Maple Syrup Digest. Dec 2023. 62(4): 7-17.

A 20-Year Record of Syrup Production at UVM Proctor Maple Research Center from 2004-2023

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The University of Vermont (UVM) Proctor Maple Research Center (PMRC) in Underhill, Vermont, has along history of research on sap production. Maple syrup has been made at PMRC since shortly after its founding in 1946, in part for research and in part for demonstration. Syrup production has always been an important component of the work of PMRC as it keeps the faculty and staff aware of the issues involved in sap collection and syrup production, it provides more of a "buy in" from producers when they understand that we face the same hurdles as they do each season, and the revenue gained from the sale of maple syrup helps to fund the operation.

The tubing system after the turn of the century had been constructed piecemeal over several previous decades since tubing systems had been introduced as funding allowed and as a result of different research projects. Vacuum was provided by a modified dairy pump and a custom-built releaser generating (at best) 15" Hg of vacuum. Clearly, PMRC was not operating a "state-of-the art" tubing production system at that time. Syrup production averaged 0.34 gallons per tap, about 42% above the Vermont industry average at that time (including all types of production).

In 2003, the decision was made to totally replace the legacy system in the main portion of the PMRC sugarbush with a modern high-yield sap collection system and to more fully incorporate sap collection into the research program and to progressively work on tubing or retubing other sections of the PMRC lands. A generous grant from the Chittenden County (VT) Maple Sugarmakers Association and financialassistance from several other Vermont maple groups funded the project in large-part. The goals of the project were:

1. To design and install a state-of-the-art (for 2004) maple sap collection system in the main bush.

2. To progressively replace other sections of the PMRC sugarbush and to expand into non-tapped areas of the woods.

3. To compare equipment, installation techniques, and economics among several mapleequipment manufacturers.

4. To incorporate more of the production woods into the research program.

5. To allow quantification of sap yields from different portions of the

sugarbush.

Methods

To accomplish these goals, the main sugarbush at PMRC was divided into four roughly equal-sized areas based upon tap count. Several maple equipment companies were invited to participate in this project. Guidelines for the companies included a restriction on tree diameters and general system considerations for installation (# taps per lateral – "strive for five", short laterals running downhill) were discussed. This was followed by a walk-through of the woods in the fall of 2003 with representatives from the various companies selected. Afterwards, sections were randomly assigned to each company and their costs estimates developed and provided. UVM PMRC paid the full installation costs, including materials and labor, for each of the installed systems. Companies were allowed to design, choose the materials and methods used, and install the sap collection system in their portion of the woods, keeping in mind that the costs could be included in the presentation of results, the costs weighed against the sap yields achieved, and that maintenance efforts, costs, and problems might also be reported. A fourth system was installed by a professional tubing installation company which was allowed to select the equipment (tubing materials) they thought was economically advantageous and worked best irrespective of the maple supply company. All the tubing systems terminated at the Sumner Hill Williams Sugarhouse at PMRC with individual Lapierre mechanical releasers equipped with counters connected to a common vacuum pump (initially a Leader Oil-Flood pump, but upgraded to a Busch Rotary-Claw pump several years later). In this way, sap volumes for each section could be monitored.

In the fall of 2005, the remaining portion of the current sugarbush at PMRC was also retubed. This area, called "Red Series" was set up primarily as a research platform, with 16 separate ¾" mainlines, with each mainline connected to its own custom Lapierre mini-releaser. A professional tubing installer set up the woods at the direction and guidance of PMRC staff. The entire system was serviced by a Busch Rotary-Claw vacuum pump.

Land adjacent to the Red Series section was acquired in 2009 and was tubed in time for the 2010 season. This "Martin Block" section was set up in a similar fashion to the "Red Series" section, with 12 individual ¾" mainlines each connected to their own custom Lapierre mini-releaser, again professionally installed. This system also had its own Busch Rotary-Claw vacuum pump.

In 2021, a 1,000 tap expansion was conducted in a new section of the woods. This consisted of two duplicate single-pipe systems: one servicing approximately 500 red maple trees and the other servicing approximately 500 sugar maple trees. Sap flowed through one of two identical Lapierre electric releasers (one for red maple sap, the other for sugar maple sap) equipped with meters and connected to a common Busch Rotary-Claw vacuum pump. The mainline was installed by a professional tubing installer, but the lateral line system was installed by PMRC staff.

Changes to all parts of the sugarbush after retubing were primarily aimed at maintenance and sanitation related efforts, but also included some occasional modest expansion into peripheral areas as well as the addition of trees due to ingrowth. Over the 20 yr span of this work, the type, number, and capability of vacuum pumps used at the sites varied. For the majority of the time, Busch rotary-claw vacuum pumps were used and a vacuum level of around 24-25+ "Hg was the target (our woods average above 1,500 ft elevation). In some years the vacuum level achieved was better than others for various reasons (powerfailure, pump/moisture trap/releaser failure, major tubing failure, etc.).

During each spring season, after sap volume and sap sugar content were measured, the sap was concentrated then boiled to syrup.

Results

Our goal in this paper is not to examine each of the individual factors contributing to total syrup yield during this 20 yr time period at UVM PMRC in detail, but rather to provide a high-level overview ofproduction and make generalized conclusions about the performance of the tubing systems used.

The main bush area initially totaled approximately 1,175 taps averaging 18.6 inches diameter (dbh). Themajority of tapped trees were over 12 inches dbh in 2003. Only 5.2% of trees that ended up being connected to the new tubing systems had diameters less than 12 inches – most of these were over 11 inches dbh. The minimum tapped tree dbh was 9.8 inches – the maximum was 47.3 inches. This area of the sugarbush was the original PMRC sugarbush and had been heavily managed for maple production according to existing standards from the early-1900s to early-2000s. Thus, this area was dominated almost exclusively by large sugar maples that had been tapped for decades. By 2023 tap count in the main bush had expanded to 2,689 trees, more than doubling the original tap count. This occurred primarily though the addition of trees between 9 and 12 inches dbh (as tapping guidelines relaxed due to the introduction of the "small" spout), growth of trees, extension of mainlines into upper areas of that were less accessible by tractor, and the addition of red maple taps that had been passed over in the legacy tubing system.

Three of the four subsections in the main bush were tubed with dual-pipe systems. The fourth was a single-pipe system. Three systems used blue-translucent HDPE maple mainline – the other used thinner-walled, black, poly waterpipe. All of the dual-pipe systems used PVC-pipe manifolds (common in 2004). Failure of these due to breakage by sap freezing in them was common in the first several years, sometimes resulting in considerable sap loss before the breakage was located and repaired. Initially the PVC manifolds were repaired or replaced with like items, then later were replaced by stainless steel-manifolds, and eventually all of the "pipe" manifolds were replaced with "whip" style manifolds. These proved to be very robust and reliable.

All lateral line installed in the woods was either semi-stiff tubing or rigid tubing. Although the companies used were instructed to "strive for five, no more than ten" taps on a lateral line, the lateral tubing installation actually averaged under three taps per lateral. Only rarely were more than five taps installed on a single lateral. Lateral lines tended to be short as a consequence of this.

All spouts used for the duration of this study were 5/16". For all but two years, all trees received only 1 tap – regardless of diameter. Tapholes generally averaged 2" deep (including bark), but varied somewhat by year, ranging from 1 1/2" to 2 1/2 deep. Sanitation was initially accomplished by air-water pressure cleaning, but later (after about 2010) was done by the use of new spouts each year, the use of Check-valve spouts, and/or periodic dropline replacement.

The one single-pipe system failed after five yrs use, probably due to low or insufficient UV inhibitors in the plastic used for extrusion. Both the lateral line tubing and mainline became brittle and shattered under light impact. Repair was impractical, so the system was entirely replaced with a dual-pipe system at that time.

In the "Red Series" sections, tap count for the newly tubed area for the first sap collection season in 2006 was around 630 trees. By 2023 tap count in Red Series had doubled to 1,285 due to the same factors described for the Main Bush area above. Average tree size in 2005 was 14.8 inches dbh. About 62% of trees were sugar maple – the remaining 38% were red maple. The number of taps per lateral averaged three. Research in this section of the woods originally focused on spout and tubing sanitation approaches before transitioning to a platform to study various the effects of various tapping factors (tapping depth etc.) on sap yield.

The "Martin Bush" section, added for the 2010 season, originally added 885 taps, all lines with exactly three taps per lateral. Mainlines averaged 74 taps. By the 2023 season it reached 1,411 taps, a growth of 59%. Research in this area has focused on exploring tubing system design factors to improve yields.

The "Red/Sugar" section, added in 2021, consisted of 534 red maple taps averaging 11.4 inches dbh and 499 sugar maple taps averaging 12.7 inches dbh.

Overall, the tap count at UVM PMRC grew from 1,549 taps in 2004 to 6,248 taps in 2023 (Figure 1) values shown across top of graph), a four-fold increase, or about 20% per year when averaged over the 20 yrs. This largely mirrors the growth in taps of the Vermont maple industry over the same time period. As described above, growth in the number of taps was not uniform over time, but was usually associated with the extending tubing into new sections of woods, the lowering of minimum diameter for tapping, and the addition of ingrowth as trees reached minimum tapping diameter. new sections of woods, the lowering of minimum diameter for tapping, and the addition of ingrowth as trees reached minimum tapping diameter.

The reported syrup values in Figure 1 represents mostly Grade A marketable syrup. Production at PMRC is generally halted when syrup turns sour or buddy or if the syrup becomes difficult/impossible to process (filter). In many years all syrup was Grade A. In a few seasons a small amount of syrup produced (usually only a barrel or two at the end of the year) graded commercial, generally if syrup turned sour or buddy before boiling out the pans could be accomplished.

Over the 20 yr time period from 2004-2023, average yield was 0.58 gal syrup per tap (or 6.4 lbs per tap, Figure 1). The highest yield occurred in the first season after retubing (2004) – a not unusual phenomenon in maple production. Low production years were observed in 2012 and 2021, both primarily due to weather. In 2012, record high temperatures in mid-March resulted in the early appearance of buddy off-flavor. In 2021, prolonged warm-hot weather without intervening freezes caused sap to sour or go ropey within the tubing system, making processing sap into syrup difficult and the resultant product unpalatable. Interestingly, in 2021 sap production totals averaged close to normal, however spoiling in the lines prevented much of that sap from being imum target production (0.5 gal syrup per tap), but fell below average. Only two seasons (10%) fell below the target minimum level. What is quite clear however is that syrup yields throughout this 20-year timespan are considerably higher than the average yield from the legacy sap collection system at PMRC prior to retubing (0.34 gal syrup per tap). Not a mm at PMRC prior to retubing (0.34 gal syrup per tap). Not a single year prior to retubing in 2004 resulted in breaking 0.5 gal syrup per tap at PMRC. Ninety percent of years from 2004 onward exceeded that production level. Overall, the average syrup production at UVM PMRC in this twenty-year period following retubing was 70.6% higher than the average production rate prior to retubing. During this same time period, syrup production of Vermont maple producers increased from an average of 0.24 gal syrup per tap to 0.37 gal syrup per tap, a 54% improvement in yield. This likely represents the addition or expansion of new high-yield systems in the Vermont maple industry and the replacement of older, legacy sap collection systems (older tubing, lower vacuum, 7/16" spouts) with newer high-yield systems.

Average production during the first five years in all three dual-pipe systems was almost identical at 0.60-0.61 gal syrup per tap (Figure 2). Yield was slightly lower in the single-pipe system at 0.54 gal syrup per tap. The small differences among systems from one year to the next mostly seem to stem from the timing of breakage of PVC manifolds rather than actual variation in sap flow.

While there is obvious variation in syrup yield from year-to-year, there doesn't appear to be any strong overall trend in yield over this 20 yrs of observation, either positive or negative. Despite the growth in number of taps and aging of the systems over 20 yrs, given adequate system maintenance and operation, production has remained good to this time (Figure 3). The slight (and non-significant) trend in syrup yield downward over 20 yrs is very low, averaging only 1.7-3.8% per decade. This indicates that maple tubing systems that are well-maintained and operated using good vacuum and adequate sanitation practices can remain productive for at least two decades and probably longer. Moreover, not a single year in this 20 yrs of operation fell as low as the best year of the preceding tubing system.

Although sap quality was not quantified as part of this project, observational data indicate that the sap from the system built with black water pipe may have been slightly more degraded.

The cost of retubing the main bush in 2004, including both materials and labor, ranged from $10.56 to $24.48 per tap, averaging $17.34 per tap. The variation was due in part to the type of system installed (single-pipe mainline system was considerably cheaper than the dual-line systems), the materials used (poly black waterpipe was cheaper than maple HDPE mainline), the number of taps in the section (economy of scale), and the density of trees in that section lower tree density necessitating more materials and labor to reach the same number of taps).

When the cost is expressed as a dollar amount per gallon of sap annually over the first five years of operation (2004-2008), it ranges from $0.09 to $0.20 per gallon (Figure 4), largely following the factors described above. More importantly, at the high sap yields achieved, when looking at ONLY the cost/benefit of the tubing systems themselves (and not including the equipment and labor to process sap into syrup), all of the systems achieved complete payback in the first year. The failure of the single-pipe system due to UV-breakdown after five years represents a major expense, essentially total replacement. All the remaining systems are still in place and operationally functional after 20 yrs. The tubing used in the failed system was warrantied for only five years. It is therefore recommended that producers purchase (if possible) tubing made with a considerably longer warranty period to avoid the trouble and expense of having to remove affected tubing from the woods and replace it.

While tubing system design, installation, operation, and maintenance are key factors in achieving high yield, the vagaries of different seasons imposed an overall limit on syrup production in some years. In particular, the hot years of 2012 and 2021 were quite detrimental to high productivity. Other years in which sap yields were low were associated with equipment failures of different types. Choosing the proper equipment and maintaining it in peak operating spare equipment and parts readily available in case of failures, using good spout and drop sanitation practices, and maintaining good vacuum are all recommended to avoid calamitous seasons.

Conclusions

- High syrup yields (> 0.5 gal per tap) over a long period of time are achievable with modern methods. Averages of double or more that of gravity sap collection can be realized.

- Careful attention to detail at multiple steps in the process is imperative.

- Preparing for things to go wrong, having extra equipment and spare parts readily available and identifying and repairing any failures that occur promptly will help to ensure success.

- Payback periods for the cost of a new tubing install utilizing high yield methods can be as short as one season for producers making syrup, or within two-seasons if selling sap.

- Using quality tubing materials with a long lifespan is important to avoid the need to replace systems more frequently.

- Dual-pipe systems tend to outproduce single-pipe systems on vacuum by at least 10-12%.

- Whip-style manifolds are superior in performance, less costly than PVC or stainless-steel manifolds, and require less maintenance.

- Loss in overall system productivity as measured by syrup yield, waswas very low over 20-yrs, averaging only about 0.17-0.38% per year for systems that are well operated and maintained. Acknowledgements

We are grateful to Chittenden County Maple Sugarmakers Association for their generous support of the initial retubing project. Other support was supplied by Orleans Co. Maple Producers (VT), Orange County Maple Producers (VT), Windham Co. Maple Producers (VT), and Franklin Co. Maple Producers (VT). Conversations with many maple equipment companies and individuals during this project and over the years have been instrumental. These include the folks from Leader Evaporator Company (now Leader/H2O), CDL, Dominion & Grimm, and Lapierre as well as Robert (Bob) White, Gary Corey, JR Sloan, Glenn Goodrich, and Joël Boutin (Quebec) among others. We thank all for the advice, comments, and consultation. A large number of PMRC staff, especially Brian Stowe, were involved in the planning, installation, maintenance, and operation of these tubing systems over the past 20 yrs. Their tireless work of these highly dedicated individuals is recognized and acknowledged with gratitude.

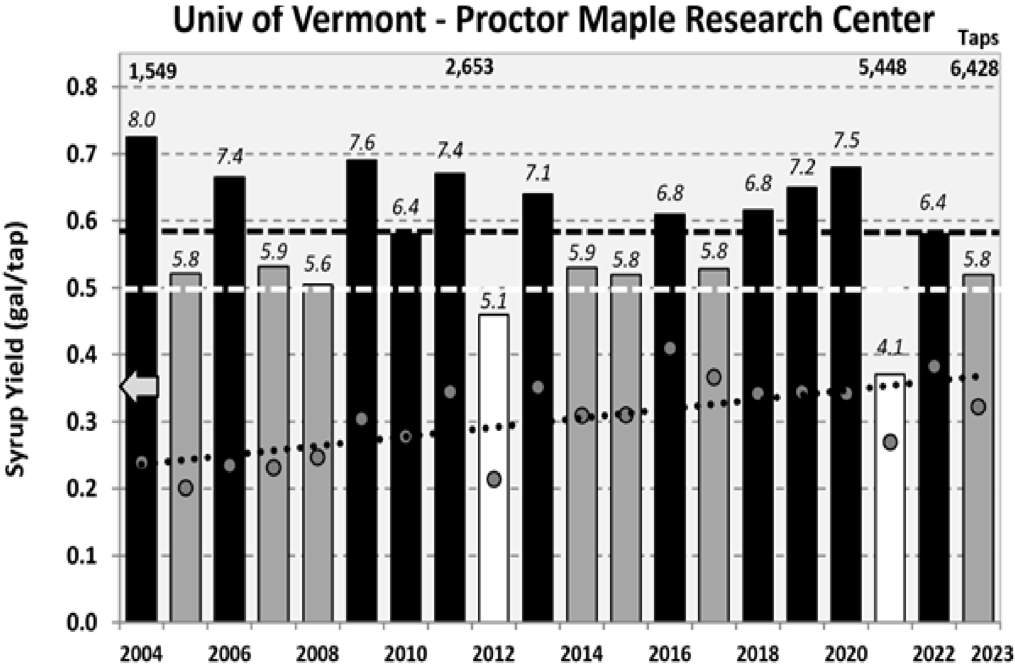

Figure 1 Total annual seasonal maple syrup production from 2004-2023 Research Center in Underhill, Vermont. Bars depict total yield of primarily Grade A syrup produced each season. The black dashed line represents the long-term average production of 0.58 gal syrup per tap. The white dashed line is the minimum annual target production of 0.5 gal syrup per tap. Black bars indicate years with at or above average production. Grey bars are seasons where syrup production was at or higher than the minimum target level, but below the long-term average. White bars indicate years in which syrup production was below the minimum target level. Numbers above each bar are the annual syrup production. in lbs per tap. Grey dots represent the average annual yield per tap for Vermont producers as reported by NASS and black dotted line is the linear trend of those data. The arrow along the left Y-axis inicates the average UVM PMRC production for the 20-yr period prior to 2004. Numbers near the top of the chart indicate the approximate number of taps for that year.

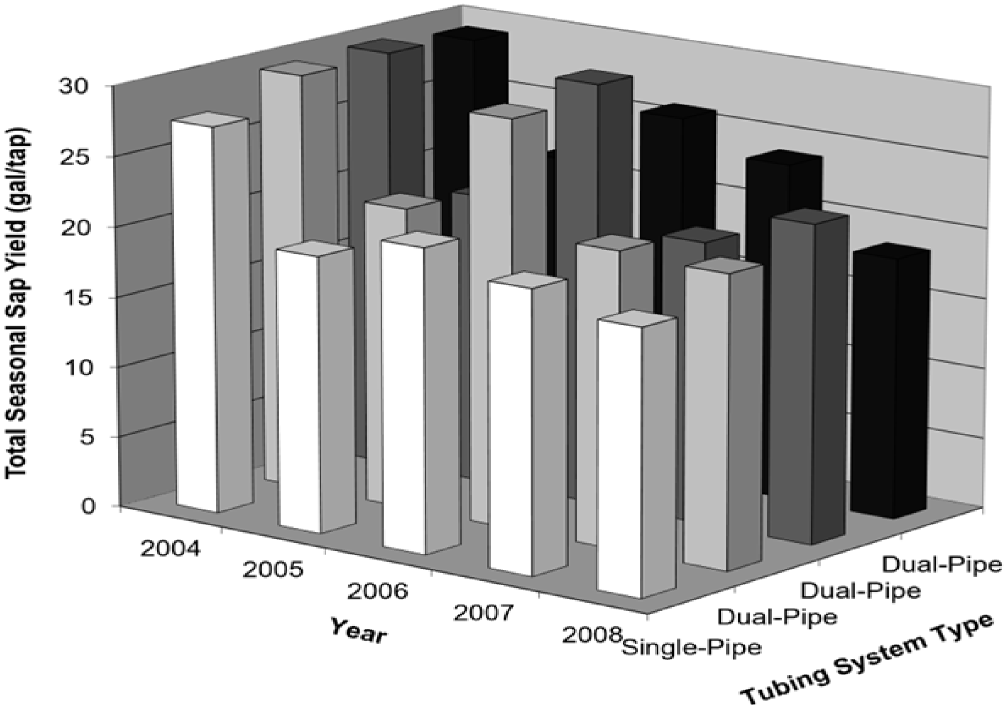

Figure 2. Total seasonal sap yield (gal per tap) for each section in the UVM Proctor Maple Research Center Main Bush for the first five years following installation. The single-pipe system (white bars) tended to produce about 11.4% less each season than the average of the dual-pipe systems. The dual-pipe system with black water pipe mainlines (black bars) typically produced just slightly less than the translucent-blue dual-pipe mainline systems (grey and dark grey bars).

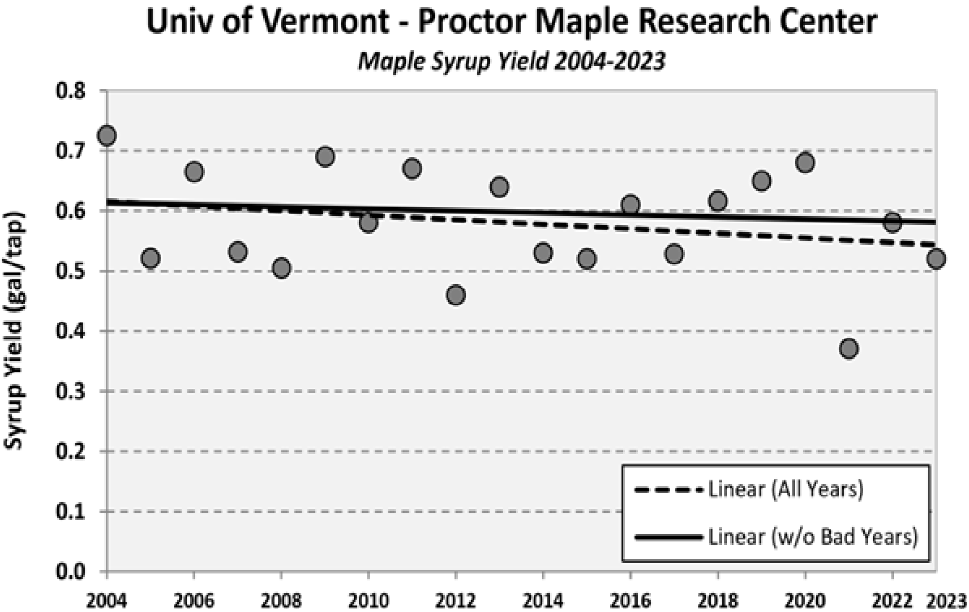

Figure 3. Annual syrup production from 2004-2023 at the University of Vermont Proctor Maple Research Center in Underhill, VT. The linear trend in syrup yield over this time period (dashed black line) shows a (non-significant) loss of approximately 0.38% per year, or 7.6% over the 20-yr time. If poor production years due to obvious weather-related issues (2012, 2021) are removed, the (non-significant) linear trend (solid black line) is reduced by more than half to only 0.17% per year, or 3.4% over 20-yrs. This indicates that tubing system aging of modern tubing systems that are maintained properly does not contribute to long-term loss of sap yield up to at least 20 yrs of age as long as proper sanitation practices are employed.

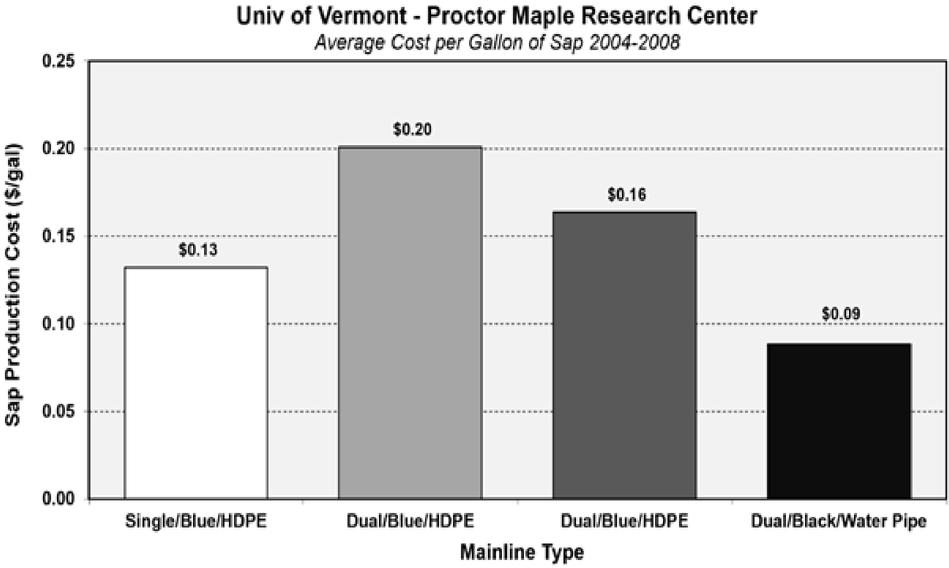

Figure 4. Average cost of a gallon of sap over the first five seasons (2004-2008) after installation by mainline type at UVM Proctor Maple Research in Underhill, Vermont, for the four individual sections of the Main Bush. These are: a single-pipe/blue/HDPE tubing system, a dual-pipe/blue/HDPE tubing system, a dual-pipe/blue/HDPE tubing system, and a dual-pipe/black/water-pipe system. This cost includes only material and labor to install and excludes regular operation and maintenance expenses over that time period. The mainline, lateral line, and drops of the single-pipe system failed due to brittle fracture (due to suspected lack of sufficient UV inhibitors) after the fifth season and had to be completely replaced. The dual/black/water pipe system had over twice as many taps and a higher density of trees compared to the other systems, so the lower cost reflected some economy of scale as well as reduced material cost.