Environmental Conditions and Floral Structure Affecting Nectar Production in Four Missouri Honey-Flow Plants

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August 2026

Abstract. To determine what environmental conditions and floral structure most affect nectar production in the four honey-flow plants that small-scale Missouri beekeepers consider most important (black locust, American basswood, tulip poplar, and white clover) and specifically whether rain during bloom washes nectar out of flowers or simply dilutes it, this literature review compiles and compares published research on temperature and rainfall for each species. Beekeepers plan their season around an assumed bloom calendar, but honey yields can swing from year to year, especially during the short spring tree flow. Where rain wash-out has been tested directly, rain dilutes nectar rather than washing it out. For black locust, temperature, not rainfall, influences when it blooms and how much nectar it secretes. Black locust's short bloom and tulip poplar's short per-flower nectar window both leave little room to recover from a few bad days, while white clover's long season gives it repeated opportunities for a surplus. That argues for watching colony readiness and current conditions rather than counting on a fixed bloom calendar and for moving on to the next management goal once a short window gets cut short by weather.

Keywords. black locust; American basswood; tulip poplar; white clover; nectar production; rain washout; nectar dilution; floral structure; honey bee foraging

1. Introduction

When beekeepers talk about a nectar flow, they mean two major conditions aligning. The first is available nectar in the floral sources. The second is short-term weather impacts on foraging flights.

Both need to align to produce a honey flow. This paper will look at climatic factors that impact nectar production for four of the floral sources that beekeepers in the central US view as key inputs to their honey crop. While those species are significant for beekeepers, they are not major economic drivers given the limited scale of commercial activity for beekeepers in these areas. USDA's national honey statistics don't track Missouri, Arkansas, or Oklahoma individually, lumping all three into a catch-all "Other States" category alongside roughly two dozen other states (USDA National Agricultural Statistics Service, 2026). The factors that affect nectar availability and quality are also not well covered in the published, peer-reviewed research. Those floral sources are major economic drivers in other parts of the world (black locust in Hungary, Italy and Korea, white clover in New Zealand) and there are relevant papers that can be used as directional findings while keeping in mind the different latitudes and climatic factors.

Nectar production itself is not constant. The same floral source can yield heavily one year and almost nothing the next, and beekeepers usually put that down to the weather without being specific about which conditions matter. The main question is what the published research actually establishes about the conditions that drive nectar secretion, chiefly temperature and moisture, and how much of that work covers these four plants.

A second, related question interacts with the main question. Beekeepers often talk anecdotally about nectar 'wash-out', which is the concept that a heavy rain will wash out the nectar from a given floral source for a day or two and it needs to 'recharge'. This paper will weigh that against the possibility that the nectar is only diluted, look at whether flower structure explains why some plants seem more affected than others, and lay out potential theories that are candidates for future data-collection and research.

2. Materials and Methods

This is a literature review, so the materials are published sources and the method is how they were found, checked, and compared against each other.

Candidate sources were identified through Google Scholar and pulled in full through the University of Montana Mansfield Library. Older and more obscure material needed other routes. Anderson's 1976 Tilia study came through JSTOR, the 1953 Kansas agricultural bulletin through HathiTrust's public-domain scan, and Marvin's 1933 tulip poplar study out of a free full-issue scan of the Journal of Economic Entomology at the Internet Archive. Two standard apiculture references, *The Hive and the Honey Bee* (Graham, 2015) and *Honey: A Comprehensive Survey* (Crane, 1976), came from the author's own copies rather than any online source. Recent open-access plant science came through PubMed Central, and the Polish field studies through the online archive of Pszczelnicze Zeszyty Naukowe.

The search focused on nectar production, meaning volume, sugar concentration, and secretion timing, not pollen. Where no data existed for these plants in the Missouri region, studies from the closest comparable climates were used and the location is stated with the finding.

Every source was logged in an Excel literature matrix, 82 entries in all, recording the plant, the condition studied, the study type, location and climate, the key finding, the specific numbers, how the source was obtained, and whether it had been verified. Forty-nine of the 82 are peer-reviewed; the rest are government species reviews, agricultural extension bulletins, standard apiculture references, a dissertation, and market reports, and each was labeled as such. The sources span 1933 to 2026.

Where a finding was available only through another paper's citation of it, it is labeled "as cited in" and credited to the paper that was actually read. Thirty-four of the 82 logged sources are cited here. The rest turned out to be off-topic once read, could not be obtained, or were covered better by a stronger source.

AI assistance was used. Claude was used to search for candidate sources, to follow citation trails out of reference lists, to translate the Polish papers, and to build Figure 1 from the bloom and flow dates given in the text. The Polish papers carry English summaries but have their detail in Polish. Every citation, quotation, and number in this report was then checked by the author against the original source before use.

3. Results

Each plant is covered against the same set of conditions: bloom timing, temperature, rain and humidity, how long a single flower keeps producing nectar, and floral structure. Weather's effect on bee flight, as opposed to on the plants, is covered first. The rest of this section is about the plants. Figure 1 shows the bloom windows side by side, Table 1 gives taxonomy and range, Table 2 collects the weather thresholds for forager flight, and Table 3 collects the temperature, rain, and structure findings for the four plants.

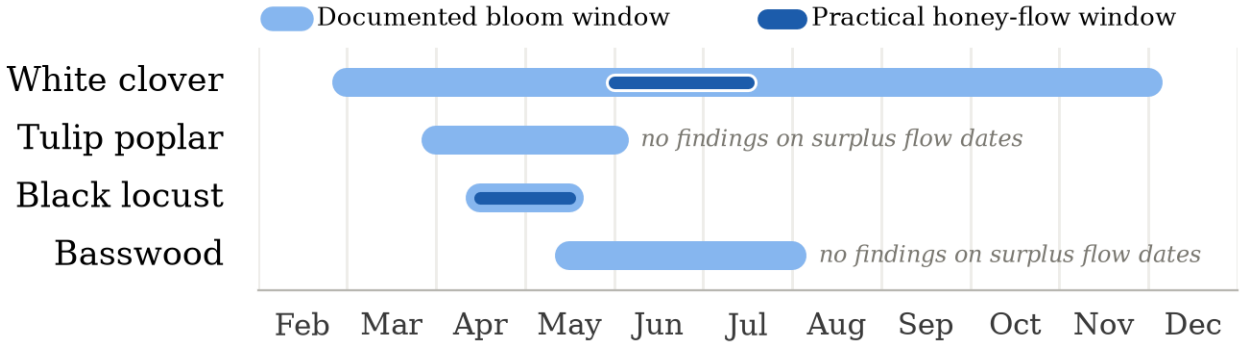


Figure 1. Bloom windows for the four plants around St. Louis, with the practical honey-flow window marked inside the documented bloom window. Windows are drawn to the nearest half month, which is the precision the sources give. Bloom windows are from the Missouri Botanical Garden (n.d.) for black locust and tulip poplar and the Missouri Department of Conservation (n.d.-a) for basswood and (n.d.-b) for white clover. The honey-flow windows and black locust's 7 to 10 day bloom are the author's own observation over the past decade. Basswood and tulip poplar have not produced surplus for the author, so no flow window is shown for either.

Table 1. Taxonomy, native range, and other notes.

Plant	Order, family, subfamily	Native range	Other notes
Black locust	Fabales, Fabaceae, Papilionoideae (also called Faboideae)	The Appalachian Range from central Pennsylvania to northern Alabama and Georgia, plus the Ozark Plateau of southern Missouri, northern and western Arkansas, and eastern Oklahoma (Keresztesi, 1983)	Introduced worldwide, with major populations in Hungary, Romania, and South Korea (Keresztesi, 1983), and in Italy (Alilla et al., 2022)
White clover	Fabales, Fabaceae, Papilionoideae (also called Faboideae)	Europe (Ogle & St. John, 2008)	Naturalized across the cool temperate northern hemisphere, throughout Canada and the United States including Hawaii and Alaska (Ogle & St. John, 2008).
Tulip poplar	Magnoliales, Magnoliaceae	Eastern North America, from Vermont west through southern Ontario and Michigan, south to Louisiana and east to northern Florida (Griffith, 1991).	Honey is reddish-amber, of full but good flavor, and mostly marketed locally (Marvin, 1933), and is described as a flavorful dark honey produced through much of the East (Graham, 2015)
Basswood	Malvales, Malvaceae, formerly placed in its own family Tiliaceae (Missouri Department of Conservation, n.d.-a)	New Brunswick and Maine west to Manitoba, south to eastern Kansas and northeastern Oklahoma, east to western North Carolina (Sullivan, 1994)	Known as the bee-tree in parts of that range for the amount of nectar its flowers produce (Crow, 1990)

3.1. Weather and Forager Flight

Short-term weather influences how many collection flights a colony can make, and therefore how much of the available nectar actually reaches the hive. Precipitation, wind, solar radiation, and temperature all play a part (Vincze et al., 2025), and the measured thresholds are collected in Table 2. Bee traffic at the hive entrance responds quickly to temperature swings; a small rise or drop shows up in the number of bees flying in and out (Stone, 1994, Vicens & Bosch, 2000, Chen et al., 2015, and Razanova et al., 2021, all as cited in Vincze et al., 2025).

Table 2. Weather thresholds for honey bee forager flight. All values are reported in Vincze et al. (2025), which is the source read; the original studies are credited as cited there.

Condition	Finding	Original source
Most efficient foraging temperature	20 to 30C (68 to 86F)	Vincze et al., 2025
Temperature at which activity begins	Above 12 to 14C (53.6 to 57.2F)	Vicens & Bosch, 2000
Upper limit of flight activity	Near 40C (104F)	Heinrich, 1979, 1996
Temperature against flight activity	Positive, R2 = 0.28 to 0.52	Szabo, 1980
Temperature against flight activity	Positive, R2 = 0.19 to 0.71	Burrill & Dietz, 1981
Solar radiation against flight activity	Positive, R2 = 0.40 to 0.87	Burrill & Dietz, 1981
Relative humidity against flight activity	Negative, R2 = 0.65	Burrill & Dietz, 1981
Wind speed at which foraging is hampered	1.6 to 8 m/s (3.6 to 17.9 mph), depending on the study	Pinzauti, 1986; Brittain et al., 2013
Effect of 2.8 m/s (6.3 mph) wind	Foraging rate cut by 37 percent in laboratory tests	Hennessy et al., 2020

These conditions govern whether bees can fly and collect at all, which is a separate question from how much nectar the plants are producing for them to collect. Vincze et al. (2025) draw that same distinction.

3.2. Black Locust (*Robinia pseudoacacia*)

Robinia pseudoacacia, called black locust in the US and false acacia in Europe (Alilla et al., 2022), blooms for 7 to 10 days in late April or early May in the Midwest (Figure 1), with a Kansas agricultural bulletin giving a May 1-20 window (Parker, 1953). In the years when conditions line up it is a major early honey source, but yields vary across years. A standard US apiculture reference describes the tree as widespread and abundant in the Appalachians and to a lesser degree the Ozarks, able to give a heavy nectar flow "every few years," with a crop requiring "just the right combination of warm, sunny weather (often a challenge in spring when it blooms)" (Graham, 2015). The measured evidence for that volatility comes from elsewhere: a single late-spring frost during bloom collapsed a season's crop in Poland (Jabłoński & Kołtowski, 1993), and a cold, rainy stretch during bloom had the same effect in Romania (Pătruică et al., 2017).

Almost all peer-reviewed research on black locust comes from the introduced-range countries in Table 1, much of it on bred or selected plant varieties rather than the wild trees of the US Midwest. No published research covers the native range using the common wild type, so this review interpolates from introduced-range work.

Bloom timing tracks heat accumulation rather than the calendar, with no significant effect from rainfall or drought, and nectar secretion has its own separate temperature range (Table 3). Applying Alilla et al.'s (2022) Normal Heat Hours model to ten years of Missouri daily temperatures (2016-2025) predicts full bloom around May 6, which matches the observed local window, though the model was calibrated on Italy's introduced-range population and has never been validated against native-range bloom records. Checked year by year against the author's own recorded bloom dates for seven recent years, the model missed by an average of 5 days and by as much as two weeks in one year, so it is not reliable for predicting whether a specific spring will run early or late. Timing matters for colony readiness. If bloom arrives early, colonies in Missouri are often not built up for it, typically not until the last week of April or the first week of May (author observation).

The rain impacts identified from the literature for black locust does not point in a single direction. A 2026 Hungarian study tested rainfall in the 7 days before sampling at three sites: more rain meant more nectar weight at one site, less at another, and no relationship at the third, with sugar concentration dropping significantly at only one (Porcsin et al., 2026). A Polish field study watched conditions day by day through the bloom instead of using a fixed window, and found light rain, especially at night, appeared to help secretion, while cool, windy, cloudy stretches, which usually came with a temperature drop, hurt it (Jabłoński & Kołtowski, 1993).

Black locust flowers are keel flowers, the type typical of the Papilionoideae subfamily within Fabaceae (Uluer et al., 2022). The keel petal encloses the reproductive parts and, more to the point here, the nectar itself (Table 3), and a bee has to trip the keel open with its own weight to reach it (Konarska, 2020; Aronne et al., 2014; Prenner, 2004). The published work on that structure concerns protection of pollen; the one existing mention of rain protection is a brief aside, not a tested finding (Westerkamp, 1997; Uluer et al., 2022).

3.3. White Clover (*Trifolium repens*)

Trifolium repens, white clover, blooms across a long season, March through November in Missouri, with the working honey flow much narrower, from the first week of June to early or mid-July (Figure 1). A 2025 study in a New Jersey habitat recorded bloom from mid-May through late September, with multiple peaks rather than one flush (Moran-Bariso & Gilley, 2025).

White clover's temperature requirements look contradictory at first (Table 3). The reported minimum of about 23C (73F) for any secretion at all sits above the 10 to 18C (50 to 64F) optimum range measured for individual plant varieties (Crane, 1976; Jakobsen & Kristjansson, 1994). The two are different measurements, and the gap from beekeeper experience may partly reflect the plant varieties studied: Jakobsen and Kristjansson's optimum came from Icelandic and Danish varieties measured in their own native climates, not the common lawn ecotype Missouri beekeepers actually see. Sweetclover, a close relative, shuts its flow down after several days above 100 to 105F (37.8-40.6C) (Parker, 1953). The flow has limits at both ends: too cold and secretion does not start, too hot and dry and it stops again.

Rain and humidity dilute nectar rather than washing it away, which leaves foragers carrying more water home and evaporating off the excess (Crane, 1976). The strongest quantitative support is the gap between growth-chamber and field sugar concentrations in this species, which the authors attribute to the absence of rain and dew indoors (Table 3; Jakobsen & Kristjansson, 1994, citing Southwick et al., 1981). A longer-term Kansas study covering 1918 to 1948 tested weather against surplus nectar and honey directly and found no association between weather and nectar flows from one season to the next (Moffett & Parker, 1953, as cited in Crane, 1976).

White clover is a keel flower, with the same enclosure as black locust, and its nectary sits at the base of the fused stamens (Table 3; Uluer et al., 2022; Jakobsen & Kristjansson, 1994). The rain-protection question is untested here for the same reason it is untested for black locust: the one existing mention is a brief aside, not a tested finding (Westerkamp, 1997; Uluer et al., 2022).

3.4. Tulip Poplar (*Liriodendron tulipifera*)

Liriodendron tulipifera, tulip poplar, blooms April through May around St. Louis (Figure 1). A 1932 USDA field study near Washington, D.C. put it in the latter part of May there and noted that black locust "comes on at approximately the same time" (Marvin, 1933). That tree's bloom ran about 22 days, May 16 to June 6, longer than black locust's 7 to 10 days and close to basswood's roughly 2 weeks, though it is one tree in one season. That overlap can cost the crop. Marvin's bees stayed on locust and left the tulip poplar ungathered, which matches the author's own observation.

The one measured weather effect for tulip poplar runs toward cooler being better (Table 3). Across 32 tagged flowers, those opening in the early morning yielded more nectar overall (1.69 grams) than those opening in the afternoon (1.54 grams), and Marvin's own summary states that "the total yield of nectar from flowers opening in the cool of the morning was greater than from flowers opening in the heat of the day." That points the same way as the Kansas findings for basswood and white clover, where hot, dry weather reduces or stops the flow (Parker, 1953). The temperature comparison rests on 16 buds across two mornings, so dataset size is tiny.

The per-flower window is the shortest of the four, about a day and a half against roughly 3 days for the others (Table 3). Marvin found nectar on a flower's first day and the following morning, and once it was drawn off the blossom "remained practically dry from that time on" (Marvin, 1933).

The flower is a large upward-facing cup, 3 to 4 inches across (Table 3). Nectar collects in drops on the nectary band until, as Marvin puts it, "adhesion not being strong enough to hold them to the petal, they run down and collect in the corolla of the flower" (Marvin, 1933). An open vessel of that shape is likely the most rain-exposed of the four, the opposite of black locust's keel enclosure and of basswood's hanging flowers, though that is an assumption, not a finding. No literature tests wash-out for this species at all, and Marvin covered his buds each evening with cellophane "to exclude bees or other insects and rain" (Marvin, 1933), designing the rain effect out rather than measuring it.

3.5. Basswood (*Tilia americana*)

Tilia americana, American basswood, blooms late May through July in Missouri (Figure 1), with a Kansas agricultural bulletin giving a narrower June 10-30 (Parker, 1953). Flowering follows leaf-out and runs about 2 weeks, its start shifting with latitude and with year-to-year temperature (Crow, 1990). A three-season study of eight *Tilia* species measured that shift at 11 to 20 days between seasons (Dmitruk et al., 2024). The author has not taken enough surplus from basswood to set a practical honey-flow window from his own observation.

No secretion threshold has been measured on *Tilia americana* itself. The available cold-end figure is for lime generally, and basswood is described as "quite susceptible to unfavorable atmospheric conditions such as hot, dry weather" (Table 3; Parker, 1953).

A Polish field study found that light rain does not rinse nectar out of basswood flowers but only dilutes it, tying that directly to the flowers hanging downward in their inflorescences (Jabłoński & Kołtowski, 1999). This is the most direct test of the wash-out question found for any of the four plants. A second Polish study, using local weather-station data, found greater rainfall during bloom combined with good sunshine went with more abundant secretion, and weaker secretion in dry weather (Czubacki, 1996).

Within a single flower the window runs about 3 days, with over 90 percent of flowers carrying nectar by the second night and quantity peaking then at 3.8 microlitres and about 28 percent sugar (Table 3; Anderson, 1976). In over 100 tests, flowers two or three days old regenerated nectar that had been drawn off, so a flower emptied by a forager is not necessarily finished.

How much a flower yields varies between years. The same trees across three seasons gave 8.21 to 11.66 mg of nectar per flower and 29.5 to 43.2 percent sugar, over 40 percent difference in nectar and a third in sugar between the best year and the worst (Dmitruk et al., 2024). Those trees were planted in Poland rather than growing in the native range, so the figures describe the species outside its home climate.

Basswood's nectary is open and exposed rather than enclosed, and the nearest structural work is on the European small-leaved lime rather than on American basswood itself (Table 3; Konarska, 2013). In that species, weather protection comes from non-glandular sepal hairs rather than from any enclosing structure. The hanging, downward orientation of basswood's flowers may be doing similar work through position rather than through the nectary itself.

Table 3. Temperature, rain, floral structure, and the per-flower nectar window by plant.

Plant	Temperature	Rain and humidity	Nectar position and floral structure	Nectar window per flower
Black locust	Secretion reported between about 10C (50F) and 35C (95F) (Pătruică et al., 2017, as cited in Vincze et al., 2025). Bloom timing tracks heat accumulation, with no significant rainfall effect (Szabó et al., 2016; Alilla et al., 2022)	Mixed across three Hungarian sites: more nectar weight at one, less at another, no relationship at the third (Porcsin et al., 2026). Light rain, especially at night, appeared to help, while cool, windy, cloudy stretches hurt (Jabłoński & Kołtowski, 1993)	Keel flower. Nectar sits at the base of the corolla inside the receptacle, reached through two openings at the base of the filament tube (Konarska, 2020; Aronne et al., 2014; Prenner, 2004)	About 3 days (Jabłoński & Kołtowski, 1993)
White clover	No nectar at all below about 23C (73F) (Crane, 1976). Optimum for a given plant variety 10 to 18C (50 to 64F) (Jakobsen & Kristjansson, 1994). Hot, dry weather and low soil moisture	Rain and humidity dilute nectar rather than wash it away (Crane, 1976). Growth-chamber sugar of 59 to 73 percent against 20 to 57 percent measured in the field, attributed to	Keel flower. Discoid nectary at the base of the fused stamens, with nectar in two pockets either side of the ovary base (Jakobsen & Kristjansson, 1994)	About 3 days (Jakobsen & Kristjansson, 1994)

	reduce or stop the flow (Parker, 1953)	the absence of rain and dew (Jakobsen & Kristjansson, 1994, citing Southwick et al., 1981)		
Tulip poplar	Cooler produced more nectar. Buds opening at 82 to 88F averaged 0.76 g of nectar against 1.06 g for those opening at 74 to 77F (Marvin, 1933). No minimum or optimum secretion temperature found	None found. Marvin covered his buds to exclude rain by design rather than measuring its effect	Open, upward-facing cup 3 to 4 inches across. The nectary sits on an orange band about 15 mm up the inner petal surface, and nectar runs down to pool in the corolla (Marvin, 1933; Zhou et al., 2016; Liu et al., 2019)	About a day and a half (Marvin, 1933)
Basswood	No threshold measured on *Tilia americana* itself. Lime generally is reported to yield no nectar below about 15C (59F) (Crane, 1976), and basswood is described as susceptible to hot, dry weather (Parker, 1953)	Light rain dilutes nectar rather than rinsing it out, tied to the flowers hanging downward (Jabłoński & Kołtowski, 1999). Greater rainfall combined with good sunshine was associated with more abundant secretion (Czubacki, 1996)	Open flowers hanging downward. Nectar collects in droplets at the sepal bases (Anderson, 1976). Protective non-glandular sepal hairs are described in the European *Tilia cordata* rather than in American basswood (Konarska, 2013)	About 3 days (Anderson, 1976)

No published study was found that tests rain washout directly for any of the four plants.

4. Discussion

Weather affects nectar in more than one way. Where this has been tested, the clearest result is basswood's, light rain dilutes nectar rather than washing it out. White clover's growth-chamber data points the same way. Black locust's evidence is mixed, with rain's effect on nectar weight going in different directions across three Hungarian sites. Temperature also affects black locust, white clover, and tulip poplar: whether nectar is secreted at all, and how much. No research was found on basswood's temperature ranges.

A plant's nectar productivity as viewed by a beekeeper may come as much from timing as from any specific weather mechanism. A short per-flower window plus a short bloom period leaves no room to absorb bad weather. Black locust has both: it secretes about 3 days per flower across a 7 to 10 day bloom. Tulip poplar's per-flower window is shorter still, roughly a day and a half, though its own bloom season runs longer, about 22 days. A couple of bad days can still cost most of a flower's nectar even in a longer season.

White clover's per-floret window is just as short, about 3 days. The more important difference may be its much longer bloom season, with multiple peaks rather than one flush. A single bad week has more chances to be offset by good conditions elsewhere in the season. Length of season, not length of the individual flower's window, is what seems to raise the odds of a surplus. Tulip poplar doesn't get those repeated chances, and its bloom overlaps black locust's, which in at least one documented case meant the bees stayed on locust and the tulip poplar crop went ungathered even though the nectar was there (Marvin, 1933). Basswood similarly has short windows: about 3 days per flower across a bloom of roughly 2 weeks (Anderson, 1976; Crow, 1990).

Black locust and white clover keep their nectar enclosed in a keel. Basswood's nectary is open but the flowers hang downward. Tulip poplar's sits exposed, pooling in an upward-facing open cup. Whether any of that structure changes how much rain impacts nectar availability for a beekeeper is unknown. No source found for this paper has tested that question directly for any of the four plants.

5. Benefits

For beekeepers, the practical value in this review is knowing that the spring tree flow is short to begin with. Black locust secretes for about 3 days per flower across a 7 to 10 day bloom, and tulip poplar for about a day and a half per flower. A colony that is not already strong when that window opens cannot be built up in time to use it. Once poor weather has cut a bloom short there is little chance of recovering that crop in the same season. *The better response should be to stop managing for the crop and start managing for the next goal*, whether that is splits, queen rearing, or the next flow.

Bloom dates are also changing, which makes managing to a fixed calendar a poor plan. Across 68 native wildflowers and forbs in Franklin County, Missouri, the community's spring flowering peak moved about 17 days earlier over the past century, and 78 percent of those species start flowering earlier with each degree of spring warming (Austin et al., 2024). The direction is not uniform. About a third of those species began flowering earlier across the study period while a tenth began later. None of the four plants reviewed here are among the 68, and all 68 are herbaceous rather than trees, so this describes the plant community a Missouri colony forages in rather than these four species. Black locust itself showed no significant multi-decade shift over 1952 to 2000 (Szabó et al., 2016). That is a bloom calendar moving underneath the beekeeper without a dependable direction, *which argues for managing colony readiness to the conditions in front of you rather than to dates on a calendar*.

The rain finding can help with apiary management also. Where the question has been tested, rain dilutes nectar rather than washing it out, so *a bloom that has been rained on is probably still worth working, weaker and wetter rather than empty*. This could lead to higher moisture contents in the honey and the need to pay closer attention at harvest. White clover is the more reliable bet of the four for the same reason its numbers look unremarkable: a long season with multiple peaks provides a chance for a bad week to be offset somewhere else in the bloom window, which the spring tree flows cannot do.

For new knowledge, this review turned up two areas for potential follow-on research. No published study tests directly whether floral structure protects nectar from rain in any of these four plants. And no research exists on black locust in its native range using the common wild type, since everything published comes from introduced-range countries and much of it studies selected plant varieties. Both are questions a beekeeper in this region is well placed to help answer.

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