A dynamic accumulator database and field trials for six promising species

Ben Tyler and Greta Zarro
December 2021

Abstract

As sustainable and organic farming practices grow in popularity, there is an increasing interest in the field of dynamic accumulators and their potential as nutrient catch crops, nutrient-rich mulches, and liquid fertilizers (Rawson, 2013; Walke, 2011). This growing demand necessitates the establishment of clear criteria for the identification of dynamic accumulator species, through the use of nutrient concentration thresholds, consistent with the practices of the closely related field of hyperaccumulators (Reeves, Baker, Jaffré, Erskine, Echevarria, and van der Ent, 2018). Following the recommendations of Kourik (2014), the USDA-hosted "Dr. Duke's phytochemical and ethnobotanical databases" were used to compile peer-reviewed data across thousands of entries and calculate dynamic accumulator thresholds across 20 beneficial nutrients. An easy-to-navigate online database titled "Dynamic accumulator database and USDA analysis" was created, providing nutrient concentration data on 340 qualifying dynamic accumulator species to aid in further research. Following this, 6 dynamic accumulator species (*A. retroflexus, C. album, S. peregrinum, T. officinale, T. pratense,* and *U. dioica*) were selected from the database and underwent on-farm trials over 2 years at Unadilla Community Farm in central New York. Crop yields and nutrient concentrations in the soil, dried plant tissue, and liquid extracts derived from the trial crops were measured. Dried *C. album* foliage was found to possess K concentrations that exceeded dynamic accumulator thresholds (40,715 ppm), and liquid extract derived from steeping *C. album* foliage for 5 days contained the highest K concentrations of all the trial crops (903 ppm). *S. peregrinum* foliage also surpassed dynamic accumulator threshold concentrations for K (52,959 ppm) and Si (513 ppm), with similarly high K concentrations found in the resulting liquid extract (889 ppm). *U. dioica* foliage possessed the highest Ca concentrations of all trial crops, and liquid extract derived from its foliage contained the highest nutrient concentrations and nutrient carryover rates for P, B, Ca, Cu, and Mn after 5 days of steeping compared to all other trial crops. When grown as an understory crop in a food forest environment, stinging nettle produced yields more than double commercial standards (17.8 tons/acre). Chopping and dropping with stinging nettle foliage coincided with a doubling or more of soil nutrient concentrations for P, Ca, Co, Cu, Mg, Ni, and Zn. Most notably, Ca concentrations doubled in the 0-6" and 6-12" soil horizons while dropping to 63% in the 12-24" soil horizon.

This material is based upon work supported by Sustainable Agriculture Research and Education (SARE) in the National Institute of Food and Agriculture (NIFA), U.S. Department of Agriculture (USDA), under Award No. 2019-38640-29877. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Introduction

Since the 1970s, there has been a growing body of research on the uptake and transport of nutrients in plant tissue (Reeves, Baker, Jaffré, Erskine, Echevarria, and van der Ent, 2018). As every plant species has different nutrient needs, they employ a variety of biological processes to take from the soil the minerals they need, while leaving behind those they do not. Generally speaking, plants' behavior towards a particular soil mineral can be classified in 3 ways:

1. **Excluders** block the uptake of potentially harmful quantities of a particular mineral, in an attempt to maintain a constant, healthy nutrient concentration, regardless of the soil it is grown in.
2. **Indicators**' absorption of a particular nutrient changes relative to that mineral's concentration in the soil.
3. **Accumulators** continue to extract a particular mineral from the soil and accumulate it in their above-ground parts, regardless of that mineral's concentration in the soil (Baker, 1981).

It is the third group, mineral accumulators, that has attracted the most attention from researchers, due to the wide range of practical applications envisioned for these plants. One of the more popular areas of research involves hyperaccumulators, "hyper" referring to the unusual excess of a particular mineral that these plants accumulate. Hyperaccumulators are plants that accumulate high concentrations of toxic heavy metals in their above-ground parts, extracting these elements from the soil (Jaffré, Reeves, Baker, Schat, van der Ent, 2018). To qualify as a hyperaccumulator, plants must meet concentration thresholds for specific heavy metals – *i.e.*, 100 ppm for Cd, 1000 ppm for Ni, 10,000 ppm for Mn, etc. (Reeves *et al.* 2018). The use of hyperaccumulators on polluted land has been shown to be a relatively cheap and environmentally friendly method of soil and groundwater remediation, making it an attractive area of research for commercial mining and other heavy industries (Keeran, Balasundaram, Govindan, and Parida, 2019). It has even been suggested that hyperaccumulators could be used for phytomining, where these plants extract from the soil desirable metals such as nickel, which can then be harvested and refined (van der Ent, Baker, Reeves, Chaney, Anderson, Meech, Erskine, Simonnot, Vaughan, Morel, Echevarria, Fogliani, Qiu, and Mulligan, 2015).

Agriculture is another industry with practical applications for mineral accumulators. But whereas hyperaccumulators are used to extract toxic heavy metals, in farming the focus is on conserving beneficial soil nutrients. For example, barley and oats are two popular cover crops because of their ability to accumulate high concentrations of nitrogen and other nutrients, preventing runoff into waterways or leaching into groundwater. Buckwheat has been shown to accumulate high concentrations of phosphorus; in addition, its roots are believed to secrete mild acids into the soil that solubilize rock phosphate and other forms of phosphorus that are otherwise unavailable to plants. Mineral accumulator cover crops such as these can then be used as nutrient-rich forage, mulch, or incorporated into the soil, slowly releasing their accumulated nutrients back into the soil for subsequent crops (Clark, 2007).

But unlike the field of hyperaccumulators, where research is centered around the concept of mineral accumulation and its myriad potential applications, in agriculture the study of these plants has historically been treated as a subset of the practices of cover cropping or forage production. While pragmatic, this approach limits the scope of mineral accumulator research to these practices. Other potential applications include the targeted extraction and harvest of specific nutrients from buffer strips, overfertilized fields, or from deep in the subsoil, and the application of these nutrients to crops through the generation of plant-based, nutrient-rich compost, amendments, mulches, and liquid fertilizers.

Fortunately, the study of mineral accumulators and all of their potential agricultural applications has existed on the sidelines for almost as long as the study of hyperaccumulators (Brooks, 1977; Kourik, 1986). In the context of agriculture these plants are called dynamic accumulators, “dynamic” referring to the plants’ use of active transport, rather than normal diffusion, to transport a nutrient against the concentration gradient – in other words, to achieve a higher nutrient concentration in the plant than in the surrounding soil. Literally speaking, hyperaccumulation and dynamic accumulation are two terms referring to the same biological process. But whereas the study of hyperaccumulation is specifically focused on the accumulation of toxic heavy metals, dynamic accumulation focuses on the accumulation of beneficial nutrients.

However, while the term “hyperaccumulator” has enjoyed over 40 years of enthusiastic research and discussion in peer-reviewed journals, the term “dynamic accumulator” has existed only in the realm of informal on-farm research, and in books on gardening and permaculture. This has led many to believe that dynamic accumulation is unproven pseudo-science, even though the accumulation of beneficial nutrients in the context of cover cropping has been extensively researched and accepted as fact (Clark, 2007; Kitsteiner, 2015).

In recent years, there has been growing interest in dynamic accumulators, coinciding with shifting values among farmers towards greater emphasis on sustainable and organic farming methods. Both MOFGA (Maine Organic Farmers and Gardeners Association, with a membership of over 6,000 farms) and NOFA-Massachusetts (Northeast Organic Farmers Association Massachusetts, with over 1,000 members) have promoted the use of dynamic accumulators for sustainable nutrient management on Northeast farms (Rawson, 2013; Walke, 2011). This growing demand for proven on-farm applications for dynamic accumulators necessitates further research.

Due to the similarities between the areas of hyperaccumulation and dynamic accumulation, and the fact that research of the former is further along than research of the latter, a clear pathway has already been established for researchers of dynamic accumulators to follow. A major component of clearly defining hyperaccumulation has been the establishment of nutrient concentration thresholds that plants must meet in order to be considered hyperaccumulators. Plants that have been proven to meet the thresholds are then entered into an easily searchable database. The database assists researchers in identifying promising plants for further study, and real-world applications for these plants can then be developed. The model hasn’t been perfected yet, and hyperaccumulator researchers are still facing some challenges, such as the existence of multiple competing sets of thresholds, several databases with conflicting criteria for inclusion, and additional quality control issues such as the use of “spiked” growing medium or contaminated plant tissue samples giving inflated nutrient readings (Reeves, Baker, Jaffré, Erskine, Echevarria, van der Ent, 2018; Jansen, Broadley, Robbrecht, and Smets, 2002; Rascio and Navari-Izzo, 2011). But the implementation of nutrient thresholds and curated databases of hyperaccumulator species has gone a long way in advancing the study of these plants.

Robert Kourik, popularly believed to have coined the term “dynamic accumulator” in the 1980s, proposed in 2014 that the USDA-hosted “Dr. Duke’s phytochemical and ethnobotanical databases” could be used to compare nutrient values across thousands of plant species to help identify dynamic accumulators (Kourik, 2014). A year later, Dean Brown pointed out the similarities between dynamic accumulators and hyperaccumulators, and suggested that nutrient concentration thresholds should be set for dynamic accumulators, using ppm concentrations of dried plant tissue samples, consistent with hyperaccumulator thresholds (Brown, 2015).

USDA database analysis

The first step taken as part of this study was to analyze the USDA phytochemical and ethnobotanical databases and create an up-to-date, easy-to-navigate online tool titled "Dynamic accumulator database and USDA analysis" of all available peer-reviewed data on dried plant tissue concentrations of 20 beneficial nutrients. Following Brown's advice, USDA's "high ppm" values are used as these correspond with dried plant tissue samples, consistent with hyperaccumulator thresholds. This data was used to calculate nutrient value averages across 7,098 entries. Threshold concentrations were then set across 20 nutrients, following the model used for the identification of hyperaccumulators.

Unlike hyperaccumulators, which accumulate toxic heavy metals or metals of interest to the mining industry, dynamic accumulators are defined by their ability to accumulate nutrients that are beneficial to plants. Therefore threshold concentrations were calculated for 20 nutrients that have been shown to be either essential or beneficial for plant health: N, P, K, Al, B, Ca, Cl, Co, Cu, Fe, I, Mg, Mn, Mo, Na, Ni, S, Si, Se, and Zn (Provin and McFarland, 2018; Uchida, 2000; Vatansever, Ozyigit, and Filiz, 2017; Kiferle, Martinelli, Salzano, Gonzali, Beltrami, Salvadori, Hora, Holwerda, Scaloni, and Perata, 2021; Leyva, Sánchez-Rodríguez, Ríos, Rubio-Wilhelmi, Romero, Ruiz, Blasco, 2011). Dynamic accumulator thresholds of roughly 200% of average concentrations result in a total of 340 plant species that have been shown to achieve nutrient concentrations high enough to qualify as dynamic accumulators. On average, dynamic accumulators currently account for 9.59% of plants in each nutrient category in the USDA database. Plant species that meet dynamic accumulator thresholds are presented in the online tool in a detailed list, along with all available nutrient concentration data, to assist in further research.

An article titled "Breaking ground with dynamic accumulators" was published through the Permaculture Research Institute in March of 2020 to publicly share the online tool and discuss its relevance to the study of dynamic accumulators. **Table 1** shows data excerpted from the online tool, including a general analysis of nutrient concentration data from the USDA databases and concentration thresholds for dynamic accumulators.

When outlining the general model for identifying dynamic accumulators, Kourik (2014) describes that researchers should point to nutrient concentration data, in ppm, "as compared to other plants." In Kourik's model, the USDA phytochemical and ethnobotanical databases are used to form the data set of "all known plant tissue nutrient concentrations." Average nutrient values are calculated across this data set, and dynamic accumulators' nutrient concentrations are compared to these averages. These comparisons can be expressed as a percent of an average nutrient value or, as Brown (2015) proposes, as a biome-concentration factor (Bf). In this case, the "biome" referred to is the group of plants currently included in the USDA database. Both comparisons are made by dividing the plant's nutrient concentration by the average across the data set. For example, the fruit of the cucumber plant has been shown to contain 80,000 ppm of nitrogen (N). When compared to the N concentrations of 94 plant entries in the USDA databases, cucumbers contain 336% the N of the average plant, or a Bf of 3.36 - more than 3 times the average. Both methods of nutrient concentration comparison are included in the Dynamic accumulator database and USDA analysis online tool.

	N	**P**	**K**	**Al**	**B**	**Ca**	**Cl**	**Co**	**Cu**	**Fe**
Total number of nutrient entries	94	703	625	223	186	841	77	241	413	756
Total number of unique species	88	519	504	192	158	639	72	204	363	594
Average nutrient values (ppm)	23758	3985	18905	693	41	9437	2126	17	18	283
200% of average values (ppm)	47516	7970	37810	1386	82	18874	4252	34	36	566
Dynamic accumulator thresholds (ppm)	**50,000**	**10,000**	**40,000**	**2,000**	**100**	**20,000**	**5,000**	**40**	**40**	**500**
Thresholds as percent of average	210.5%	250.9%	211.6%	288.6%	243.9%	211.9%	235.2%	235.3%	222.2%	176.7%
Thresholds as biome-concentration factor (Bf)	2.10	2.51	2.12	2.89	2.44	2.12	2.35	2.35	2.22	1.77
Number of nutrient entries that qualify	10	36	61	11	14	107	12	21	22	100
Number of unique species that qualify	9	34	57	11	12	91	10	20	18	80
Percent of nutrient entries that qualify	10.64%	5.12%	9.76%	4.93%	7.53%	12.72%	15.58%	8.71%	5.33%	13.23%
Percent of unique species that qualify	10.23%	6.55%	11.31%	5.73%	7.59%	14.24%	13.89%	9.80%	4.96%	13.47%

	I	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**S**	**Se**	**Si**	**Zn**
Total number of nutrient entries	83	538	490	110	554	130	143	208	185	498
Total number of unique species	78	451	416	93	467	109	133	177	168	427
Average nutrient values (ppm)	21	3043	161	3	1999	7	2535	8	240	53
200% of average values (ppm)	42	6086	322	6	3998	14	5070	16	480	106
Dynamic accumulator thresholds (ppm)	**40**	**5,000**	**400**	**5**	**5,000**	**20**	**5,000**	**20**	**500**	**100**
Thresholds as percent of average	190.5%	164.3%	248.4%	166.7%	250.1%	285.7%	197.2%	250.0%	208.3%	188.7%
Thresholds as biome-concentration factor (Bf)	1.90	1.64	2.48	1.67	2.50	2.86	1.97	2.50	2.08	1.89
Number of nutrient entries that qualify	3	84	37	16	36	7	21	12	20	43
Number of unique species that qualify	3	68	31	9	33	7	20	11	18	35
Percent of nutrient entries that qualify	3.61%	15.61%	7.55%	14.55%	6.50%	5.38%	14.69%	5.77%	10.81%	8.63%
Percent of unique species that qualify	3.85%	15.08%	7.45%	9.68%	7.07%	6.42%	15.04%	6.21%	10.71%	8.20%

Table 1*: Dynamic accumulator threshold nutrient concentrations, taken from "Dynamic accumulator database and USDA analysis."*

Since the USDA databases receive regular updates as new plant tissue analyses make their way into peer-reviewed journals, the data set relied on for the study of dynamic accumulators is growing. This means that average nutrient values and biome-concentration factors are constantly changing. For example, archived data is available from the USDA databases from 2013, listing cucumber N concentrations as 476% of the average, or a Bf of 4.76. Almost 10 years later, there have been 2,167 new entries added to the database, and the cucumber fruit's Bf has been revised to 3.36. This illustrates the "dynamic" nature of the USDA databases themselves, and the importance of stable nutrient concentration thresholds to assist in further studies of dynamic accumulators. The online tool presented here should likewise undergo regular updates, to ensure it includes the most up-to-date information on plant nutrient concentrations, averages, and biome-concentration factors. The nutrient concentration thresholds used for the classification of dynamic accumulators should also be periodically reviewed and possibly updated to reflect our growing understanding of plants' nutrient concentrations, as is done in the field of hyperaccumulators.

An additional consideration with the current method of using nutrient concentration thresholds to identify dynamic accumulators is that it does not take into account the effect of soil nutrient concentrations on plant tissue concentrations. As mentioned earlier, it has been noted in the field of hyperaccumulator research that growing medium that has been "spiked" or amended to artificially raise a particular nutrient's concentration in the soil can result in heightened plant tissue concentrations (Reeves, Baker, Jaffré, Erskine, Echevarria, van der Ent, 2018). For this reason, plant tissue concentrations should be reported along with nutrient concentrations of the growing medium used. With these two data points, bioaccumulation factors (BAFs) can be calculated, by dividing plant tissue concentrations (in ppm) by "background" concentrations in the soil (also in ppm). BAFs are useful for assessing whether plant tissue concentrations are in fact the result of nutrient *accumulation* (BAF > 1), *exclusion* (BAF < 1), or simply an *indication* of soil nutrient concentrations (BAF = 1). BAFs can vary based on a range of factors, such as overall plant health, growing conditions such as soil moisture, or interrelated soil processes (Sharpley, 1997). For this reason, it is only by reporting BAFs for a plant species across a range of growing conditions and growing media that we can better understand how to effectively use dynamic accumulators to achieve tangible benefits for farmers.

Methodology for on-farm trials

Using the newly created dynamic accumulator database, 6 plant species were selected for on-farm trials. The criteria for selection were:

1. Plants must meet dynamic accumulator threshold concentrations for at least 1 beneficial nutrient.
2. Plants must be easy-to-grow perennials or self-seeding annuals, to address the need for on-farm nutrient management strategies that require minimal time and financial investment.
3. Plants must be viable for Northeast farmers in USDA hardiness zone 4 or greater, as on-farm trials will take place in zone 4.

Following this selection criteria, the 6 plant species chosen for on-farm trials were:

1. *Amaranthus retroflexus* (Redroot amaranth)
2. *Chenopodium album* (Lambsquarters)

3. *Symphytum peregrinum* (Russian comfrey)
4. *Taraxacum officinale* (Dandelion)
5. *Trifolium pratense* (Red clover)
6. *Urtica dioica* (Stinging nettle)

Russian comfrey was selected for on-farm trials despite there being no available USDA data for its above-ground parts. Instead, data from the University of Minnesota agricultural experiment station was used to determine if nutrient concentrations met dynamic accumulator thresholds (Robinson, 1983). This exception was made due to comfrey's widespread popularity as a dynamic accumulator with the permaculture community, combined with the fact that it is one of the highest-yielding crops in the world in tons per acre (Hills, 1976).

On-farm trials were carried out over a 2-year period, from 2020 to 2021. In the first year, 12 trial rows were planted, with two rows dedicated to each species, plus a thirteenth row left fallow for the duration of the study, to serve as a control group. For each species, one trial row had harvested plant material removed (referred to as "extraction" rows in this study), and one trial row was harvested and mulched with its harvested material (called "chop and drop" rows in this study). Trial rows measured 2.5 feet wide and 30 feet long, equaling 75 square feet each. These rows were cared for and allowed to establish over the course of the first year. In the second year, all rows were harvested, taking multiple cuts when possible, and harvest dates and weights were recorded to determine annual crop yield estimates.

During the second year of field trials, plant tissue samples were collected from each of the 6 trial crops and plant tissue analysis carried out by Cornell University's nutrient analysis laboratory, using a combination of hot plate digestion and ICP-AES (inductively coupled plasma-atomic emission spectrometry).

During the second year of field trials, harvested material from each trial crop was used to produce non-aerated liquid plant extracts, following the process outlined by Brinton (2011). Steep tanks were filled with a ratio of 1 part fresh plant tissue to 10 parts rainwater, by weight. Rainwater collected on-site was used to minimize the presence of dissolved solids in the water. Pure rainwater pH and nutrient concentrations were measured before use. Liquid temperature and pH was measured and recorded daily and liquid nutrient analysis was carried out by Cornell University's nutrient analysis laboratory after 3 and 5 days, to determine steep time recommendations for Northeast farmers who may be operating at less than the ideal 72°F for most of the growing season. Liquid nutrient concentrations were compared with plant tissue concentrations to assess carryover rates from plant tissue to liquid extract. Liquid extract pH and nutrient concentrations were analyzed to assess the 6 trial crops for the on-farm production of liquid fertilizers high in specific nutrients.

Soil samples were collected at depths of 0-6", 6-12", and 12-24" three times for all test rows: prior to planting, after one year of cultivation, and after two years of cultivation. The thirteenth row, left fallow, was also sampled at these times. Samples were sent to Cornell nutrient analysis laboratory for total elemental analysis. Soil nutrient concentrations were used to attempt to determine whether trial crops were primarily gathering nutrients from the upper 6" of soil or from deeper underground, to assess their application for nutrient scavenging or subsoil nutrient accumulation. Soil nutrient concentrations were compared between extraction rows and chop and drop rows, to assess the application of trial crops for nutrient-rich mulch production. Soil nutrient concentrations were also compared to plant tissue nutrient concentrations to calculate bioaccumulation factors for all nutrients.

Results and Discussion

The results and discussion will be divided into 4 sections: crop yields, plant tissue analysis, liquid nutrient analysis, and soil analysis.

1. Crop yields

Based on the USDA analysis discussed above, 6 trial crops were selected for on-farm trials. These crops were started indoors, transplanted into dedicated rows, and allowed to establish over the course of the first year of this study. All trial crops were then harvested during the second year, following established recommendations for when to harvest, where available. Multiple cuts were taken throughout the growing season whenever possible. Information such as harvest date ranges, average heights of trial crops at time of harvest, and yields were recorded and compared to available data on these crops (see **Tables 2** and **3**). All yields mentioned throughout this study refer to the weight of fresh material.

Trial crop	Harvest date range	Avg height at harvest	# of cuts per season	Addt'l harvest information	Yield per season (lbs/sq ft)	Yield per season (tons/acre)
A. retroflexus	Jul – Sep	-	multiple	-	-	-
C. album	May – Oct	-	multiple	-	-	-
S. peregrinum	Early June – Sept	-	3-5	Harvest up to the onset of flowering	0.6-2.8	13-61
T. officinale	Spring – early Fall	-	multiple	-	0.03-0.04	0.8-1
T. pratense	Late May – 45 days before frost	Min. 8"	2-4	Harvest at 25-50% bloom	0.5-1	10-20
U. dioica	Mar – Nov	Min. 12"	2-3	Harvest up to the onset of flowering	0.36-0.39	8-8.7

***Table 2**: Harvest information available through a literature review (Carpenter and Carpenter, 2015; Clark, 1998; Hagemann, Burnham, and Neubauer, 1997; Hall, 2008; Robinson, 1983; Teynor, Putnam, Doll, Kelling, Oelke, Undersander, and Oplinger, 1997).*

Trial crop	Harvest date range	Avg height at harvest	# of cuts per season	Yield per cut (lbs/75 sq ft row)					Yield per season (lbs/sq ft)	Yield per season (tons/acre)
				1st cut	2nd cut	3rd cut	4th cut	5th cut		
A. retroflexus	8/20 – 10/14	18-24"	2	30.6	10.8				0.55	12
C. album	7/28 – 8/27	12-18"	1	12.2	7.2				0.26	5.6
S. peregrinum	5/28 – 10/14	18-24"	5	38.9	32.8	47.4	65.9	22	2.76	60.1
T. officinale	7/2 – 10/14	6-12"	3	2.1	4.1	4.2			0.14	3
T. pratense	6/25 – 10/18	6-9"	2	2.6	1.3				0.05	1.1
U. dioica	6/11 – 10/14	12-18"	4	13.7	16.5	18.2	12.9		0.82	17.8

***Table 3**: Harvest information from "extraction" trial rows.*

Some of the plants included in this study are not commonly cultivated, and there was a lack of relevant information available on them. For example, redroot amaranth is commonly regarded as a noxious weed, and studies of this plant to-date seem to be confined to its harmful effects on livestock and the yields of cash crops, its status as an invasive weed currently spreading across the globe, and how to effectively exterminate it. Others, specifically red clover and Russian comfrey, and, to a lesser extent, stinging nettle, are enjoying increasing interest due to their perceived potential economic benefits as cash crops and, in the case of red clover, also as a nitrogen-fixing cover crop.

Each of the six trial crops being studied was grown in a dedicated "extraction" trial row, measuring 3 ft wide and 25 ft long. These rows were allowed to establish during the first growing season and were repeatedly harvested over the second growing season, with the intent to extract as much nutrient-rich plant material as possible from the rows. **Table 3** shows the yields from the "extraction" trial rows.

It is worth noting that the findings of this study are just as much an examination of the cultivation methods used and their suitability to the crops being trialed as they are an examination of the crops themselves. As this study set out to examine these 6 crops' potential as dynamic accumulators, integrated into nutrient management plans of Northeast farms, an element of the study's design is to assess the feasibility of establishing permanent rows of these crops, with minimal effort on the part of the farmer, relying on the plants to fend for themselves against weed pressure, moisture or nutrient deficiencies, and the challenges of maintaining a thick stand in the row year after year, either by renewing and spreading by rhizome (as in the case of Russian comfrey), by self-seeding (lambsquarters and redroot amaranth), or a combination of both (stinging nettle and red clover). For this reason, all trial crops were planted into unamended soil and given minimal attention, apart from 1 month of irrigation at the start of the first year and occasional hand weeding during the two years of the field trials. Another notable feature of the method of cultivation used in this study is that all rows were given 2 inches of wood chip mulch at the time of planting, consistent with Unadilla Community Farm's method of establishing perennial rows in the food forest, where these field trials took place.

A. retroflexus: As shown in **Table 3**, harvest dates for redroot amaranth were 1 month later than expected, possibly due to the relatively cold, Northern location of the field trials, where frosts regularly extend into June. As a tender annual, redroot amaranth was slow to emerge in the spring, waiting for all danger of frost to pass before seedling emergence. While there doesn't seem to be any data available on yields for this crop, based on observations made during field trials it seems this plant would be better suited to be grown as a single-cut annual, as is the norm for other commercially grown *Amaranthus* species. Second-year growth failed to meet the volume and vigor of first-year growth. It is possible that the use of wood chip mulch prevented adequate seed-to-soil contact. Uneven germination could also be an inherent feature of this species, suggesting seedlings could emerge year after year, interfering with subsequent crops but failing to maintain a thick stand over multiple years through self-seeding alone.

C. album: The harvest dates for lambsquarters fell within the established range, with a later start date and a shorter harvest window most likely due to the relatively cold climate and short seasons of the Northeast. However, despite exhibiting promising growth during its first year, it failed to adequately reseed to produce a thick stand during the second year, as evidenced by the low yields reported in **Table 3**. This was a commonality between both lambsquarters and redroot amaranth, the two annuals being trialed in this study that relied exclusively on self-seeding to maintain a thick stand across two seasons. As mentioned earlier, the use of wood chip mulch could have impeded the plants' efforts to reseed; low germination rates could also be an inherent feature of both of these uncultivated species.

S. peregrinum: Russian comfrey made a strong performance in the on-farm trials. The harvest window for this crop exceeded established norms by about 2 weeks, and both the number of cuts (5) and the overall yield (60.1 tons/acre) were at the high end of the expected range. This could be owed in part to the use of wood chip mulch, which has the potential to both conserve soil moisture and reduce soil temperatures in the summer months, both of which have been shown to have a positive impact on comfrey yields (Hills, 1976; Teynor, Putnam, Doll, Kelling, Oelke, Undersander, and Oplinger, 1997). As a long-lived perennial and sterile hybrid that spreads exclusively via rhizome, its ability to thrive and spread were not negatively impacted by the mulch as some of the self-seeding trial crops were.

T. officinale: Dandelion's harvest date range proved later than expected. However, by the second year of trials the dandelion was well established and producing relatively high yields (3 tons/acre), compared to established data (0.8-1 ton/acre). Dandelion's strong performance could be due in part to the moisture-conserving and soil-cooling effects of wood chip mulch.

T. pratense: Red clover failed to establish a thick ground cover during on-farm trials. The first summer was hot and dry, and combined with a strategy of minimal irrigation and no intercropping, this resulted in dry soil and full sun exposure, factors that are known to result in poor red clover performance (Clark, 2007). These seasonal factors could have been mitigated with increased irrigation and/or interplanting with a grain or other early-harvest annual crop during the first season to provide shelter from extreme summer conditions (Hall, 2008). However, intercropping would have complicated efforts to isolate the effects of red clover on soil nutrient levels.

U. dioica: Stinging nettle thrived in the field trials, transplanting easily and spreading via rhizome to quickly fill in its test rows. As a moisture-loving plant, it is possible that the use of moisture-conserving wood chip mulch in this study helped fuel stinging nettle's rapid growth and spread. It proved to be an excellent ground cover, outcompeting and suppressing weeds. During the second year, 4 cuts were taken, exceeding the normative range of 2-3. Total yields for the season (17.8 tons/acre) far surpassed the established range (8-8.7 tons/acre).

2. Plant tissue analysis

During the second year of field trials, plant tissue samples were collected from each of the six trial crops and dried on-site in a shade house converted into a drying shed. Plant tissue analysis was carried out by Cornell University's nutrient analysis laboratory. Nutrient concentrations were then compared to data derived from the USDA database analysis discussed above. In the case of Russian comfrey, where no data is available in the USDA databases, nutrient concentrations were compared with data from the University of Minnesota agricultural experiment station (Robinson, 1983).

Table 4 lists nutrient concentrations, in ppm, for the 6 trial crops, as reported by the USDA databases and University of Minnesota agricultural experiment station, with nutrient concentrations that exceed dynamic accumulator thresholds displayed in bold. **Table 5** expresses the same data, in the form of "percent of average."

Table 6 lists nutrient concentrations for plant tissue samples collected during on-farm trials, with nutrient concentrations that exceed dynamic accumulator thresholds displayed in bold. Nutrient values overall are relatively lower, and there are fewer nutrient values that exceed dynamic accumulator thresholds, when compared to previous findings. This underscores the potential variability of plant tissue nutrient concentrations – while capable of impressive nutrient concentrations when grown in the right conditions, results can vary considerably from site to site. This suggests that dynamic accumulators may be better suited for tying up excessive nutrients in rich soil, rather than extracting desirable nutrients from poorer soil.

However, **Table 6** does show 2 trial crops that demonstrate nutrient concentrations that exceed dynamic accumulator thresholds: lambsquarters (with a K concentration of 40,715 ppm) and Russian comfrey (with a K concentration of 52,959 ppm and an Si concentration of 513 ppm). While relatively high K concentrations for these two crops are consistent with available data, the sources referenced in **Table 4** do not provide data for Si concentrations of Russian comfrey. Our findings indicate that in addition to K, Russian comfrey may be a dynamic accumulator of Si as well.

Comparing plant tissue samples (**Table 6**) with soil samples collected during the same year (**Appendix 2**) allows for the calculation of bioaccumulation factors (BAFs) for the trial crops. This is calculated by dividing plant tissue nutrient concentrations (in ppm) by "background" nutrient concentrations in the soil (also in ppm), and provides some insight into a plant's ability to accumulate nutrients while taking into account the soil quality it was grown in. **Table 7** displays BAFs for all trial crops, calculated using soil nutrient concentrations from 3 soil horizons (0-6",6-12", 12-24"). **Table 8** displays BAF averages for all 6 trial crops. Bioaccumulation factors vary from site to site, but these values can be useful for making comparisons between trial crops within this study. It is also important to note that the soil analyses conducted in this study measured total nutrient concentrations, rather than available concentrations. This will skew the BAF values for nutrients that are mostly present in the soil in unavailable forms. For this reason, BAF values that fall below 1 (which normally indicates a plant is excluding a nutrient) will be included and compared in this discussion.

A. retroflexus: While redroot amaranth foliage failed to exhibit nutrient concentrations above dynamic accumulator thresholds, it did contain the highest concentrations of Al (17.7 ppm), Mn (87.4 ppm), S (2,431 ppm), and Zn (37.9 ppm) compared to all other trial crops. It also possessed the largest average BAF for all 4 of these nutrients, as well as for Mg. Most notably, redroot amaranth possessed a BAF for S of 7.4, indicating that it actively accumulated this nutrient at concentrations over 7 times greater than the surrounding soil. According to USDA data, redroot amaranth has been shown in previous studies to meet dynamic accumulator thresholds for Mg and Zn, among other nutrients, but there is no information available on its nutrient concentrations for Al, Mn, or S. Future research should investigate redroot amaranth's Al, Mn, and S content when grown in a variety of soils, to assess its potential as a dynamic accumulator of these nutrients.

C. album: Plant tissue analysis revealed that lambsquarters accumulated a very high concentration of K (40,715 ppm), surpassing the concentration threshold for dynamic accumulators. It demonstrated a BAF of 47.8 for K, accumulating K concentrations over 47 times greater than the surrounding soil. Lambsquarters also accumulated the highest concentration of Mg (3,267 ppm) of all the trial crops, although its BAF for Mg was 1.3, indicating that lambsquarters' Mg content was not terribly high relative to soil concentrations. Other relatively high bioaccumulation factors reported for lambsquarters include P (3.7), Ca (4.0), and S (6.0). The USDA databases

		N	**P**	**K**	**Al**	**B**	**Ca**	**Cl**	**Co**	**Cu**	**Fe**
Dynamic accumulator thresholds		**50000**	**10000**	**40000**	**2000**	**100**	**20000**	**5000**	**40**	**40**	**500**
Amaranthus sp.	Leaf		**10082**	**73503**			**53333**			19	**1527**
Chenopodium album	Leaf		**36833**	**87100**			**33800**				250
Symphytum peregrinum	Plant	35300	5000	**58600**	385	45	14400			10	364
Taraxacum officinale	Leaf		5268	30000		**125**	**42232**	**22000**		**49**	**900**
Trifolium pratense	Shoot, Hay		4500	26700			**22900**				**1850**
Urtica dioica	Leaf	**55555**	4470	17500	138	47	**29000**	2700	13.2	15	42

		I	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**S**	**Se**	**Si**	**Zn**
Dynamic accumulator thresholds		**40**	**5000**	**400**	**5**	**5000**	**20**	**5000**	**20**	**500**	**100**
Amaranthus sp.	Leaf		**6616**			2406					**108**
Chenopodium album	Leaf					250					
Symphytum peregrinum	Plant		3000	116		70	2				45
Taraxacum officinale	Leaf		2500	206		**5300**	5.6				**230**
Trifolium pratense	Shoot, Hay		**8100**	**464**							
Urtica dioica	Leaf		**8600**	7.8	3	49	2.7	**6665**	2.2	10.3	4.7

Table 4*: Plant tissue nutrient concentrations, in ppm, as reported by Robinson (1983) and USDA-ARS (2016). Values that surpass dynamic accumulator thresholds are displayed in bold.*

Trial crop	**N**	**P**	**K**	**Al**	**B**	**Ca**	**Cl**	**Co**	**Cu**	**Fe**
Amaranthus retroflexus		**253.00%**	**388.80%**			**565.10%**			108.20%	**540.00%**
Chenopodium album		**924.30%**	**460.70%**			**358.20%**				88.40%
Symphytum peregrinum	148.60%	125.50%	**310.00%**	55.60%	109.80%	152.60%			55.60%	128.60%
Taraxacum officinale		132.20%	158.70%		**305.60%**	**447.50%**	**440.00%**		**279.00%**	**318.30%**
Trifolium pratense		112.90%	141.20%			**242.70%**				**654.20%**
Urtica dioica	**233.80%**	112.20%	92.60%	19.90%	114.90%	**307.30%**	54.00%	76.60%	85.40%	14.90%

Trial crop	**I**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**S**	**Se**	**Si**	**Zn**
Amaranthus retroflexus		**217.40%**			120.40%					**205.60%**
Chenopodium album					12.50%					
Symphytum peregrinum		98.60%	72.00%		3.50%	28.60%				84.90%
Taraxacum officinale		82.20%	127.70%		**265.20%**	79.80%				**437.90%**
Trifolium pratense		**266.20%**	**287.60%**							
Urtica dioica		**282.60%**	4.80%	60.00%	2.50%	38.50%	**262.90%**	11.00%	2.10%	9.00%

Table 5*: Plant tissue nutrient concentrations, expressed as percent of average nutrient values of all plant species in the USDA-ARS phytochemical and ethnobotanical databases (accessed December 2021). Concentrations that surpass dynamic accumulator thresholds are displayed in bold.*

	N	**P**	**K**	**Al**	**B**	**Ca**	**Cl**	**Co**	**Cu**	**Fe**
Dynamic accumulator thresholds	**50000**	**10000**	**40000**	**2000**	**100**	**20000**	**5000**	**40**	**40**	**500**
Amaranthus retroflexus		2550.8	34386.5	17.7	20.7	12125.2		0	4.4	36.9
Chenopodium album		2551.7	**40715.8**	7.7	18.2	9108.4		0	5.8	33.9
Symphytum peregrinum		2983.2	**52959.2**	10.6	30.3	14544.5		0	10.3	47.2
Taraxacum officinale		3495.4	28523.5	7.6	15.7	7020.8		0	12.6	47.6
Trifolium pratense		2029.2	18799.5	11.7	13.8	7203.1		0	5.7	57.3
Urtica dioica		2663.7	18678.8	3.9	17.1	17440.7		0	4.6	35.6

	I	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**S**	**Se**	**Si**	**Zn**
Dynamic accumulator thresholds	**40**	**5000**	**400**	**5**	**5000**	**20**	**5000**	**20**	**500**	**100**
Amaranthus retroflexus		2773.4	87.4	0.8	25.2	0	2431.4		51.6	37.9
Chenopodium album		3267.8	52.3	0.7	8.1	0	1959.3		12.6	37.8
Symphytum peregrinum		1865.5	56.3	0.6	68.2	0	1484.3		**513.2**	21.9
Taraxacum officinale		1925	37.2	0.9	169.5	0	2129.3		23.1	37.6
Trifolium pratense		1873.6	22.7	0.9	22.8	0	1248.2		41.9	19.9
Urtica dioica		2068.3	45.4	1	12.8	0	1973.3		325.7	12.2

Table 6*: Plant tissue nutrient concentrations, expressed in ppm, of cuttings taken during on-farm trials. Values that surpass the nutrient thresholds for dynamic accumulators are displayed in bold.*

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		4.9	51.3	0.0017	0.0833	8.5		0	0.5009	0.0016		1.2	0.1386	1.7	2	0	10.4			0.5934
		6-12"		4.3	47.4	0.0018	0.0892	7.6		0	0.4861	0.0017		1.3	0.1525	1.7	2.1	0	8.4			0.5845
		12-24"		3.3	36.6	0.0021	0.1	2.6		0	0.4685	0.0019		1.3	0.1656	1.4	1.8	0	5.4			0.6232
	chop and drop	0-6"		4.7	58.2	0.0024	0.0942	9.9		0	0.7423	0.0018		2.9	0.3362	2	2.7	0	9.3			0.9581
		6-12"		3.5	45.4	0.0025	0.1058	7.9		0	0.6276	0.002		2.6	0.2723	1.2	2.5	0	6			0.8272
		12-24"		3.1	37.8	0.0025	0.1037	5		0	0.5696	0.002		2.2	0.2963	1.3	2.1	0	5			0.7954
C. album	extraction	0-6"		3.2	40.6	0.0009	0.0785	2.8		0	0.6023	0.0016		1.5	0.1322	1.3	0.7	0	4.2			0.659
		6-12"		4	55.6	0.0007	0.0738	5.3		0	0.6361	0.0014		1.5	0.1294	1.8	0.6	0	6.4			0.6094
		12-24"		4.8	55.4	0.0006	0.0646	5.6		0	0.5992	0.0013		1.2	0.146	1.8	0.4	0	8.6			0.5944
	chop and drop	0-6"		2.9	37.5	0.0008	0.0834	1.9		0	0.5572	0.0017		1.3	0.1153	1.5	0.4	0	3.6			0.58
		6-12"		3.2	44.6	0.0006	0.0708	3.8		0	0.5536	0.0013		1.2	0.1022	1.5	0.4	0	5.5			0.5309
		12-24"		3.9	53.1	0.0007	0.07	4.6		0	0.5729	0.0014		1.2	0.1207	1.5	0.5	0	7.9			0.6185
S. peregrinum	extraction	0-6"		2.7	53.9	0.0013	0.1373	4.3		0	1.0872	0.0023		1.3	0.153	0.9	4.8	0	2.4			0.351
		6-12"		3.2	68.8	0.0013	0.1264	8.1		0	1.0736	0.002		1.6	0.1443	0.8	5.9	0	3.4			0.3701
		12-24"		3.6	80.3	0.0012	0.1227	6.8		0	1.215	0.002		1.4	0.1267	1	6	0	3.7			0.3354
	chop and drop	0-6"		3.8	60.8	0.0013	0.1408	4.1		0	1.0894	0.0024		0.9	0.1052	1.1	6.1	0	3.6			0.3615
		6-12"		4	65.2	0.0012	0.1315	6.3		0	1.075	0.0021		1	0.0853	1	5.3	0	4.3			0.3492
		12-24"		4.9	79.8	0.0012	0.1305	7.4		0	1.1239	0.0022		1	0.0725	1.2	5.2	0	5.6			0.3786
T. officinale	extraction	0-6"		3.9	31.3	0.0007	0.0672	2.1		0	1.1168	0.0021		0.8	0.0628	1.4	6.4	0	5.1			0.5862
		6-12"		4.8	37.9	0.0006	0.0651	3		0	1.1101	0.002		0.8	0.0488	1.9	7.5	0	6.8			0.5497
		12-24"		6.6	40.5	0.0006	0.0623	3.5		0	1.1986	0.002		0.7	0.053	2.3	9.1	0	10.5			0.6074
	chop and drop	0-6"		4.2	28.6	0.0007	0.0667	1.1		0	1.1662	0.0022		0.7	0.0693	2	9	0	5			0.5273
		6-12"		4.7	37.3	0.0007	0.0678	3		0	1.1721	0.0021		0.8	0.0762	2.3	9.4	0	6.5			0.5847
		12-24"		6	41	0.0006	0.0631	3.3		0	1.2231	0.002		0.8	0.0571	2.3	10.1	0	9			0.6102
T. pratense	extraction	0-6"		2.9	23.2	0.0011	0.0579	3.3		0	0.4521	0.0026		0.8	0.0405	1.8	1.2	0	4.1			0.3008
		6-12"		2.5	20.4	0.0011	0.0601	3		0	0.4527	0.0025		0.8	0.0393	1.8	1.4	0	3.2			0.2949
		12-24"		1.9	15.9	0.0012	0.0659	1.3		0	0.45	0.003		0.7	0.044	1.5	1.5	0	1.7			0.2761
	chop and drop	0-6"		3.3	21.3	0.001	0.0549	3.6		0	0.5776	0.0024		0.8	0.0331	2.2	0.9	0	4.9			0.294
		6-12"		2.6	18.3	0.0011	0.0575	3.5		0	0.5813	0.0025		0.8	0.0391	1.8	1	0	3.5			0.2975
		12-24"		2.2	15.3	0.0012	0.0621	1.9		0	0.5495	0.0027		0.8	0.0428	1.6	1.4	0	2.6			0.2915
U. dioica	extraction	0-6"		5.2	26.1	0.0003	0.0699	9.1		0	0.513	0.0015		0.7	0.1203	2.5	0.4	0	9.1			0.1901
		6-12"		4	26.2	0.0004	0.0729	8		0	0.5024	0.0016		0.8	0.0983	2.5	0.5	0	6.7			0.1939
		12-24"		2.9	22	0.0004	0.0819	3.3		0	0.457	0.0017		0.9	0.0785	2.2	0.5	0	4.4			0.1825
	chop and drop	0-6"		4.5	27.8	0.0005	0.0791	11.2		0	0.6868	0.0018		1.8	0.1423	1.8	1	0	6.5			0.2827
		6-12"		3.6	21.3	0.0005	0.0813	12.2		0	0.617	0.0018		1.7	0.1423	1.8	1	0	4.9			0.2493
		12-24"		3.4	22.8	0.0006	0.0995	4.8		0	0.6622	0.0022		1.7	0.1782	1.6	1.2	0	4.3			0.2788

***Table** 7: Bioaccumulation factors, calculated by dividing plant tissue nutrient concentrations derived from on-farm trial rows (**Table 6**) by nutrient concentrations across all soil horizons, from samples collected in the spring of the same year (**Appendix 2**).*

Trial Crop	**N**	**P**	**K**	**Al**	**B**	**Ca**	**Cl**	**Co**	**Cu**	**Fe**
Amaranthus retroflexus		3.9	46.1	**0.0022**	0.096	6.9		0	0.6	0.0018
Chenopodium album		3.7	47.8	0.0007	0.0735	4		0	0.6	0.0014
Symphytum peregrinum		3.7	**68.1**	0.0013	**0.1315**	6.2		0	1.1	0.0022
Taraxacum officinale		**5**	36.1	0.0007	0.0654	2.7		0	**1.2**	0.0021
Trifolium pratense		2.6	19.1	0.0011	0.0597	2.8		0	0.5	**0.0026**
Urtica dioica		4	24.4	0.0005	0.0808	**8.1**		0	0.6	0.0018

Trial Crop	**I**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**S**	**Se**	**Si**	**Zn**
Amaranthus retroflexus		**1.9**	**0.2269**	1.5	2.2	0	**7.4**			**0.7303**
Chenopodium album		1.3	0.1243	1.6	0.5	0	6			0.5987
Symphytum peregrinum		1.2	0.1145	1	5.6	0	3.8			0.3576
Taraxacum officinale		0.8	0.0612	2	**8.6**	0	7.2			0.5776
Trifolium pratense		0.8	0.0398	1.8	1.2	0	3.3			0.2925
Urtica dioica		1.3	0.1266	**2.1**	0.8	0	6			0.2295

***Table 8**: Bioaccumulation factor averages for 6 trial crops.*

confirm that lambsquarters has been shown to meet dynamic accumulator thresholds for P, K, and Ca, but there is no available USDA data on lambsquarters' S concentrations, revealing an opportunity for further research.

S. peregrinum: Russian comfrey was shown to possess the highest concentrations of K (52,959 ppm), B (30.3 ppm), and Si (513 ppm) of all trial crops, with concentrations of K and Si surpassing dynamic accumulator thresholds. Russian comfrey also demonstrated the highest BAF of all trial crops for K (68.1) and B (0.13), with no data available for Russian comfrey's BAF of Si. These findings are in alignment with data from Robinson (1983) showing Russian comfrey surpassing the dynamic accumulator threshold for K, although Robinson did not provide data on Si concentrations. Additional peer-reviewed research is needed on Russian comfrey's plant tissue nutrient concentrations and bioaccumulation factors, especially for K and Si, when grown in a variety of soils.

T. officinale: The foliage of dandelion possessed the highest nutrient concentrations and bioaccumulation factors for P (3,495 ppm, BAF = 5.0), Cu (12.6 ppm, BAF = 1.2), and Na (169.5 ppm, BAF = 8.6) of all trial crops. Dandelion also possessed impressive BAFs for K (36.1), Ca (2.7), Mo (2.0) and S (7.2). According to USDA data, dandelion has been previously shown to accumulate above-average concentrations of P and K, and to surpass dynamic accumulator thresholds for Ca, Cu, and Na, among other nutrients. There is no peer-reviewed data available through USDA on dandelion tissue concentrations of Mo and S, revealing an opportunity for further research.

T. pratense: Plant tissue analysis for red clover shows the highest concentration and bioaccumulation factor for Fe (57.3 ppm, BAF = 0.0026) of all trial crops. This is in alignment with data from USDA, which shows red clover surpassing dynamic accumulator thresholds for Fe, among other nutrients. It should be noted that Fe soil concentrations reported in this study refer to total Fe, rather than available Fe, suggesting that red clover's bioaccumulation factor for Fe is being underreported. Further research is needed to calculate BAFs for red clover, using available soil nutrient concentrations across a range of growing media, to further explore red clover's potential as a dynamic accumulator of Fe.

U. dioica: Stinging nettle foliage demonstrated both the highest concentration and bioaccumulation factor for Ca (17,440 ppm, BAF = 8.1) of all trial crops. This is in alignment with data from USDA, which shows stinging nettle surpassing dynamic accumulator thresholds for Ca, among other nutrients.

3. Liquid nutrient analysis

During the second year of on-farm trials, plant material harvested from trial rows was steeped in rainwater, without agitation, to produce non-aerated liquid plant extracts, following the guidelines put forward by Brinton (2011). Rainwater catchment was used because of its affordability and widespread availability for Northeast farmers, and also to minimize the presence of dissolved solids in the water. Liquid temperature and pH was measured daily for all batches, using a digital pH meter with an accuracy rating of ±0.1 pH. This data is reported in **Table 9**.

The batches of liquid plant extracts were left to steep outdoors in a shaded location, to monitor the effects of temperature fluctuations on pH. **Table 9** shows a range of recorded temperatures from 55.6°F to 84.9°F across all trials, with a mean temperature of 70.25°F. Temperature swings did not appear to significantly affect pH levels, and the mean temperature is quite close to Brinton's recommendation of 72°F. This suggests that the naturally occurring temperature range on Northeast farms from June to September is conducive to producing non-aerated liquid plant extracts outdoors or in unheated buildings, reducing potential production costs for farmers.

The temperature and pH of the rainwater used for each batch was measured prior to adding plant material; these data points are expressed in **Table 9** as entries with a steep time of 0 days. The pH of pure rainwater fluctuated from 5.3 to 5.9 across all batches. According to the United States Geological Survey (USGS, 2019), rainfall normally has a pH just under 6, while acid rain pH can range from 4.0 to 5.5. Our findings confirm USGS reports that the Northeast experiences acid rain as a result of air pollution. This complicates the formulation of non-aerated liquid plant extracts using rainwater on Northeast farms, as the ideal pH range for most vegetable crops is 5.5 to 7.0 (Liu and Hanlon, 2012). A recommendation to address this issue in future trials would be to correct rainwater pH prior to steeping plant material. The effects of pH and pH correction methods on nutrient solubility could be explored in future studies.

For all on-site measurements, pH steadily decreased once plant material was introduced, due to the almost immediate onset of fermentation during the steeping process. **Table 9** shows the daily pH measurements taken on-site. After 3 and 5 days of steeping, liquid samples were mailed to the nutrient analysis laboratory. **Table 10** shows pH measurements taken at the laboratory. There are some irregularities present in these pH measurements that are not present in the measurements taken on-site, including a higher frequency of rising pH levels, and an unlikely pH of 8.15 for a liquid sample of stinging nettle extract that had steeped for 3 days. This suggests that the laboratory's measuring device was poorly calibrated at times, and brings into question the accuracy of the laboratory's pH data. In future research, conducting all liquid nutrient analyses on-site would allow researchers to ensure testing is done in a timely manner and with properly calibrated equipment. That said, a steady decrease of pH over time would confirm the findings of Brinton (2011), and would indicate that regarding pH, a shorter steep time of 3 days would be preferable, to minimise the need for pH adjustment.

However, **Table 10** also shows that nutrient concentrations generally increased from 3 to 5 days of steeping. Concentrations of B, Fe, Mg, and Mn always increased over this time period; Ca, K, Na, S, and Zn were twice as likely to increase; and concentrations of P increased from 3 to 5 days of steeping in all batches apart from one (the dandelion extract). Changes in the concentrations of Al and Cu did not follow a clear trend. These findings suggest that a steep time of 5 days would result in higher concentrations of desirable nutrients, when compared to a steep time of 3 days. However, it is unlikely that Northeast farmers relying on acid rain would be able to achieve acceptable pH levels over that time period without initially adjusting the rainwater's pH.

Nutrient carryover from plant tissue to liquid plant extract was explored by comparing the results of the dried plant tissue analysis with the liquid nutrient analysis. **Table 11** lists liquid extract nutrient concentrations, expressed as the percentage of dried plant tissue nutrient concentrations. The highest percentage of nutrient carryover for each nutrient, after both 3 days of steeping and 5 days of steeping, has been bolded.

The analysis of nutrient carryover provides a useful method of comparison between these 6 plants. However, since plant tissue nutrient concentrations for dried samples were used, this method of measuring nutrient carryover is skewed by differences in water content of fresh tissue. Therefore the results presented here are probably biased in favor of plants that possess less water content in their foliage. This bias could be addressed in future studies by either measuring nutrient concentrations in fresh plant tissue instead of dried, or by measuring the ratio of fresh weight to dry weight for plant tissue samples and factoring that into the calculation of nutrient carryover.

Another shortcoming of this liquid nutrient analysis is that it is limited to a single batch of liquid extract per plant. Due to the complex relationship between pH and nutrient solubility, further research is needed to study the production of non-aerated liquid plant extracts across multiple batches, using rainwater at different initial pH values. This would allow researchers to study the effect of pH on nutrient solubility. Different methods of pH adjustment and their effect on nutrient solubility should also be explored.

Finally, future studies should produce multiple batches of liquid extract for each set of variables, to allow for a larger sample size. This would allow for nutrient concentration ranges and averages to be drawn across multiple samples, minimizing the effect of data outliers or inaccuracies in measurement.

A. retroflexus: Redroot amaranth extract demonstrated the highest concentration and rate of nutrient carryover for Fe, when compared at both 3 days (1.13 ppm, 3.05% carryover) and 5 days (1.29 ppm, 3.51% carryover) of steeping. It also demonstrated the highest concentration and rate of nutrient carryover for S after 3 days (105.22 ppm, 4.33% carryover), although the fact that the concentration of this nutrient decreases by day 5 suggests these measurements could be inaccurate.

C. album: Liquid extract derived from lambsquarters foliage possessed the highest concentrations of all the trial crops for Al (0.49 ppm), Cu (0.10 ppm), Mg (48.35 ppm), and Zn (0.42 ppm) after a 3 day steep, and the highest concentrations of K (903.54 ppm), Al (0.53 ppm), Mg (56.43 ppm), and Zn (0.55 ppm) after a 5 day steep. Lambsquarters also demonstrated the highest rate of nutrient carryover for Al after 3 days (6.39%), and for Al (6.91%), Na (12.50%), and Zn (1.46%) after 5 days.

S. peregrinum: Russian comfrey extract possessed the highest K concentration of all the trial crops after 3 days of steeping (889.65 ppm), and the highest S concentration after 5 days (131.63 ppm). It produced the highest rate of nutrient carryover for S when compared to other batches at 5 days of steeping (8.87%).

T. officinale: Dandelion extract possessed the highest P concentration of all the trial crops after 3 days of steeping (62.05 ppm), and the highest Na concentration after both 3 days (1.57 ppm) and 5 days (2.22 ppm) of steeping. It did not demonstrate high rates of nutrient carryover for any nutrients, neither after 3 days nor 5 days of steeping.

T. pratense: Red clover extract was not measured as having high concentrations or rates of carryover for any nutrients.

U. dioica: Stinging nettle extract demonstrated the highest rates of nutrient carryover, both when compared at a 3 day steep time and at a 5 day steep time, for P (2.18%, 3.35%), K (2.65%, 3.21%), B (1.81%, 2.78%), Ca (1.76%, 2.04%), Cu (6.72%, 1.62%), Mg (1.83%, 2.07%) and Mn (2.21%, 2.98%). Stinging nettle also demonstrated the highest rate of nutrient carryover after a 3 day steep for Na (9.32%) and Zn (3.13%).

Batch #	Trial crop	Steep time (days)	Temperature (F)	pH
1	*S. peregrinum*	0	65.5	5.7
		1	70.2	5.7
		2	71.8	5.7
		3	72.6	5.5
		4	82.6	5.1
		5	84.9	5.1
2	*T. officinale*	0	72.5	5.4
		1	73	5.2
		2	71	5.2
		3	73.1	5
		4	77.4	4.8
		5	78.3	4.7
3	*S. peregrinum*	0	72.9	5.7
		1	65.3	5.7
		2	66.4	5.8
		3	55.6	5.6
		4	63.1	5.3
		5	66.7	5.2
4	*C. album*	0	72.1	5.9
		1	64.8	5.5
		2	66.7	5
		3	56.5	5
		4	64.2	5
		5	66.4	4.9
5	*U. dioica*	0	76.1	5.9
		1	64.9	6.3
		2	67.5	6.2
		3	55.9	5.5
		4	65.3	5.2
		5	66.6	5.1
6	*A. retroflexus*	0	78.4	5.7
		1	77.7	5
		2	78.3	5.1
		3	75.4	5.1
		4	70.7	5.2
		5	73.6	5.2
7	*T. pratense*	0	67.3	5.3
		1	64.5	5
		2	60.1	4.8
		3	66.7	4.7
		4	65.1	4.7
		5	60.1	4.7
8	*S. peregrinum*	0	76.8	5.8
		1	75.7	5.7
		2	76.4	5.3
		3	59.5	5.1
		4	77.5	5.1
		5	78.3	4.9
9	*S. peregrinum*	0	76.8	5.8
		1	75.7	5.8
		2	76.4	5.7
		3	59.5	5.7
		4	77.5	5.5
		5	78.3	5.4
10	*U. dioica*	0	76.8	5.8
		1	75.7	5.7
		2	76.4	5.7
		3	59.5	5.3
		4	77.5	5.1
		5	78.3	4.9
11	*U. dioica*	0	76.8	5.9
		1	75.7	5.8
		2	76.4	5.8
		3	59.5	5.5
		4	77.5	5.3
		5	78.3	5.1

***Table 9**: Temperature and pH of non-aerated liquid plant extracts.*

Trial crop	Steep Time (days)	pH	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe
Rainwater	0			0	2.18	0	0	0		0	0	0
A. retroflexus	3	5.3		35.65	494	0.34	0.04	3.26		0	0	**1.13**
A. retroflexus	5	5.2		57.19	755.28	0.48	0.05	2.34		0	0	**1.29**
C. album	3	5.2		41.11	789.55	**0.49**	0.18	0.77		0	**0.1**	0.93
C. album	5	5.3		54.32	**903.54**	**0.53**	0.21	0.52		0	0.04	1.07
S. peregrinum	3	5.8		42.62	**889.65**	0	0.25	37.19		0	0.06	0.61
S. peregrinum	5	4.9		42.74	744.12	0	0.26	38.67		0	0.03	0.84
T. officinale	3	4.9		**62.05**	634.47	0	0.16	84.53		0	0.05	0.71
T. officinale	5	4.8		54.95	585.13	0.08	0.25	99.8		0	0.03	1.11
T. pratense	3	4.8		18.2	293.47	0.08	0.02	52.76		0	0.02	0.28
T. pratense	5	4.9		22.48	321.82	0.06	0.03	54.94		0	0.02	0.34
U. dioica	3	8.2		58.15	494.78	0.05	**0.31**	**306.73**		0	0.31	0.11
U. dioica	5	4.9		**89.31**	599.39	0.05	**0.48**	**354.99**		0	**0.08**	0.25

Trial crop	Steep Time (days)	pH	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
Rainwater	0			0.01	0	0	0.16	0	0.08			0.06
A. retroflexus	3	5.3		14.52	0.27	0	0.62	0	**105.22**			0.17
A. retroflexus	5	5.2		25.35	0.45	0	1.09	0	99.05			0.27
C. album	3	5.2		**48.35**	0.5	0	0.32	0	18.82			**0.42**
C. album	5	5.3		**56.43**	0.58	0	1.02	0	24.19			**0.55**
S. peregrinum	3	5.8		12.24	0.32	0	0.79	0	57.64			0.16
S. peregrinum	5	4.9		14.39	0.34	0	0.74	0	**131.63**			0.15
T. officinale	3	4.9		27.41	0.43	0	**1.57**	0	51.07			0.18
T. officinale	5	4.8		29.53	0.53	0	**2.22**	0	18.56			0.24
T. pratense	3	4.8		12.58	0.19	0	1.44	0	36.37			0.14
T. pratense	5	4.9		14.57	0.22	0	1.82	0	48.69			0.18
U. dioica	3	8.2		37.8	**1.01**	0	1.19	0	45.68			0.38
U. dioica	5	4.9		42.8	**1.35**	0	0.59	0	116.81			0.15

***Table 10**: Liquid nutrient analysis, expressed in ppm, for plain rainwater and 6 trial crops steeped in rainwater. The highest nutrient concentrations at 3 and 5 days are displayed in bold.*

Trial crop	Steep Time (days)	pH	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe
A. retroflexus	3	5.3		1.40%	1.44%	1.91%	0.19%	0.03%		0%	0.00%	**3.05%**
A. retroflexus	5	5.2		2.24%	2.20%	2.69%	0.25%	0.02%		0%	0.00%	**3.51%**
C. album	3	5.2		1.61%	1.94%	**6.39%**	0.96%	0.01%		0%	1.65%	2.73%
C. album	5	5.3		2.13%	2.22%	**6.91%**	1.13%	0.01%		0%	0.74%	3.16%
S. peregrinum	3	5.8		1.43%	1.68%	0.00%	0.84%	0.26%		0%	0.56%	1.28%
S. peregrinum	5	4.9		1.43%	1.41%	0.00%	0.87%	0.27%		0%	0.31%	1.79%
T. officinale	3	4.9		1.78%	2.22%	0.00%	1.01%	1.20%		0%	0.37%	1.48%
T. officinale	5	4.8		1.57%	2.05%	1.11%	1.61%	1.42%		0%	0.26%	2.34%
T. pratense	3	4.8		0.90%	1.56%	0.69%	0.16%	0.73%		0%	0.30%	0.49%
T. pratense	5	4.9		1.11%	1.71%	0.48%	0.18%	0.76%		0%	0.30%	0.59%
U. dioica	3	8.2		**2.18%**	**2.65%**	1.23%	**1.81%**	**1.76%**		0%	**6.72%**	0.32%
U. dioica	5	4.9		**3.35%**	**3.21%**	1.36%	**2.78%**	**2.04%**		0%	**1.62%**	0.71%

Trial crop	Steep Time (days)	pH	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	3	5.3		0.52%	0.31%	0%	2.47%		**4.33%**			0.45%
A. retroflexus	5	5.2		0.91%	0.51%	0%	4.31%		4.07%			0.70%
C. album	3	5.2		1.48%	0.96%	0%	3.90%		0.96%			1.11%
C. album	5	5.3		1.73%	1.10%	0%	**12.50%**		1.23%			**1.46%**
S. peregrinum	3	5.8		0.66%	0.56%	0%	1.16%		3.88%			0.73%
S. peregrinum	5	4.9		0.77%	0.61%	0%	1.09%		**8.87%**			0.69%
T. officinale	3	4.9		1.42%	1.16%	0%	0.93%		2.40%			0.48%
T. officinale	5	4.8		1.53%	1.44%	0%	1.31%		0.87%			0.63%
T. pratense	3	4.8		0.67%	0.85%	0%	6.34%		2.91%			0.69%
T. pratense	5	4.9		0.78%	0.96%	0%	7.99%		3.90%			0.89%
U. dioica	3	8.2		**1.83%**	**2.21%**	0%	**9.32%**		2.31%			**3.13%**
U. dioica	5	4.9		**2.07%**	**2.98%**	0%	4.64%		5.92%			1.25%

***Table 11**: Liquid nutrient analysis, expressed as percent of dried plant tissue nutrient concentrations. The highest percentage of nutrient carryover for each nutrient at 3 and 5 days is displayed in bold.*

4. Soil analysis

Three rounds of soil samples were collected from all trial rows, at 3 soil horizons: 0-6", 6-12", and 12-24". Soil samples were sent to Cornell nutrient analysis laboratory and underwent total elemental analysis. The first round of soil samples was collected during spring of the first year, before planting (see **Appendix 1**). A second round of soil samples was collected during spring of the second year, after all trial crops had been established in their rows over the course of the first growing season (see **Appendix 2**). A third and final round of soil samples was collected during autumn of the second year, after all rows had undergone heavy harvesting throughout the second growing season (see **Appendix 3**).

Appendix 4 illustrates the change in soil nutrient concentrations after the first year of growth, expressed as a percentage of initial soil concentrations. Stinging nettle rows saw the greatest overall reduction in soil nutrients when compared to other rows at 0-6" and 6-12" horizons, and specifically the greatest reduction in P and K levels in the top 0-6" of soil. Redroot amaranth rows also saw a relatively large decrease in Na levels, at all soil horizons. Conversely, rows planted with dandelion showed an overall increase in soil nutrients over the first year of growth. An unrealistic jump in boron concentrations is evident in **Appendix 4**, across all trial rows and all soil horizons. This suggests that there may have been an error made in the measuring or recording of boron levels. In light of this, all data on soil concentrations of boron will be ignored in this discussion.

During the second year of growth, all trial rows were heavily harvested, taking multiple cuts across the season whenever possible. One "extraction" row of each trial crop had its harvested plant material removed from the row. **Table 12** shows the percent of change in soil nutrient concentrations across all extraction rows, calculated using data from the second round of soil samples (collected in the spring prior to harvesting) and the third round of soil samples (collected in the autumn following harvesting). Contrary to expectations, none of the extraction rows demonstrated a significant reduction in soil nutrient concentrations. On the contrary, the data shows a slight trend towards increasing concentrations for all nutrients apart from Na, which consistently decreased. In fact, the stinging nettle extraction row shows Mn concentrations more than doubling across all soil horizons. Similarly, the redroot amaranth extraction row shows large increases in Ca concentrations in the 0-6" horizon (347% increase) and the 6-12" horizon (208% increase). These unexpected results could be due to microbial activity and decomposing organic matter enriching the soil and more than compensating for the trial crops' extraction of nutrients from the soil. The use of wood chip mulch in the trial rows and across the larger food forest where these trials took place could be contributing to this. Also, the decision not to harvest during the first year of this study, and instead to leave the trial crops to establish, resulted in all trial rows heavily mulching themselves over the winter, as above-ground plant material died back and covered the surface of the rows. This plant debris may have been decomposing and returning nutrients to the soil over the course of the second year.

During the second year of growth, one "chop and drop" row of each trial crop was mulched with the plant material that had been harvested from that row. **Table 13** shows the percent of change in soil nutrient concentrations across all chop and drop rows, calculated using data from the second round of soil samples (collected in the spring prior to harvesting) and the third round of soil samples (collected in the autumn following the "chopping and dropping" of harvested material). This data shows a slight trend towards increasing concentrations for all nutrients apart from Na. The chop and drop rows tended to demonstrate larger nutrient increases than the extraction rows, apart from Na concentrations which consistently decreased.

A. retroflexus: As shown in **Table 13**, one year of chopping and dropping with redroot amaranth coincided with large increases in nutrient concentrations in the top 0-6" of soil for 10 nutrients: P (213%), K (197%), Ca (420%), Co (229%), Cu (246%), Mg (312%), Mn (232%), Ni (294%), S (252%), and Zn (225%). Interestingly, plant tissue analysis conducted as a part of this study shows redroot amaranth possessing the highest nutrient concentrations for Mn, S, and Zn, among others, and the largest bioaccumulation factors of any trial crop for Mg, Mn, S, and Zn, among others (see **Tables 7** an **8**). Data from the USDA phytochemical and ethnobotanical databases (see **Tables 4** and **5**) also shows redroot amaranth possessing high concentrations for several of these nutrients, meeting dynamic accumulator thresholds for 5 of them (P, K, Ca, Mg, and Zn), and failing to meet the threshold for only 1 of them (Cu). There is no data available in the USDA databases for 4 of these nutrients (Co, Mn, Ni, and S).

C. album: Soil nutrient concentrations of the lambsquarters "chop and drop" row did not differ greatly from the "extraction" row. This is most likely due to poor growth during the second year of trials (see the **Crop Yields** section of this discussion).

S. peregrinum: Despite producing yields much higher than any other trial crop (see **Table 3**), there was little difference in soil nutrient concentrations between Russian comfrey's extraction row and chop and drop row (**Table 12**, **Table 13**). In fact, despite producing more than triple the mass of any other trial crop, there was little difference in soil nutrient concentrations after chopping and dropping with Russian comfrey (**Table 13**). The one notable change in soil nutrient concentrations in the Russian comfrey chop and drop row is a 293% increase in Cu concentrations in the top 0-6" of soil, which does not correlate with plant tissue Cu concentrations. This lack of change in soil nutrient concentrations could be explained by the relatively low nutrient concentrations of Russian comfrey's foliage, reported both in this study (**Table 6**) and by Robinson (1983) (**Table 4**, **Table 5**). Unfortunately, the soil analyses conducted for this study do not include data on N or Si concentrations, Si being one of the two nutrients Russian comfrey has been shown to accumulate in high amounts. It is also possible that the widely reported benefits of mulching with Russian comfrey are not so much caused by its high nutrient content, but by other benefits resulting from mulching with plant tissue: increased organic matter, conservation of soil moisture, reduction in soil temperature, etc.

T. officinale: Soil nutrient concentrations did not noticeably increase in the dandelion chop and drop row. This could be due to dandelion's relatively low yields, both projected and actual, when compared to the other trial crops (**Table 2**, **Table 3**).

T. pratense: Soil nutrient concentrations of the red clover "chop and drop" row did not differ greatly from the "extraction" row (**Table 12**, **Table 13**). This could be due to poor growth during the second year of trials (**Table 3**), combined with lower than expected nutrient concentrations in its foliage (**Table 6**).

U. dioica: **Table 13** shows that one year of chopping and dropping with stinging nettle coincided with a doubling or more of soil nutrient concentrations for P, Ca, Co, Cu, Mg, Mn, Ni, and Zn over at least one soil horizon. Most notably, Ca levels more than doubled in both the 0-6" soil horizon (263%) and the 6-12" soil horizon (227%), while Ca levels dropped in the 12-24" soil horizon (63%). These findings are consistent with the hypothesis that dynamic accumulators enrich the topsoil by extracting nutrients from the subsoil. Plant tissue analysis conducted as part of this study (**Table 6**) showed stinging nettle foliage possessed the highest Ca concentrations of any of the trial crops (17,440 ppm), suggesting that chopping and dropping with calcium-rich stinging nettle foliage may have helped to enrich the topsoil with that nutrient. This hypothesis is further

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe
A. retroflexus	extraction	0-6"		209.50%	155.40%	106.00%	88.20%	**347.00%**		96.30%	143.20%	105.10%
		6-12"		157.60%	130.20%	114.50%	98.20%	**208.90%**		112.60%	130.80%	113.50%
		12-24"		111.00%	84.20%	152.60%	121.10%	60.30%		144.00%	151.10%	145.40%
C. album	extraction	0-6"		123.00%	102.60%	118.60%	123.40%	135.10%		134.20%	158.50%	147.40%
		6-12"		136.50%	128.10%	110.30%	100.90%	148.20%		109.90%	133.70%	113.50%
		12-24"		111.60%	117.30%	121.00%	107.50%	122.20%		133.00%	347.20%	124.20%
S. peregrinum	extraction	0-6"		105.00%	85.10%	114.20%	105.00%	139.10%		122.00%	156.70%	123.30%
		6-12"		106.90%	108.80%	136.10%	111.40%	141.60%		107.70%	111.90%	129.90%
		12-24"		70.20%	81.90%	159.30%	131.50%	64.00%		166.20%	112.00%	154.80%
T. officinale	extraction	0-6"		134.00%	149.70%	121.00%	102.00%	131.20%		127.90%	131.70%	118.40%
		6-12"		134.60%	159.50%	124.60%	111.30%	119.40%		132.00%	135.20%	129.60%
		12-24"		145.70%	154.70%	123.20%	120.00%	129.50%		161.10%	147.90%	139.90%
T. pratense	extraction	0-6"		137.50%	108.70%	71.90%	77.00%	226.70%		65.50%	72.50%	92.50%
		6-12"		97.30%	88.40%	81.30%	92.60%	88.70%		65.70%	71.20%	105.40%
		12-24"		62.10%	**48.10%**	106.50%	116.40%	**22.40%**		69.70%	61.00%	139.80%
U. dioica	extraction	0-6"		213.80%	116.90%	103.90%	85.60%	161.10%		109.40%	133.10%	102.20%
		6-12"		152.30%	118.10%	122.00%	96.90%	124.40%		127.40%	134.30%	114.20%
		12-24"		68.30%	98.70%	143.00%	118.10%	**44.10%**		129.60%	116.80%	134.50%
Fallow	-	0-6"		106.20%	99.80%	98.00%	92.30%	99.80%		105.20%	102.50%	118.40%
		6-12"		109.10%	98.20%	74.80%	77.40%	66.30%		**50.90%**	71.70%	90.40%
		12-24"		77.70%	63.90%	76.80%	82.70%	**32.40%**		59.90%	77.90%	100.30%

Trial crop	Row type	Depth	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		114.90%	95.50%	0.00%	79.40%	105.00%	**273.60%**			132.60%
		6-12"		119.00%	108.20%	0.00%	60.80%	118.60%	172.60%			126.70%
		12-24"		128.10%	163.70%	0.00%	67.60%	**200.20%**	86.50%			142.40%
C. album	extraction	0-6"		117.20%	136.40%	0.00%	**47.80%**	168.00%	121.80%			140.90%
		6-12"		110.10%	136.10%	0.00%	**42.30%**	112.60%	138.70%			127.70%
		12-24"		119.20%	156.40%	0.00%	**46.50%**	**450.40%**	112.70%			136.90%
S. peregrinum	extraction	0-6"		119.60%	103.90%	0.00%	**50.00%**	131.70%	110.40%			141.40%
		6-12"		154.30%	101.40%	0.00%	56.40%	133.90%	123.30%			166.70%
		12-24"		**201.60%**	90.30%	0.00%	54.00%	**200.70%**	59.10%			138.30%
T. officinale	extraction	0-6"		117.70%	135.40%	0.00%	**24.50%**	128.20%	151.80%			139.40%
		6-12"		130.70%	125.20%	0.00%	**30.80%**	139.70%	137.00%			133.40%
		12-24"		130.60%	147.30%	0.00%	**39.80%**	150.70%	156.70%			144.30%
T. pratense	extraction	0-6"		76.80%	64.40%	0.00%	**27.80%**	66.50%	186.50%			91.00%
		6-12"		68.30%	60.40%	0.00%	**36.70%**	67.70%	115.40%			88.30%
		12-24"		**50.80%**	**45.80%**	0.00%	**41.90%**	66.40%	**47.80%**			74.40%
U. dioica	extraction	0-6"		85.50%	**236.00%**	0.00%	**34.10%**	94.30%	**215.20%**			138.90%
		6-12"		107.50%	**243.00%**	0.00%	55.10%	125.30%	140.80%			147.80%
		12-24"		143.00%	**228.10%**	0.00%	59.10%	142.60%	56.20%			140.40%
Fallow	-	0-6"		93.80%	105.20%	0.00%	**23.00%**	103.60%	129.40%			124.10%
		6-12"		**45.80%**	51.20%	0.00%	**26.50%**	**47.50%**	138.40%			79.60%
		12-24"		**44.90%**	62.10%	0.00%	**26.60%**	119.70%	84.00%			78.00%

Table 12: *soil nutrient concentrations of "extraction" rows, after removing harvested plant material during second year of growth, expressed as a percent of the previous year's soil nutrient concentrations.*

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe
A. retroflexus	chop and drop	0-6"		**213.60%**	**197.70%**	164.80%	104.60%	**420.20%**		**229.50%**	**246.90%**	124.20%
		6-12"		132.40%	134.00%	185.10%	127.50%	196.70%		**249.40%**	194.30%	149.30%
		12-24"		81.40%	101.90%	177.70%	126.70%	114.20%		**261.60%**	197.00%	154.30%
C. album	chop and drop	0-6"		99.50%	87.10%	105.20%	102.10%	109.70%		116.60%	110.90%	123.50%
		6-12"		99.70%	96.60%	108.70%	104.90%	110.40%		109.20%	107.10%	118.90%
		12-24"		91.00%	117.40%	130.20%	111.80%	112.30%		143.50%	**271.50%**	142.90%
S. peregrinum	chop and drop	0-6"		116.00%	140.30%	122.90%	101.30%	89.60%		120.20%	**293.10%**	122.70%
		6-12"		89.00%	98.10%	104.20%	87.90%	78.00%		102.70%	114.30%	101.90%
		12-24"		96.00%	120.60%	125.40%	98.90%	92.30%		118.00%	110.60%	120.70%
T. officinale	chop and drop	0-6"		120.80%	101.40%	127.40%	114.40%	58.60%		136.30%	129.10%	137.80%
		6-12"		96.70%	94.40%	109.00%	104.70%	117.40%		125.50%	112.80%	117.60%
		12-24"		102.70%	99.00%	102.20%	91.00%	116.90%		105.60%	108.50%	107.70%
T. pratense	chop and drop	0-6"		147.00%	98.00%	84.00%	80.90%	229.90%		83.70%	110.00%	94.80%
		6-12"		90.90%	79.50%	97.60%	87.10%	117.20%		104.60%	105.30%	102.80%
		12-24"		127.70%	79.60%	76.10%	73.60%	148.30%		60.20%	95.10%	85.90%
U. dioica	chop and drop	0-6"		**200.60%**	159.80%	172.90%	106.20%	**263.80%**		192.50%	**200.90%**	129.30%
		6-12"		121.50%	108.20%	162.50%	104.70%	**227.60%**		**207.10%**	177.00%	126.60%
		12-24"		75.20%	89.10%	179.90%	125.20%	63.20%		**226.30%**	157.70%	153.70%
Fallow	-	0-6"		106.20%	99.80%	98.00%	92.30%	99.80%		105.20%	102.50%	118.40%
		6-12"		109.10%	98.20%	74.80%	77.40%	66.30%		50.90%	71.70%	90.40%
		12-24"		77.70%	63.90%	76.80%	82.70%	32.40%		59.90%	77.90%	100.30%

Trial crop	Row type	Depth	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	chop and drop	0-6"		**312.80%**	**232.70%**	0.00%	74.20%	**294.00%**	**252.70%**			**225.60%**
		6-12"		**284.70%**	188.80%	0.00%	83.90%	**323.40%**	112.40%			193.60%
		12-24"		**265.90%**	**209.50%**	0.00%	95.20%	**422.60%**	66.70%			169.70%
C. album	chop and drop	0-6"		109.30%	116.50%	0.00%	**27.80%**	122.30%	102.00%			120.10%
		6-12"		107.40%	105.30%	0.00%	**35.30%**	114.40%	110.10%			120.30%
		12-24"		133.50%	139.60%	0.00%	60.70%	394.70%	97.00%			148.00%
S. peregrinum	chop and drop	0-6"		122.90%	121.20%	0.00%	51.50%	135.10%	112.10%			133.30%
		6-12"		105.70%	107.70%	0.00%	**40.90%**	111.60%	94.00%			109.40%
		12-24"		142.20%	94.70%	0.00%	**46.20%**	152.10%	105.10%			131.10%
T. officinale	chop and drop	0-6"		110.00%	164.10%	0.00%	**33.30%**	140.70%	114.80%			130.90%
		6-12"		117.50%	138.90%	0.00%	**42.30%**	126.30%	96.80%			113.80%
		12-24"		109.60%	89.30%	0.00%	**43.40%**	116.10%	110.50%			111.00%
T. pratense	chop and drop	0-6"		94.10%	84.90%	0.00%	**24.40%**	90.90%	189.70%			120.80%
		6-12"		105.00%	98.40%	0.00%	**23.90%**	115.60%	100.30%			116.50%
		12-24"		60.60%	73.10%	0.00%	**44.10%**	51.20%	152.80%			94.20%
U. dioica	chop and drop	0-6"		**269.80%**	177.30%	0.00%	62.70%	**259.40%**	175.70%			**206.00%**
		6-12"		**236.60%**	**212.50%**	0.00%	82.30%	**250.90%**	113.70%			167.50%
		12-24"		**222.50%**	**200.60%**	0.00%	84.80%	**272.60%**	61.00%			159.50%
Fallow	-	0-6"		93.80%	105.20%	0.00%	**23.00%**	103.60%	129.40%			124.10%
		6-12"		45.80%	51.20%	0.00%	**26.50%**	47.50%	138.40%			79.60%
		12-24"		44.90%	62.10%	0.00%	**26.60%**	119.70%	84.00%			78.00%

Table 13: *soil nutrient concentrations of "chop and drop" rows, after harvesting and mulching with harvested plant material during second year of growth, expressed as a percent of the previous year's soil nutrient concentrations.*

strengthened by a review of the USDA phytochemical and ethnobotanical databases (displayed in **Tables 4** and **5**), which found stinging nettle to possess Ca concentrations more than triple the average (307%).

Conclusion

This study was designed to serve as a preliminary investigation into dynamic accumulators and their potential applications on Northeast farms. Following the recommendations of Kourik (2014), the USDA-hosted "Dr. Duke's phytochemical and ethnobotanical databases" were used to compile peer-reviewed data across thousands of entries and calculate dynamic accumulator thresholds across 20 nutrients. An easy-to-navigate online database titled "Dynamic accumulator database and USDA analysis" was created, providing nutrient concentration data on 340 qualifying dynamic accumulator species to aid in further research. The subsequent use of the online tool for the selection of 6 dynamic accumulator species for on-farm trials demonstrates the value of implementing nutrient concentration thresholds and a curated online database for raising awareness and facilitating further research and dialogue on dynamic accumulators and their potential applications.

The resulting 2 years of on-farm trials at Unadilla Community Farm in central New York studied 6 dynamic accumulator species selected from the database (*A. retroflexus, C. album, S. peregrinum, T. officinale, T. pratense,* and *U. dioica*). Crop yields and nutrient concentrations in the soil, dried plant tissue, and liquid extracts derived from the harvested trial crops were measured. This data was used to assess the potential of these 6 species for a range of on-farm applications, including nutrient scavenging, "chop and drop" with nutrient-rich mulch, and on-farm liquid fertilizer production.

Dried plant tissue analysis measured nutrient concentrations surpassing dynamic accumulator thresholds for *C. album* (K) and *S. peregrinum* (K and Si). This confirms that plants are just as capable of accumulating unusually high concentrations of beneficial nutrients (dynamic accumulation) as they are of accumulating toxic heavy metals (hyperaccumulation). However, when grown in poor, unamended soil, all 6 trial crops possessed nutrient concentrations lower than those measured in previous studies (see **Tables 4** and **6**). This confirms similar findings made by researchers of hyperaccumulators, and demonstrates the importance of reporting nutrient concentrations for both plant tissue and the growing medium used (Reeves *et al.*, 2017). By measuring these two data points across a range of growing media, researchers can better predict plant tissue nutrient concentrations based on soil quality, aiding the development of potential applications for these plants.

Non-aerated liquid plant extracts were produced on-farm using rainwater and harvested material from the 6 trial crops. Findings suggest that outdoor temperatures in the Northeast from June to September are sufficient for on-farm liquid extract production in unheated barns or even shady areas outdoors (**Table 9**). However, the presence of acid rain in central New York and much of the Northeast suggests that if rainwater is used, pH should be corrected prior to steeping plant material. Further research is needed to assess the effects of pH and pH correction methods on nutrient solubility and nutrient uptake by different crops.

A. retroflexus: Redroot amaranth possessed high concentrations of multiple nutrients in its foliage (Mn, S, and Zn), along with high bioaccumulation factors (Mg, Mn, S, and Zn). It also proved to be a promising crop for liquid fertilizer production, as trials demonstrated that liquid extract derived from its foliage possessed the highest concentrations and the highest nutrient carryover rates of Fe and S compared to all other trial crops.

“Chop and drop” mulching with redroot amaranth also coincided with large increases in topsoil nutrient concentrations for many nutrients (P, K, Ca, Co, Cu, Mg, Mn, Ni, S, and Zn). These findings indicate that this plant is a strong accumulator of multiple nutrients, supporting USDA data that shows redroot amaranth surpassing dynamic accumulator thresholds for 6 of the nutrients mentioned here (P, K, Ca, Fe, Mg, and Zn). There is no USDA data available on redroot amaranth’s nutrient concentrations for Al, Co, Mn, Ni, or S, and the findings of this study suggest that further investigation is needed to assess whether it is in fact a dynamic accumulator of any of these nutrients as well. However, field trials indicated that redroot amaranth is best grown as a single-cut annual, and due to its invasiveness, great care should be taken to harvest before it sets seed. These additional growing considerations suggest that redroot amaranth is not suitable for intentional dynamic accumulator plantings. In fact, the invasive nature of this species, which has given it global notoriety, should serve as a warning against its intentional introduction and cultivation in any setting. Its ability to accumulate a wide range of nutrients confirms that the uncontrolled spread of redroot amaranth poses a serious threat to cropland around the world.

C. album: Lambsquarters foliage was found to possess very high concentrations of K in on-farm trials, surpassing the threshold for dynamic accumulators. It also demonstrated very high bioaccumulation factors for P, K, Ca, and S, indicating that these 4 nutrients were being accumulated at concentrations several times greater than measured in the surrounding soil. These findings are consistent with USDA data that show lambsquarters to be a dynamic accumulator of P, K, and Ca. There is no USDA data available on S concentrations for lambsquarters, and our findings suggest that further investigation is needed of lambsquarters’ potential as a dynamic accumulator of S. Liquid extract derived from lambsquarters foliage was found to be relatively high in K compared to the other trial crops, but not in P, Ca, or S. Liquid extract also possessed relatively high concentrations of Al, Cu, Mg, and Zn. Additional trials of lambsquarters liquid extract production could help determine the ideal pH range for improved P, K, Ca, and S solubility. Low yields and poor persistence in lambsquarters field trials prevented meaningful analysis of the effects of heavy harvesting and chop and drop mulching on soil nutrient concentrations. It is possible that the use of wood chip mulch in field trials negatively impacted reseeding rates. Further trials are needed to identify proper growing methods and assess the viability of establishing low-maintenance self-seeding beds of lambsquarters.

S. peregrinum: Plant tissue analysis found the foliage of Russian comfrey to possess the highest concentrations of K, B, and Si of all trial crops, with K and Si concentrations surpassing dynamic accumulator thresholds. Previous research has found comfrey to surpass the dynamic accumulator threshold for K concentrations (Robinson, 1983), with no previous data available for Si. Further peer-reviewed research is needed to measure nutrient concentrations of Russian comfrey foliage, especially K and Si, and to add this data to the USDA database. Liquid extract derived from Russian comfrey possessed the highest concentration of K compared to all other trial crops after 3 days of steeping, and the highest concentration of S after 5 days of steeping, with no data available on Si. In field trials, Russian comfrey produced the highest yields of all trial crops by far, producing over 60 tons/acre of fresh matter. However, there was little difference in before-and-after soil nutrient concentrations for Russian comfrey’s extraction row and chop and drop row. Further study of Russian comfrey is needed to investigate the relationship between plant tissue and soil nutrient concentrations, including factors that were not covered in these trials, such as soil concentrations of N, Si, and organic matter.

T. officinale: While USDA data shows dandelion foliage possessing nutrient concentrations above dynamic accumulator thresholds for B, Ca, Cu, Fe, Na, and Zn, data from this study did not show nutrient concentrations surpassing dynamic accumulator thresholds when grown in unamended soil. However, dandelion foliage did possess the highest concentrations of P, Cu, and Na compared to all other trial crops, and bioaccumulation factors calculated during this study suggest that dandelion did accumulate P, K, Ca, Cu, Na, and S in its above-ground parts at concentrations that exceeded those in the soil. A lack of data on soil concentrations of bioavailable forms of B, Fe, and Zn prevents the determination of whether accumulation took place for those nutrients as well. Liquid extract derived from dandelion foliage possessed the highest concentrations of P and Na of all trial crops after 3 days of steeping, but did not demonstrate high rates of nutrient carryover for any nutrients. Nor were soil nutrient concentrations noticeably affected in dandelion rows where plant material was heavily harvested to extract nutrients from the row, nor where dandelion foliage was used to enrich the soil through “chop and drop” mulching. This could be due to dandelion’s relatively low yields: data collected through a literature review shows dandelion with the lowest expected yields in tons per acre compared to the other trial crops (0.8-1 ton/acre, see **Table 2**), and on-farm trials recorded dandelion with the second-lowest yields of all the trial crops (3 tons/acre, see **Table 3**). Further research on dandelion is needed to measure dried plant tissue concentrations and bioaccumulation factors when grown in a variety of growing media, and to investigate the effect of improved growing methods on plant tissue nutrient concentrations, yields, and soil nutrient concentrations.

T. pratense: USDA data shows red clover foliage surpassing dynamic accumulator thresholds for Ca, Fe, Mg, and Mn. When grown in unamended soil during field trials, red clover foliage did not surpass dynamic accumulator thresholds for any nutrient, but it did exhibit the highest concentration of Fe out of all trial crops, as well as the highest bioaccumulation factor for Fe. However, liquid extract derived from red clover did not possess particularly high nutrient concentrations or carryover rates for any nutrient. Unfavorable weather conditions and growing methods resulted in poor growth and low yields during field trials, resulting in little change in soil nutrient concentrations in both extraction and chop and drop rows. Further field trials of red clover should be conducted under improved conditions.

U. dioica: USDA data shows stinging nettle foliage surpassing dynamic accumulator thresholds for N, Ca, Mg, and S, with Ca concentrations exceeding 300% the average. On-farm trials similarly found stinging nettle foliage to possess the highest Ca concentration of all trial crops, as well as the highest bioaccumulation factor for Ca. Liquid extract derived from stinging nettle foliage proved to be very nutrient rich, possessing the highest concentrations of P, B, Ca, Cu, and Mn after 5 days of steeping compared to all other trial crops, as well as the highest nutrient carryover rates for all of these nutrients plus K and Mg, suggesting stinging nettle nutrient content is particularly soluble and well suited for liquid extract production. Stinging nettle thrived under the growing conditions provided during on-farm trials, producing an annual yield (17.8 tons/acre) more than double the established range (8-8.7 tons/acre). One year of chopping and dropping with harvested stinging nettle material coincided with a doubling or more of soil nutrient concentrations for P, Ca, Co, Cu, Mg, Ni, and Zn. Most notably, Ca concentrations doubled in the 0-6” and 6-12” soil horizons while dropping to 63% in the 12-24” soil horizon. These findings are consistent with the hypothesis that dynamic accumulators enrich the topsoil by extracting nutrients from the subsoil. Overall, stinging nettle proved to be very well suited to virtually every aspect of these field trials: it thrived under low-maintenance food forest growing conditions; formed a thick, weed-suppressing ground cover; produced large yields of calcium-rich foliage with multiple commercial uses; displayed excellent potential as a source of highly soluble liquid fertilizer; and showed promise as a nutrient-rich mulch as well.

Citations

Baker A. J. M. (1981). Accumulators and excluders-strategies in the response of plants to heavy metals. Journal of Plant Nutrition, 3, 643-654.

Brinton, W. (2011). Making your own liquid fertilizer [PDF file]. Retrieved from https://opimedia.azureedge.net/-/media/Files/MEN/Editorial/Articles/Magazine-Articles/2011/02-01/Free-Homemade-Liquid-Fertilizers/Liquid-Fertilizers---Full-Report---Woods-End-Laboratories-pdf.pdf

Brooks R. R. (1977). Copper and cobalt uptake by Haumaniastrum species. Plant and Soil, 48, 541-544.

Brown, D. (2015, May 12). Qualifying dynamic accumulators: A sub-group of the hyperaccumulators. Permaculture Research Institute. Retrieved from https://permaculturenews.org/

Carpenter, J. and Carpenter, M. (2015). The organic medicinal herb farmer. White River Junction, VT: Chelsea Green Publishing.

Clark, A. (2007). Managing cover crops profitably (3rd ed.). Sustainable Agriculture Research and Education.

Clark, H. (1998). Finding and developing an export market for medicinal herbs. Proceedings of the Prairie Medicinal and Aromatic Plant Conference, 90-93. Saskatoon, SK, Canada.

Clark, Harvey. 1998. Finding and Developing an Export Market for Medicinal Herbs. Proceedings of the Prairie Medicinal and Aromatic Plant Conference 1998, Saskatoon, SK, pp. 90 - 93. (Yarrow, Catnip, Licorice, Skullcap, Burdock, Nettle)

Liu, G. and Hanlon, E. (2012, September). Soil pH range for optimum commercial vegetable production. University of Florida Institute of Food and Agricultural Sciences. Retrieved from https://edis.ifas.ufl.edu/pdf%5CHS%5CHS120700.pdf

Hagemann, R. C., Burnham, T. H., and Neubauer, D. (Eds.). (1997). Nettles. The Review of Natural Products. Saint Louis, MO: Fact and Comparisons.

Hall, M. H. (2008). Agronomy facts 21: red clover [Fact sheet]. Penn State College of Agricultural Sciences. Retrieved from https://extension.psu.edu/downloadable/download/sample/sample_id/293/

Hills, L. D. (1976). Comfrey: past, present and future. London: Faber and Faber.

Jaffré, T., Reeves, R. D., Baker, A. J. M., Schat, H., van der Ent, A. (2018, April). The discovery of nickel hyperaccumulation in the New Caledonian tree Pycnandra acuminata 40 years on: an introduction to a Virtual Issue. New Phytologist, 218(2), 397-400. Retrieved from https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.15105

Jansen, S., Broadley, M. R., Robbrecht, E., & Smets, E. (2002). Aluminum Hyperaccumulation in Angiosperms: A Review of Its Phylogenetic Significance. Botanical Review, 68(2), 235–269. Retrieved from http://www.jstor.org/stable/4354421

Keeran, N. S., Balasundaram, U., Govindan, G., Parida, A. K. (2019). Chapter 18 - Prosopis juliflora: a potential plant for mining of genes for genetic engineering to enhance phytoremediation of metals. In M. N. V. Vara Prasad (Ed.), Transgenic plant technology for remediation of toxic metals and metalloids (381-393). Academic Press. Retrieved from https://doi.org/10.1016/B978-0-12-814389-6.00018-3

Kiferle, C., Martinelli, M., Salzano, A. M., Gonzali, S., Beltrami, S., Salvadori, P. A., Hora, K., Holwerda, H. T., Scaloni, A., and Perata, P. (2021, February 17). Evidences for a nutritional role of iodine in plants. Frontiers in Plant Science, 12(1). doi:10.3389/fpls.2021.616868

Kitsteiner, J. (2015, April 10). The facts about dynamic accumulators. Permaculture Research Institute. Retrieved from http://permaculturenews.org/

Kourik, R. (1986). Designing and maintaining your edible landscape naturally. Santa Rosa, CA: Metamorphic Press.

Kourik, R. (2014). Unstacking functions: Dynamic accumulators [Word doc file]. Retrieved from https://drive.google.com/file/d/0B5968ou21abFLWhHVFNjTlYyQWc/view?usp=sharing

Leyva, R., Sánchez-Rodríguez, E., Ríos, J. J., Rubio-Wilhelmi, M. M., Romero, L., Ruiz, J. M., Blasco, B. (2011, August). Beneficial effects of exogenous iodine in lettuce plants subjected to salinity stress. Plant Science, 181(2), 195-202. doi: 10.1016/j.plantsci.2011.05.007.

Provin, T. L. and McFarland, M. L. (2018). Essential nutrients for plants [Fact sheet]. Texas A&M AgriLife Extension Service. Retrieved from https://cdn-ext.agnet.tamu.edu/wp-content/uploads/2018/11/ESC-009-essential-nutrients-for-plants.pdf

Rascio, N. and Navari-Izzo, F. (2011). Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? Plant Science, 180(2), 169-181. doi:10.1016/j.plantsci.2010.08.016

Rawson, J. (2013). Relearning to love comfrey. NOFA Mass Newsletter. Retrieved from https://www.nofamass.org/articles/2013/09/relearning-love-comfrey

Reeves, R. D., Baker, A. J. M., Jaffré, T., Erskine, P. D., Echevarria, G., van der Ent, A. (2018, April). A global database for plants that hyperaccumulate metal and metalloid trace elements. New Phytologist, 218(2), 407-411. Retrieved from https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.14907

Robinson, R. (1983). Comfrey – a controversial crop. University of Minnesota Agricultural Experiment Station, AD-MR-2210.

Sharpley, A. (1997, October 2). Phosphorus availability. In United States Department of Agriculture, Agricultural Research Service, Handbook of Soil Science. Retrieved from https://www.ars.usda.gov/research/publications/publication/?seqNo115=84257

Teynor, T. M., Putnam, D. H., Doll, J. D., Kelling, K. A., Oelke, E. A., Undersander, D. J., and Oplinger, E. S. (1997, November 17). Comfrey. Alternative Field Crops Manual. Retrieved from https://www.hort.purdue.edu/newcrop/afcm/comfrey.html

Uchida, R. (2000). Chapter 3 – Essential nutrients for plant growth: nutrient functions and deficiency symptoms. In J. A. Silva and R. Uchida (Eds.), Plant nutrient management in Hawaii's soils, approaches for tropical and subtropical agriculture (31-55). College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

United States Department of Agriculture, Agricultural Research Service. (2016). Dr. Duke's phytochemical and ethnobotanical databases [Data file]. Retrieved from https://phytochem.nal.usda.gov/

United States Geological Survey (2019, August 2). Acid rain and water. Retrieved from https://www.usgs.gov/special-topics/water-science-school/science/acid-rain-and-water

Van der Ent, A., Baker, A. J. M., Reeves, R. D., Chaney, R. L., Anderson, C. W. N., Meech, J. A., Erskine, P. D., Simonnot, M. O., Vaughan, J., Morel, J. L., Echevarria, G., Fogliani, B., Qiu, R. L., and Mulligan, D. R. (2015, April 21). Agromining: farming for metals in the future? Environmental Science and Technology, 49(8), 4773-4780. Retrieved from https://doi.org/10.1021/es506031u

Vatansever, R., Ozyigit, I., and Filiz, E. (2017). Essential and beneficial trace elements in plants, and their transport in roots: a review. Applied Biochemistry and Biotechnology, 181(1). doi:10.1007/s12010-016-2224-3

Walke, C.J. (2011). Polycultures in orchards. The Maine Organic Farmer & Gardener. Retrieved from https://www.mofga.org/Publications/The-Maine-Organic-Farmer-Gardener/Fall-2011/Polycultures-in-Orchards

Appendix 1: soil nutrient concentrations before planting trial crops, expressed in ppm.

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		946.3	1,173.1	11,183.9	10.5	1,782.5		16.3	9.9	22,744.7		2,326.8	459.6	0.4	13.6	15.3	449.4			69
		6-12"		767.6	1,128.5	10,485.4	9.4	1,537.3		15	9.4	20,215.7		2,106.1	435.8	0.31	16.2	13.9	417.4			63.5
		12-24"		588.2	746.8	11,523.4	10.6	2,142.9		18.3	9.6	23,120.1		2,365.8	565.8	0.32	33.4	16.2	268			64.6
	chop and drop	0-6"		896.8	1,145.9	11,033.5	10	2,523.1		15.3	10.3	21,231.2		2,277.8	436.1	0.39	20	14.4	524			67.9
		6-12"		755.5	759.0	11,296.0	10.9	2,136.6		16.6	10.2	23,731.8		2,285.1	466.6	0.4	22.2	15.7	389			69
		12-24"		714.7	719.9	10,360.7	9.7	2,896.7		15.1	9.9	20,734.3		2,225.4	424.2	0.32	27.8	14.3	401.4			63.7
C. album	extraction	0-6"		813.7	1,156.3	10,352.4	9.8	2,092.5		15.5	10	20,975.4		2,253.0	449	0.32	17.3	15	462			65.5
		6-12"		700.8	771.3	11,869.8	11.6	1,915.2		17.6	10.4	25,473.6		2,541.4	473.4	0.32	19.6	17.7	343.4			71.7
		12-24"		559.6	730.8	12,369.6	11	2,052.3		17	10	23,869.0		2,862.6	324.5	0.32	30.1	19.1	255			67.8
	chop and drop	0-6"		983.7	1,558.5	11,221.9	10.1	2,914.5		16.5	10.6	21,695.8		2,353.9	606.5	0.4	21.3	15.6	526			70.2
		6-12"		930.9	1,362.3	11,226.4	9.8	2,255.8		16.7	10.9	21,290.2		2,241.5	626.8	0.4	21.6	15.4	471			67.3
		12-24"		684.6	897.8	11,260.2	12	2,103.8		21.4	10	23,060.0		2,213.5	1,248.20	0.16	18.9	16.7	323.1			67
S. peregrinum	extraction	0-6"		938.5	1,211.8	9,831.1	10	2,750.7		15.3	9.9	20,299.5		2,207.7	651.4	0.39	19.8	13.9	488			68.5
		6-12"		802.4	847.5	10,444.6	9.9	1,816.9		16	9.8	20,986.7		2,158.7	719.1	0.39	16	14.5	384.9			68.4
		12-24"		567.8	581.8	11,081.3	10	1,703.9		16.8	8.8	21,544.0		2,295.6	611.5	0.32	15.2	15.6	268.4			67.2
	chop and drop	0-6"		947.5	957.5	10,550.4	10.1	2,496.0		16.4	10.6	21,563.9		2,265.8	670.4	0.4	15.9	14.8	447.2			69.8
		6-12"		806.3	718.8	11,377.2	10.3	1,911.5		17.2	10.4	22,170.0		2,207.8	847	0.39	17.6	15.5	368.5			68
		12-24"		697.2	613.6	11,367.0	10.1	2,134.0		18	9.7	21,733.7		2,222.2	994.2	0.32	17.2	15.3	330.2			67.8
T. officinale	extraction	0-6"		1257.4	1,501.9	9,127.3	9.9	4,515.5		15	11	18,615.5		2,779.7	544.5	0.24	15	14.3	789.7			69.5
		6-12"		825.3	961.6	9,332.1	9.4	1,798.4		15.4	10	18,799.0		2,077.5	598.6	0.16	10.4	14.2	428.7			63.9
		12-24"		336.4	500.8	8,055.0	9.5	1,195.2		14.6	6.3	19,671.8		2,302.5	296	0	13	15	149.9			54.7
	chop and drop	0-6"		1083.7	1,155.2	9,141.2	9.1	4,739.5		14.9	10.6	18,469.7		2,386.5	548.2	0.16	12	14.4	588.5			68.4
		6-12"		822.4	855.0	10,336.2	9.4	2,141.8		16.2	10.6	20,138.4		2,223.4	582.9	0.08	12.1	15.4	414.3			64.5
		12-24"		600.9	662.1	11,814.4	11.5	2,095.0		20.7	10.4	25,227.6		2,960.5	644.9	0	16.4	20.3	269.8			67.9
T. pratense	extraction	0-6"		965.1	893.6	10,796.5	10.3	5,987.5		16.1	10.7	21,901.5		2,324.3	656.4	0.4	25	15.1	504.6			69
		6-12"		977.5	717.3	11,704.8	10.9	2,221.9		17.1	11.2	22,593.1		2,296.8	696.3	0.4	25.3	15.8	427.4			71.9
		12-24"		694.0	630.8	13,197.0	11.5	2,156.2		20.8	10.7	24,653.5		2,668.3	1,247.70	0.39	25.7	19.5	310.9			70.3
	chop and drop	0-6"		1010.3	1,101.3	11,070.0	10.2	3,628.8		17.1	11.2	21,487.3		2,333.9	690.2	0.4	22.5	15.1	500.6			70.1
		6-12"		990.5	808.2	11,735.4	10.8	2,321.9		17.1	11.5	23,267.2		2,328.8	658	0.23	23.5	15.8	409.4			72.4
		12-24"		862.7	758.1	12,047.8	10.7	3,333.6		18.3	11.9	23,083.4		2,241.6	747.7	0.31	32.9	15.4	401.2			69.7
U. dioica	extraction	0-6"		1025.1	1,664.7	12,170.1	11.5	3,631.1		17.6	11.3	24,581.8		2,621.9	540.6	0.48	37.8	16.7	535.1			73.6
		6-12"		880.9	1,194.5	12,462.8	11	2,389.6		18.3	11.2	23,625.5		2,435.7	554.9	0.4	36.2	16.7	435			73.5
		12-24"		675.0	811.8	13,600.9	11.6	2,536.7		22.6	12.1	25,491.8		2,650.6	766.1	0.24	50.8	18.6	300.7			71.7
	chop and drop	0-6"		1175.0	1,834.3	11,434.8	11.4	2,453.5		17.8	10.6	24,419.3		2,482.8	508.1	0.55	19.8	15.8	539.5			69.6
		6-12"		827.5	1,418.1	11,125.7	10.3	2,112.3		16.4	10.5	22,180.8		2,287.2	498.9	0.47	28.7	15.5	400.9			68.3
		12-24"		597.3	897.3	8,958.7	8.4	1,968.2		13.9	8.5	17,846.9		1,932.6	403	0.31	27.1	12.8	304.7			53.7
Fallow	-	0-6"		1000.6	1,064.5	11,143.0	10.8	2,861.1		16.6	11.5	23,095.2		2,368.5	556.1	0.32	29	15.7	486.9			69.8
		6-12"		959.9	772.0	12,141.2	11.4	2,062.7		18.4	11.8	24,521.3		2,385.6	621.3	0.47	31.7	17.5	425.4			70.8
		12-24"		904.8	865.0	13,030.5	11.4	2,998.7		18.6	12	24,519.3		2,660.9	685.4	0.32	43.3	17.8	420			72.8

Appendix 2: soil nutrient concentrations after first year of growth, expressed in ppm.

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		523.9	670.5	10,416.6	248.0	1,428.4		18.0	8.8	23402.6		2,344.4	630.7	0.48	12.5	16.1	233.5			63.9
		6-12"		597.4	725.0	9,864.1	231.8	1,593.9		16.2	9.0	22295.1		2,158.3	573.5	0.48	12.1	14.8	289.7			64.9
		12-24"		782.0	940.6	8,376.2	206.6	4,700.2		14.1	9.4	19103.0		2,089.3	528.0	0.56	13.8	12.6	447.0			60.9
	chop and drop	0-6"		543.0	590.4	7,345.6	219.3	1,225.1		8.1	5.9	20714.4		954.7	260.1	0.40	9.5	7.0	262.4			39.6
		6-12"		726.8	757.3	7,233.6	195.3	1,543.4		8.8	7.0	18691.0		1,084.4	321.1	0.64	10.3	7.1	406.9			45.9
		12-24"		835.0	910.1	7,201.0	199.3	2,445.4		8.3	7.7	18302.5		1,240.4	295.1	0.63	11.7	7.2	487.9			47.7
C. album	extraction	0-6"		807.4	1003.6	8,887.0	231.3	3,300.4		14.3	9.6	21646.9		2,163.0	396.0	0.55	11.1	13.4	463.5			57.4
		6-12"		633.7	732.5	10,375.3	246.0	1,711.1		16.4	9.1	24388.8		2,220.0	404.5	0.40	14.2	15.5	307.8			62.1
		12-24"		535.9	735.6	11,997.2	280.9	1,636.4		17.3	9.7	27102.5		2,775.6	358.6	0.41	18.3	18.8	226.7			63.6
	chop and drop	0-6"		891.1	1086.6	9,941.8	217.6	4,696.2		14.9	10.4	20107.2		2,584.6	454.1	0.48	20.4	14.7	536.8			65.2
		6-12"		795.6	912.7	12,180.0	256.4	2,419.3		18.1	10.5	25222.6		2,697.0	512.1	0.47	19.4	18.0	359.3			71.2
		12-24"		652.4	766.3	11,093.9	259.2	2,001.6		17.7	10.1	24393.0		2,719.9	433.7	0.48	16.6	18.1	246.5			61.1
S. peregrinum	extraction	0-6"		1113.0	983.1	7,931.1	220.4	3,361.0		9.9	9.4	20641.0		1,446.3	367.7	0.73	14.1	8.5	609.2			62.5
		6-12"		942.9	770.3	7,897.6	239.4	1,806.4		12.9	9.6	23041.7		1,203.0	390.0	0.81	11.6	10.2	437.0			59.3
		12-24"		839.4	659.6	8,743.3	246.6	2,136.9		11.1	8.4	23230.2		1,371.6	444.2	0.66	11.3	9.4	399.3			65.4
	chop and drop	0-6"		792.4	871.0	8,372.6	215.0	3,513.4		14.2	9.4	20051.4		2,014.2	534.6	0.56	11.2	12.8	410.1			60.7
		6-12"		753.3	812.2	8,880.1	230.1	2,324.5		15.6	9.5	22045.7		1,897.5	659.2	0.64	12.9	13.4	345.8			62.8
		12-24"		611.9	663.7	8,833.0	231.8	1,957.1		15.6	9.1	21267.3		1,799.2	775.8	0.56	13.1	12.3	264.5			57.9
T. officinale	extraction	0-6"		897.2	912.5	10,664.7	233.3	3,288.1		16.3	11.3	22224.3		2,489.3	591.9	0.64	26.4	16.0	414.9			64.2
		6-12"		733.9	752.7	11,938.2	240.7	2,371.0		18.0	11.4	24076.0		2,415.1	762.2	0.49	22.7	17.3	311.7			68.5
		12-24"		526.8	705.1	12,199.0	251.5	2,023.5		18.1	10.5	24091.6		2,744.2	701.1	0.41	18.7	19.3	202.4			62.0
	chop and drop	0-6"		833.3	999.1	10,716.5	235.1	6,351.9		16.8	10.8	22083.5		2,862.4	536.1	0.47	18.9	16.4	429.6			71.4
		6-12"		741.5	765.6	11,359.9	231.3	2,375.9		16.3	10.8	23019.9		2,349.2	487.7	0.40	18.0	16.0	328.8			64.4
		12-24"		580.9	695.3	11,673.0	248.6	2,108.1		17.8	10.3	23678.0		2,552.0	651.0	0.40	16.8	17.9	236.3			61.7
T. pratense	extraction	0-6"		704.3	810.4	10,839.3	238.1	2,197.3		17.0	12.6	22402.7		2,484.6	561.1	0.49	18.7	17.0	306.1			66.1
		6-12"		813.1	921.6	11,026.4	229.3	2,425.2		17.2	12.6	22634.1		2,410.7	577.1	0.49	15.9	16.4	391.7			67.4
		12-24"		1055.4	1183.4	9,693.3	209.2	5,609.2		15.0	12.7	19360.1		2,535.1	515.7	0.57	15.2	15.1	713.6			72.0
	chop and drop	0-6"		613.8	881.6	11,262.3	251.2	1,975.3		19.7	9.9	23807.7		2,466.9	684.7	0.41	25.6	16.7	253.8			67.6
		6-12"		771.2	1028.9	10,482.1	239.9	2,061.4		16.4	9.8	22793.2		2,242.5	581.2	0.49	23.0	14.8	352.1			66.8
		12-24"		904.0	1231.3	9,516.5	222.1	3,727.8		15.5	10.4	21173.8		2,405.9	530.9	0.56	16.1	14.9	488.3			68.2
U. dioica	extraction	0-6"		513.1	715.8	11,265.8	244.9	1,919.6		16.8	9.0	23206.4		2,869.1	377.4	0.40	28.7	18.8	217.4			64.1
		6-12"		661.9	713.8	10,499.1	234.9	2,184.7		16.4	9.2	22257.9		2,484.8	461.8	0.41	24.2	15.9	292.8			62.9
		12-24"		918.3	849.9	9,618.2	209.0	5,264.0		17.9	10.1	20759.6		2,244.1	578.3	0.47	24.3	16.4	449.5			66.8
	chop and drop	0-6"		587.1	671.1	7,315.8	216.4	1,560.1		9.8	6.7	19903.7		1,118.3	319.1	0.56	12.5	7.9	302.0			43.1
		6-12"		735.0	876.2	7,670.6	210.4	1,434.5		8.9	7.5	19647.4		1,185.4	319.1	0.55	12.4	8.0	403.5			48.9
		12-24"		773.3	818.0	6,070.6	172.1	3,618.1		7.9	7.0	15813.2		1,252.9	254.8	0.63	10.7	7.3	462.6			43.7
Fallow	-	0-6"		632.2	808.0	11,778.6	261.6	2,135.1		20.0	10.8	24928.9		2,822.3	810.9	0.41	27.4	19.5	248.5			66.6
		6-12"		905.7	818.1	11,018.7	251.8	2,569.7		17.7	11.6	24561.4		2,581.6	645.1	0.57	19.9	17.6	371.4			70.2
		12-24"		961.6	954.4	10,884.1	240.4	3,341.3		16.3	11.6	22570.7		2,525.5	541.3	0.65	17.7	16.8	457.8			67.4

Appendix 3: soil nutrient concentrations after second year of growth, expressed in ppm.

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		1,097.5	1,042.2	11,045.7	218.8	4,956.7		17.3	12.5	24,606.3		2,693.3	602.2	0.0	10.0	17.0	638.9			84.8
		6-12"		941.2	944.3	11,296.6	227.6	3,328.8		18.2	11.8	25,302.7		2,568.3	620.5	0.0	7.4	17.5	499.9			82.2
		12-24"		867.9	791.6	12,780.3	250.2	2,832.2		20.3	14.1	27,779.2		2,677.0	864.2	0.0	9.3	25.3	386.8			86.7
	chop and drop	0-6"		1,159.7	1,167.5	12,106.7	229.5	5,148.2		18.7	14.6	25,727.2		2,985.7	605.4	0.0	7.0	20.7	663.3			89.3
		6-12"		962.2	1,015.0	13,386.2	249.0	3,035.8		21.8	13.6	27,913.8		3,087.3	606.2	0.0	8.6	23.1	457.2			88.8
		12-24"		680.0	927.8	12,795.8	252.5	2,793.7		21.8	15.2	28,236.4		3,298.0	618.2	0.0	11.2	30.5	325.7			80.9
C. album	extraction	0-6"		993.4	1,029.5	10,542.2	285.5	4,458.8		19.2	15.3	31,913.8		2,535.6	540.1	0.0	5.3	22.6	564.6			80.9
		6-12"		865.0	938.4	11,440.6	248.1	2,535.2		18.0	12.2	27,676.2		2,443.6	550.4	0.0	6.0	17.5	427.0			79.2
		12-24"		597.8	862.6	14,517.6	302.0	2,000.0		23.0	33.7	33,653.7		3,309.3	561.0	0.0	8.5	84.8	255.4			87.1
	chop and drop	0-6"		886.6	946.6	10,461.7	222.2	5,149.5		17.4	11.6	24,839.8		2,824.6	529.2	0.0	5.7	18.0	547.7			78.3
		6-12"		793.3	881.7	13,236.0	269.0	2,669.9		19.8	11.2	29,987.2		2,897.5	539.2	0.0	6.9	20.6	395.6			85.7
		12-24"		593.5	899.6	14,447.7	289.7	2,246.9		25.3	27.5	34,857.2		3,629.9	605.5	0.0	10.1	71.3	239.2			90.5
S. peregrinum	extraction	0-6"		1,168.9	836.3	9,056.6	231.4	4,676.0		12.1	14.8	25,458.5		1,729.4	381.8	0.0	7.1	11.3	672.4			88.4
		6-12"		1,008.3	838.2	10,750.7	266.7	2,557.8		13.9	10.7	29,923.4		1,856.4	395.2	0.0	6.5	13.7	538.8			98.8
		12-24"		589.6	540.3	13,928.9	324.1	1,367.5		18.5	9.5	35,959.2		2,764.9	401.0	0.0	6.1	18.9	235.9			90.4
	chop and drop	0-6"		919.1	1,221.7	10,291.9	217.8	3,149.7		17.1	27.6	24,603.0		2,474.8	647.9	0.0	5.8	17.3	459.7			80.9
		6-12"		670.7	796.5	9,252.2	202.2	1,814.2		16.0	10.9	22,470.7		2,005.6	710.2	0.0	5.3	14.9	325.1			68.7
		12-24"		587.2	800.4	11,080.7	229.4	1,806.1		18.3	10.1	25,670.1		2,557.8	734.7	0.0	6.1	18.7	278.0			76.0
T. officinale	extraction	0-6"		1,202.3	1,365.9	12,899.6	237.8	4,313.0		20.8	14.9	26,304.4		2,929.1	801.6	0.0	6.5	20.4	630.0			89.5
		6-12"		987.6	1,200.5	14,877.2	267.9	2,831.3		23.8	15.4	31,204.4		3,157.2	954.6	0.0	7.0	24.1	427.1			91.4
		12-24"		767.6	1,090.4	15,032.6	301.8	2,619.5		29.2	15.6	33,696.5		3,584.4	1,032.6	0.0	7.4	29.0	317.2			89.4
	chop and drop	0-6"		1,006.8	1,012.8	13,656.6	268.8	3,723.5		22.9	14.0	30,425.0		3,148.8	879.7	0.0	6.3	23.1	493.1			93.4
		6-12"		717.1	722.4	12,383.0	242.2	2,789.9		20.4	12.2	27,062.3		2,761.5	677.6	0.0	7.6	20.3	318.3			73.2
		12-24"		596.4	688.5	11,933.2	226.3	2,464.2		18.8	11.2	25,499.6		2,797.7	581.5	0.0	7.3	20.8	261.2			68.4
T. pratense	extraction	0-6"		968.8	880.7	7,792.1	183.3	4,981.0		11.1	9.1	20,727.2		1,909.1	361.1	0.0	5.2	11.3	570.8			60.1
		6-12"		791.2	814.6	8,966.4	212.5	2,150.2		11.3	9.0	23,864.0		1,647.0	348.5	0.0	5.9	11.1	452.1			59.5
		12-24"		655.7	569.1	10,320.6	243.5	1,257.8		10.4	7.7	27,063.0		1,286.8	235.9	0.0	6.4	10.0	340.9			53.5
	chop and drop	0-6"		902.6	863.7	9,463.5	203.3	4,541.2		16.5	10.9	22,565.9		2,321.0	581.4	0.0	6.3	15.1	481.5			81.6
		6-12"		701.0	818.3	10,230.3	209.0	2,415.5		17.2	10.3	23,436.2		2,354.2	572.0	0.0	5.5	17.2	353.2			77.8
		12-24"		1,154.1	980.4	7,240.3	163.5	5,527.4		9.4	9.9	18,188.6		1,458.0	388.2	0.0	7.1	7.6	746.3			64.2
U. dioica	extraction	0-6"		1,097.1	836.6	11,704.2	209.6	3,092.6		18.4	12.0	23,727.0		2,453.3	890.6	0.0	9.8	17.8	467.8			89.1
		6-12"		1,008.3	842.7	12,806.2	227.6	2,717.5		20.9	12.4	25,429.6		2,671.5	1,122.1	0.0	13.3	19.9	412.4			92.9
		12-24"		626.8	838.6	13,750.0	246.9	2,320.8		23.3	11.8	27,929.5		3,208.1	1,319.2	0.0	14.4	23.4	252.6			93.8
	chop and drop	0-6"		1,177.5	1,072.5	12,649.2	229.8	4,115.3		18.8	13.5	25,732.9		3,017.1	565.7	0.0	7.8	20.6	530.6			88.8
		6-12"		892.9	948.5	12,461.5	220.4	3,264.8		18.5	13.3	24,877.5		2,804.4	678.3	0.0	10.2	20.2	458.8			81.9
		12-24"		581.8	728.5	10,923.7	215.5	2,286.2		17.8	11.0	24,300.9		2,788.2	511.1	0.0	9.1	19.9	282.3			69.8
Fallow	-	0-6"		671.2	806.5	11,543.9	241.5	2,131.1		21.1	11.1	29,504.9		2,646.6	853.4	0.0	6.3	20.2	321.5			82.7
		6-12"		987.9	803.1	8,245.8	194.9	1,702.5		9.0	8.3	22,204.8		1,181.4	330.0	0.0	5.3	8.3	514.0			55.8
		12-24"		747.0	609.6	8,363.6	198.9	1,083.4		9.8	9.0	22,641.7		1,133.9	336.2	0.0	4.7	20.1	384.4			52.6

Appendix 4: soil nutrient concentrations after first year of growth, expressed as a percent of initial soil nutrient concentrations.

Trial crop	Row type	Depth	N	P	K	Al	B	Ca	Cl	Co	Cu	Fe	I	Mg	Mn	Mo	Na	Ni	S	Se	Si	Zn
A. retroflexus	extraction	0-6"		55.4%	57.2%	93.1%	**2362.1%**	80.1%		110.4%	88.1%	102.9%		100.8%	137.2%	121.2%	92.1%	105.2%	52.0%			92.6%
		6-12"		77.8%	64.2%	94.1%	**2473.6%**	103.7%		107.8%	95.5%	110.3%		102.5%	131.6%	152.1%	74.8%	106.6%	69.4%			102.3%
		12-24"		132.9%	126.0%	72.7%	**1941.4%**	219.3%		76.9%	97.5%	82.6%		88.3%	93.3%	175.0%	**41.1%**	77.8%	166.8%			94.3%
	chop and drop	0-6"		60.5%	51.5%	66.6%	**2197.5%**	**48.6%**		53.1%	57.4%	97.6%		**41.9%**	59.7%	101.6%	**47.4%**	**48.9%**	50.1%			58.3%
		6-12"		96.2%	99.8%	64.0%	**1795.4%**	72.2%		52.9%	68.8%	78.8%		**47.5%**	68.8%	160.6%	**46.2%**	**45.6%**	104.6%			66.4%
		12-24"		116.8%	126.4%	69.5%	**2054.6%**	84.4%		55.3%	78.1%	88.3%		55.7%	69.6%	198.0%	**42.2%**	**50.3%**	121.5%			74.8%
C. album	extraction	0-6"		99.2%	86.8%	85.8%	**2364.8%**	157.7%		92.3%	96.3%	103.2%		96.0%	88.2%	174.0%	64.3%	89.4%	100.3%			87.6%
		6-12"		90.4%	95.0%	87.4%	**2118.6%**	89.3%		93.3%	87.7%	95.7%		87.4%	85.5%	127.0%	72.4%	87.9%	89.6%			86.6%
		12-24"		95.8%	100.7%	97.0%	**2561.4%**	79.7%		101.3%	96.8%	113.5%		97.0%	110.5%	129.1%	60.8%	98.6%	88.9%			93.9%
	chop and drop	0-6"		90.6%	69.7%	88.6%	**2163.3%**	161.1%		90.7%	98.2%	92.7%		109.8%	74.9%	122.4%	96.0%	94.3%	102.1%			92.9%
		6-12"		85.5%	67.0%	108.5%	**2605.5%**	107.2%		108.9%	96.5%	118.5%		120.3%	81.7%	119.3%	89.9%	116.8%	76.3%			105.9%
		12-24"		95.3%	85.4%	98.5%	**2159.7%**	95.1%		82.4%	101.4%	105.8%		122.9%	**34.7%**	297.0%	88.1%	108.0%	76.3%			91.3%
S. peregrinum	extraction	0-6"		118.6%	81.1%	80.7%	**2212.7%**	122.2%		64.9%	95.5%	101.7%		65.5%	56.4%	185.1%	71.1%	61.6%	124.8%			91.3%
		6-12"		117.5%	90.9%	75.6%	**2427.0%**	99.4%		80.4%	97.7%	109.8%		55.7%	54.2%	205.3%	72.3%	70.3%	113.5%			86.7%
		12-24"		147.8%	113.4%	78.9%	**2455.8%**	125.4%		66.3%	96.3%	107.8%		59.7%	72.6%	205.7%	74.3%	60.4%	148.8%			97.4%
	chop and drop	0-6"		83.6%	91.0%	79.4%	**2132.6%**	140.8%		86.9%	89.2%	93.0%		88.9%	79.7%	140.8%	70.3%	86.5%	91.7%			86.9%
		6-12"		93.4%	113.0%	78.1%	**2239.1%**	121.6%		90.7%	92.2%	99.4%		85.9%	77.8%	162.2%	73.0%	86.5%	93.8%			92.4%
		12-24"		87.8%	108.2%	77.7%	**2304.5%**	91.7%		86.2%	93.7%	97.9%		81.0%	78.0%	174.0%	76.3%	80.2%	80.1%			85.5%
T. officinale	extraction	0-6"		71.4%	60.8%	116.8%	**2360.9%**	72.8%		108.6%	102.8%	119.4%		89.6%	108.7%	268.3%	176.1%	111.8%	52.5%			92.4%
		6-12"		88.9%	78.3%	127.9%	**2550.2%**	131.8%		117.2%	113.7%	128.1%		116.2%	127.3%	306.7%	217.9%	121.2%	72.7%			107.1%
		12-24"		156.6%	140.8%	151.4%	**2646.1%**	169.3%		124.3%	166.2%	122.5%		119.2%	236.8%		143.9%	128.0%	135.0%			113.4%
	chop and drop	0-6"		76.9%	86.5%	117.2%	**2597.2%**	134.0%		112.3%	102.2%	119.6%		119.9%	97.8%	291.2%	158.0%	114.0%	73.0%			104.4%
		6-12"		90.2%	89.5%	109.9%	**2453.4%**	110.9%		100.2%	101.5%	114.3%		105.7%	83.7%	511.1%	148.3%	104.3%	79.4%			99.8%
		12-24"		96.7%	105.0%	98.8%	**2158.3%**	100.6%		86.1%	99.2%	93.9%		86.2%	100.9%		102.4%	88.2%	87.6%			90.8%
T. pratense	extraction	0-6"		73.0%	90.7%	100.4%	**2312.3%**	**36.7%**		105.7%	118.0%	102.3%		106.9%	85.5%	124.9%	74.8%	112.3%	60.7%			95.8%
		6-12"		83.2%	128.5%	94.2%	**2102.4%**	109.2%		100.6%	112.2%	100.2%		105.0%	82.9%	120.7%	63.0%	104.2%	91.7%			93.7%
		12-24"		152.1%	187.6%	73.5%	**1814.9%**	260.2%		72.0%	118.0%	78.5%		95.0%	**41.3%**	146.0%	59.1%	77.8%	229.5%			102.4%
	chop and drop	0-6"		60.8%	80.1%	101.7%	**2462.8%**	54.4%		115.4%	88.5%	110.8%		105.7%	99.2%	102.4%	114.1%	110.6%	**50.7%**			96.4%
		6-12"		77.9%	127.3%	89.3%	**2221.0%**	88.8%		95.7%	85.3%	98.0%		96.3%	88.3%	210.7%	98.0%	93.9%	86.0%			92.3%
		12-24"		104.8%	162.4%	79.0%	**2067.3%**	111.8%		85.0%	87.1%	91.7%		107.3%	71.0%	179.6%	**49.0%**	96.9%	121.7%			97.8%
U. dioica	extraction	0-6"		**50.1%**	**43.0%**	92.6%	**2134.5%**	52.9%		95.5%	79.7%	94.4%		109.4%	69.8%	84.2%	75.9%	112.5%	**40.6%**			87.1%
		6-12"		75.1%	59.8%	84.2%	**2138.2%**	91.4%		89.7%	82.0%	94.2%		102.0%	83.2%	103.1%	66.8%	95.2%	67.3%			85.5%
		12-24"		136.0%	104.7%	70.7%	**1802.2%**	207.5%		79.5%	83.8%	81.4%		84.7%	75.5%	200.4%	**47.9%**	88.3%	149.5%			93.1%
	chop and drop	0-6"		**50.0%**	**36.6%**	64.0%	**1903.1%**	63.6%		54.9%	63.6%	81.5%		**45.0%**	62.8%	102.2%	63.3%	**50.1%**	56.0%			62.0%
		6-12"		88.8%	61.8%	68.9%	**2035.9%**	67.9%		54.3%	71.4%	88.6%		51.8%	64.0%	116.7%	**43.1%**	51.8%	100.6%			71.6%
		12-24"		129.5%	91.2%	67.8%	**2042.2%**	183.8%		56.4%	82.1%	88.6%		64.8%	63.2%	201.6%	**39.6%**	56.9%	151.8%			81.4%
Fallow	-	0-6"		63.2%	75.9%	105.7%	**2419.0%**	74.6%		120.6%	94.7%	107.9%		119.2%	145.8%	130.2%	94.4%	124.8%	51.0%			95.4%
		6-12"		94.4%	106.0%	90.8%	**2211.9%**	124.6%		96.2%	98.7%	100.2%		108.2%	103.8%	120.0%	62.8%	100.1%	87.3%			99.1%
		12-24"		106.3%	110.3%	83.5%	**2101.5%**	111.4%		87.5%	96.5%	92.1%		94.9%	79.0%	206.5%	**40.8%**	94.5%	109.0%			92.5%