combine this newfound understanding of vacuum patterns with measurements of sap yield on the same lines (ideally at the level of individual taps, but line totals would also provide valuable insight). Nonetheless, the present research provides a new understanding of **how** vacuum is transmitted through a walnut sap line, providing evidence for syrup producers making decisions about the best tubing systems for their particular topography, scale, budget and equipment.

The research team wishes to thank USDA Southern SARE for their support on this project. We also thank the Virginia Tech Department of Sustainable Biomaterials, for its support of this project and of the production of black walnut syrup while extending broader opportunities for non-timber forest production in our Central Appalachian forests.

5 - ANNEX

These files are uploaded separately:

2022-06-16-WalnutVacStudyDataMASTER – includes complete data and graphs
2022-04-11-TonolowayFarmMcdowellVaTreeSurvey C-1 – overview of the Tonoloway Farm research lines
2022-04-11-TonolowayFarmMcdowellVaTreeSurvey C-2 – detailed view of four vacuum lines
2022-04-11-TonolowayFarmMcdowellVaTreeSurvey C-3 – detailed view of two gravity lines

6 - LITERATURE CITED

US Forest Service. 2018 Assessment of Nontimber Forest Products in the United States Under Changing Conditions.

US Forest Service. 2020. EVALIDator inventory data. Forest Inventory and Analysis National Program. Accessed online at https://www.fia.fs.fed.us/tools-data/, March 25, 2020.

Rechlin, Mike, Kate Fotos, Christoph Herby, and Matt Cabral. 2020. The Effect of Vacuum on Walnut Sap Flow. Franklin, WV. Future Generations University Press.