# A Comprehensive Brief on Recent Work Demonstrating Fertilizer Use Efficiencies when Incorporating PittMoss into Growing Substrates

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## Introduction

Since the commercialization of PittMoss in 2014, it has become apparent that the fibers and particle structure of PittMoss contribute to efficient nutrient management. The fibers absorb and retain nutrients within their structure, preventing nutrients from leaching into the environment while still remaining available to plants. This property, along with the better physical, chemical, and biological environments found in PittMoss products, assists roots in using available nutrients. These benefits have been observed both in company research and by growers. Many growers say they can use less fertilizer when growing in blends containing PittMoss, and they also observe extended plant shelf life with better late crop performance. Additionally, a cannabis grower in Erie, Pennsylvania performed careful physical evaluations on the application and fate of nutrients in their production and saw significant benefits due to PittMoss. Specifically designed projects at Dr. Bethke's Research Greenhouse in Michigan and at the University of Arkansas were performed in 2023 to further evaluate and quantify these observations. This comprehensive briefing presents some of those findings and further incorporates observations on the fate of nutrients from the cannabis grower.

## Nutrient Management Research Projects at Dr. Bethke's Michigan Research Greenhouse

*This section describes several research projects specifically designed to evaluate nutrient efficiency.*

### *Methods*

*Zinnias, Kale, Cucumbers, and Basil in Small Pots*

The data presented here were extracted from a study evaluating the growth responses to fertilizer and water applications in research soils involving incorporation of varying rates of industrial hemp. Three commercial control soils were used in this project:

- PittMoss PM1: 30% PittMoss fibers, 65% sphagnum peat, and 5% perlite
- ProMix BX with mycorrhizae: 85% sphagnum peat and 15% perlite
- Fox Farm Happy Frog: approximately 60% pine bark, 25% sphagnum peat, and 15% perlite

These soils were compacted uniformly to fill containers prior to planting with one of four crops. The crops included:

- 5 replications of zinnias (Dreamland Rose) in 4.5" square pots
- 6 replications of kale (Vates) in 3.5" square pots
- 6 replications of Cucumbers (SMR 65) in 3.5" square pots
- 6 replications of Basil (Italian large leaf) in 3.5" square pots

Seeds were sown and surface watered uniformly for germination. After germination, all varieties were thinned to one plant per pot. A nutrient solution containing 180 parts per million (ppm) nitrogen was prepared using a soluble 18-6-18 fertilizer with micronutrients included. The plants were observed daily, and when more than one of the plants in each treatment showed wilting, the nutrient solution was applied. The zinnias received 200mL of the solution per watering and all other crops received 167mL per watering. The number of waterings was recorded.

When the plants developed to a market-ready stage, observations and data were recorded, including:

- a vigor rating
- a color rating
- height
- flowering (where appropriate)
- branching
- number of leaves
- fresh weight

The plants were excised and dried in brown paper bags on a bench in the greenhouse until thoroughly dry, at which point their dry weight was measured. Total water and fertilizer applications were calculated. The total quantity of fertilizer was determined from the nutrient solutions applied during the course of the study. The averages of fresh weight and dry weight were determined for each crop, and the total fertilizer used on each substrate type for each crop was calculated and converted to milligrams of fertilizer required per gram of fresh weight or gram of dry weight.

These data are graphically presented in Figures A through D.

*Large-Specimen Tomatoes in 6L Pots*

A growth study of large-specimen tomato plants in 6 liter pots was performed in a manner similar to that described in the "*Zinnias, Kale, Cucumbers, and Basil in Small Pots*" section with one liter of nutrient solution applied at each watering to the six replications in each substrate type. These plants were grown to a much larger size and were harvested when the first fruit on most of the plants was the size of a cherry. Data and observations taken were similar to those taken in the aforementioned study and the results are graphically presented in Figure E.

*Dwarf Sunflowers in 5.5" Pots*

Another study examining the absorption and leaching of applied nutrient solutions was performed on dwarf sunflowers in 5.5" pots. The procedures were the same as presented in the previous studies with six replications of each substrate. In this study, 600mL of nutrient solution (again at 180ppm N) was applied when the majority of the plants in the study started to wilt, and the leached solution was collected and recorded. When the majority of the dwarf sunflowers were in bloom, plant growth data were collected and the plants were dried for an extended time (due to the bulk of the flower heads) before the dry weight was obtained.

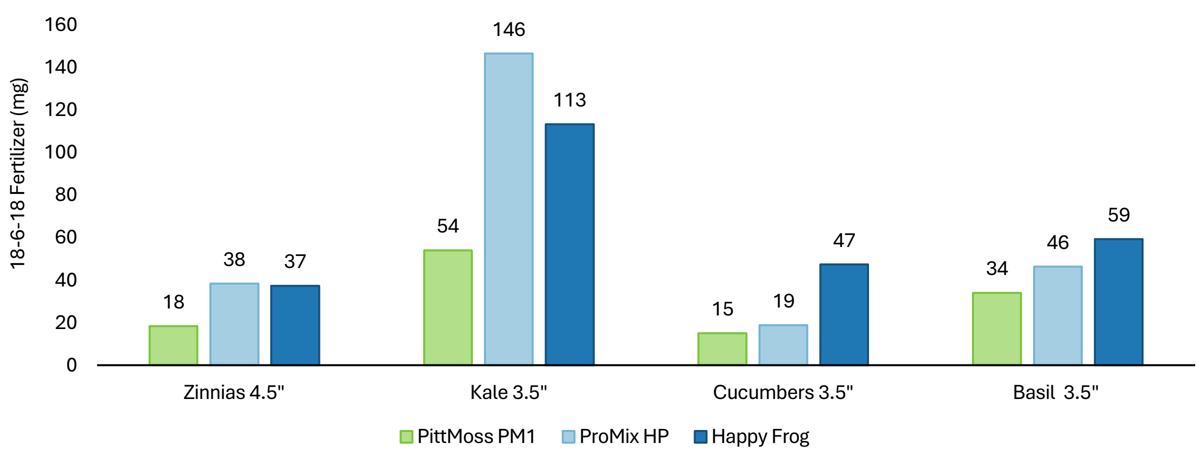
***Results***

Figure A presents the fertilizer efficiencies in producing fresh weight for the zinnia, kale, cucumber and basil crops. The numbers in Figure A are expressed as milligrams of fertilizer to produce 1 gram of fresh weight for each of the 4 crops in the 3 substrates. In general, kale required significantly more fertilizer in all substrates than did the other crops. It is further noted that the PittMoss PM1 required less fertilizer than the other two substrates for all crops. In order to unitize the comparisons of fertilizer required by each substrate, the amount required for PM1 was set as a unit (100%) and then each of the other soils were listed as the percentage of that unit. Those unitized numbers are presented in Figure B for each of the crops and substrates. These unitized numbers are also presented later in this report in Table 1.

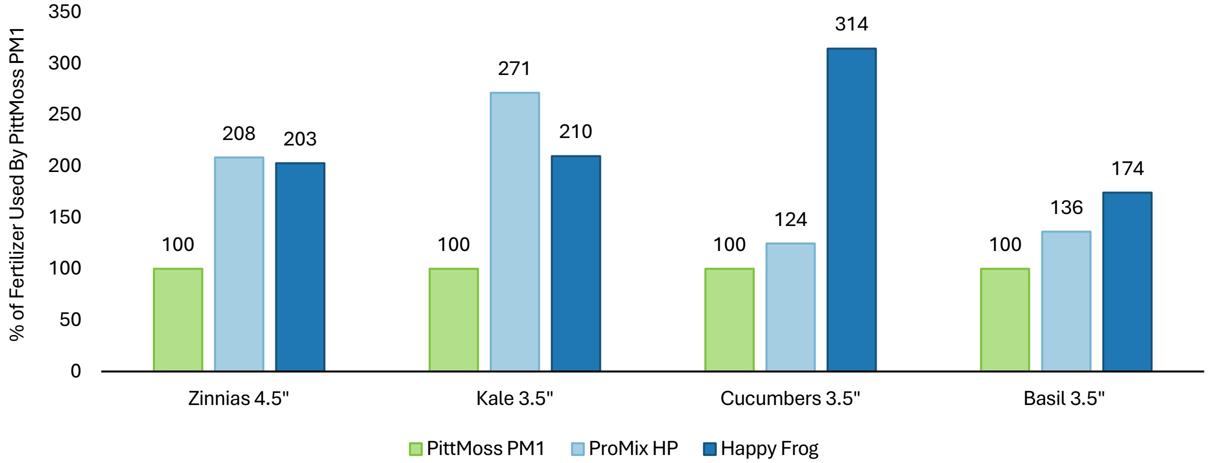
Figure C presents the efficiencies in producing dry weight for the crops listed above. Note that the figures are much higher than those for the fresh weight because the water weight has been removed. Again, in all cases, the PM1 required less fertilizer than the other blends. It is evident that the Happy Frog bark-based mix required considerably more fertilizer solution than the other blends. This may be due to some leaching and consumption of fertilizer by pine bark in the blend. As mentioned previously, Figure D presents the unitized numbers for fertilizer use for each crop in each substrate. These unitized numbers are also presented later in this report in Table 1.

Similar results are presented in Figure E, which shows the results for specimen tomatoes. It shows the milligrams of fertilizer to produce 1g of tissue on a fresh- and dry-weight basis. PittMoss PM1 significantly outperformed the other two blends. Again, the unitized figures were calculated and are included in Table 1.

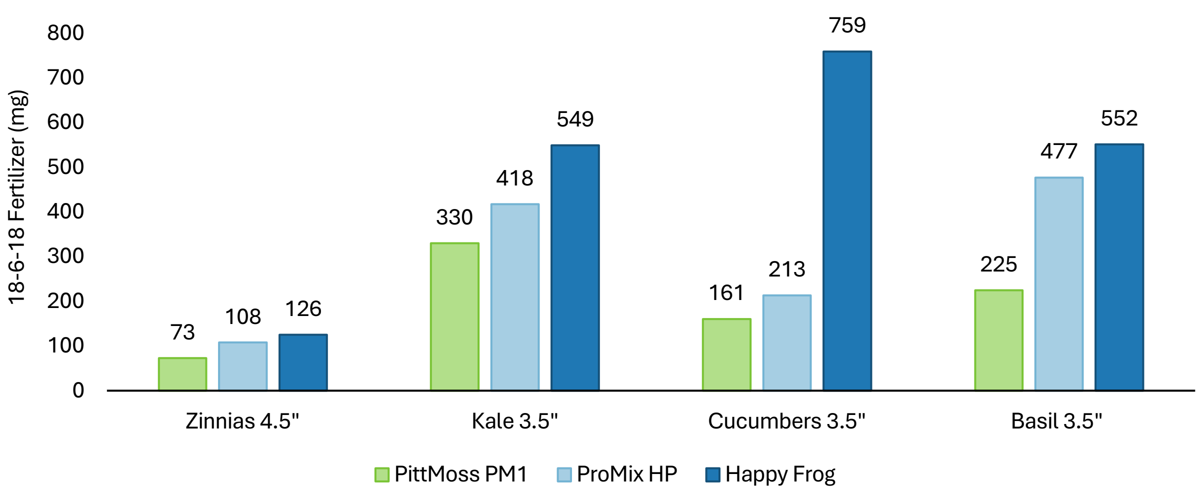
*A. Fertilizer (18-6-18) Required to Produce 1g Fresh Weight of 4 Crops in 3 Blends*



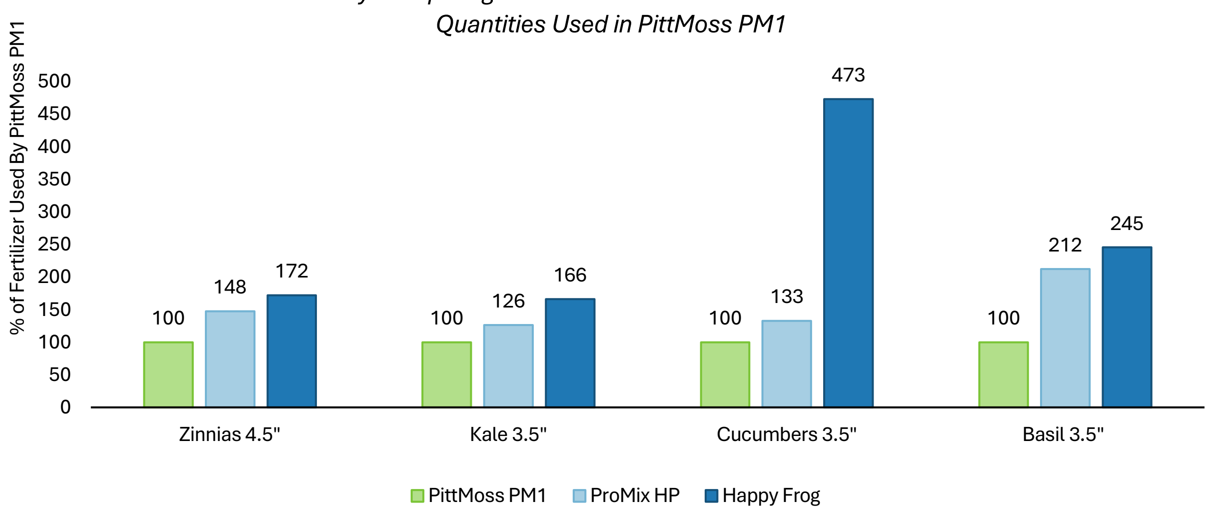
*B. Unitized Efficiency Comparing Fertilizer Effectiveness In 2 Commercial Substrates To Quantities Used in PittMoss PM1*




*C. Fertilizer (18-6-18) Required to Produce 1g Dry Weight of 4 Crops in 3 Blends*




*D. Unitized Efficiency Comparing Fertilizer Effectiveness In 2 Commercial Substrates To Quantities Used in PittMoss PM1*



The efficiency results for sunflowers are presented in Figure F, which shows the milligrams of fertilizer required to produce 1g of tissue on both a fresh- and dry-weight basis. Again, PittMoss PM1 significantly outperformed the other two blends. And again, the unitized comparisons were calculated, and they are included in the data presented in Table 1.

The water use and leachate data were used to calculate nutrients utilized vs. leached. However, the data presented in Figure F are representative of all the nutrient solution that was applied, including that which leached out. Therefore, because the Happy Frog substrate had much more leaching than ProMix BX or PittMoss PM1, the quantity of nutrients applied to produce fresh and dry weight is high. This then raises the point that, had the quantities of nutrients applied been adjusted for the limited volume of solution that the Fox Farm Happy Frog could absorb, the numbers may be closer to those of the other substrates.

In the controlled study at the Michigan Research Greenhouse, PittMoss PM1 (which contains 30% PittMoss) highly excelled in fertilizer use efficiency in every crop. In some cases, there was leaching from applications due to porosity and that was especially true in Fox Farm Happy Frog substrate. ProMix BX did not show visible leaching compared to PittMoss PM1, and the benefits from the nature of the PittMoss fibers and granular peds within the substrate are considered to be key to the improved fertilizer efficiency.

## Fertilizer Efficiency Findings from the University of Arkansas

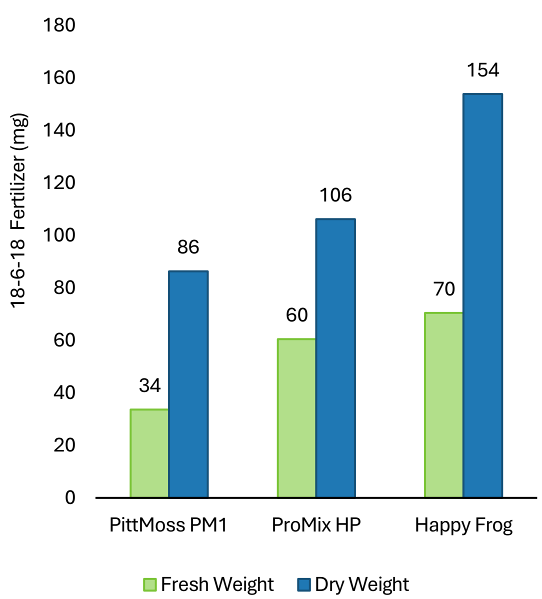
*These findings are from a growth study conducted at the University of Arkansas. This project was not specifically designed to evaluate fertilizer efficiency alone, but data were collected that allow for the*

### *Methods*

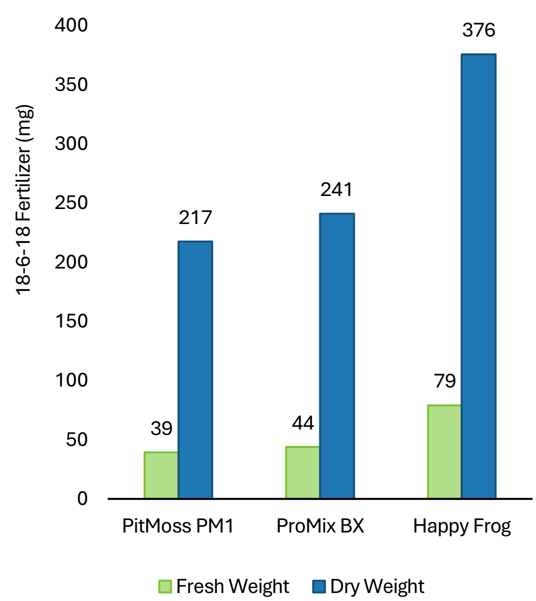
A PittMoss-sponsored but independently designed and conducted research project was performed by Dr. Ryan Dickson at the University of Arkansas beginning in March of 2023. The project was conducted to evaluate some alternate substrate materials but included two commercial control substrates. One control was the PittMoss PM1 blend, and the other was an industry-standard product from Premier Corporation: ProMix BX with mycorrhizae. The PM1 product was composed of 30% PittMoss, 65% sphagnum peat, and 5% perlite. The ProMix BX product was composed of approximately 15% perlite and 85% sphagnum peat.

The crops in this study were grown on flood tables with uniformly applied subirrigation as needed when any of the replications of the crop showed signs of moisture stress. The subirrigation solution was made up of tap water with a soluble fertilizer, 17-5-17, incorporated at rates of 150ppm nitrogen.

*E. Fertilizer (18-6-18) Required to Produce 1g of Tomato Tissue*




*F. Fertilizer (18-6-18) Required to Produce 1g of Sunflower Tissue*



The crops in this study included twelve replications of dwarf tomatoes grown in 6" pots, 2 varieties of calibrachoa with 6 replications each grown in 4.5" pots, and six replications of New Guinea impatiens grown in 4.5" pots. The soils were rated for performance metrics including height, width, fresh weight, dry weight, and foliage chlorophyll content. The PM1 outperformed the ProMix and all other research blends.

### *Results*

For the purposes of this report and given its focus on fertilizer efficiency, only the fresh weight achieved under the two control soils are compared. This is because the research soils had different components. Figure G summarizes the comparative differences in fresh weight yields realized in the different blends while applying the same amount of fertilizer side-by-side to the various crops.

For Calibrachoa "N," the plants achieved 11.2% more fresh weight in the PM1 than in the ProMix BX. Calibrachoa "B" achieved 54% more fresh weight in the PM1 than in the ProMix BX. New Guinea Impatiens achieved 99% more fresh weight. The dwarf tomatoes achieved 17% more growth in PM1 than in ProMix BX. Averaging across all four varieties, there was a 33.5% greater fresh weight in PM1, which includes 30% PittMoss. This independent university study clearly showed that when the PittMoss aggregate replaced 30% of the sphagnum peat and perlite mix, plants were able to grow larger faster without increasing fertilizer or water applications. Extrapolating these observations into commercial production, it is possible that growers could produce same size crops with approximately 33.5% less fertilizer. It is suspected that the increased fertilizer efficiency identified in PittMoss PM1 was realized due to the physical and chemical nature of PittMoss. Higher absorption and delivery of nutrients and less stress to the crop as substrate drying occurred not only fostered better availability of nutrients but also enhanced root development.

## *Information from* "Water and Fertilizer Efficacies: Comparing Two Blends at a Cannabis Production Facility"

*The following section is pulled largely from a previous report written in April of 2020 by Dr. Charles Bethke regarding findings from a cannabis production facility in Erie, PA.*

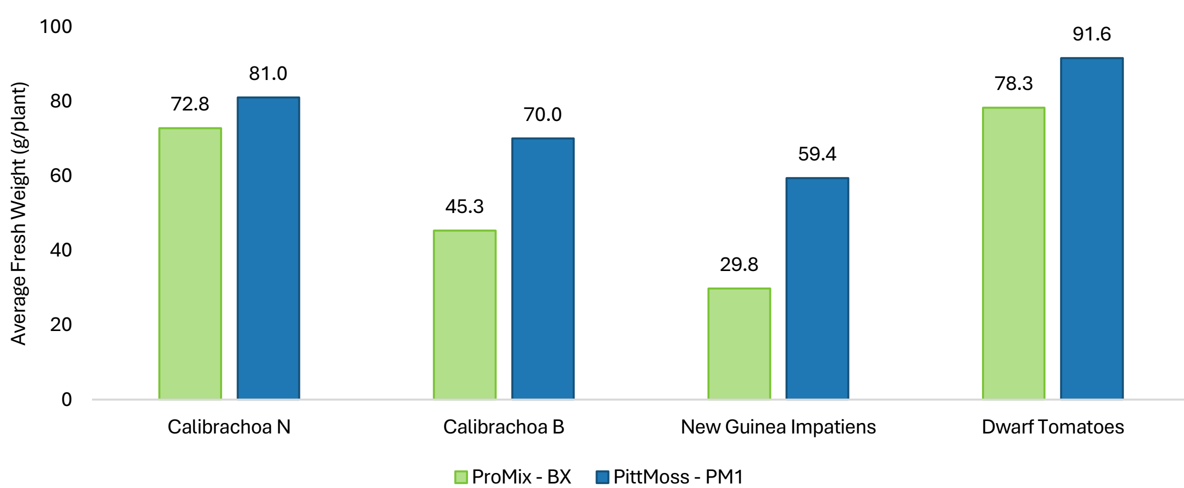
### *Methods*

Some observational work at a large cannabis production facility in Erie, PA, has provided data which appear to reveal some significant influences of the PittMoss PM1 substrate. The work was conducted comparing the efficacies of three growing substrates:

1. Premier Modified ProMix
2. PittMoss PM1 (which includes 30% PittMoss)
3. PittMoss Modified PM1 with 22% perlite

The blends were tested with "light packing" and "heavy packing" methods.

*G. Fresh Weight Differences In Four Crops Trialed at the University of Arkansas (Comparing Control Substrates Under Uniform Subirrigtion with 150 ppm Nitrogen)*
*Dr. Ryan Dickson, 2023*



Data were collected over about one month of production in 7-gallon pots. Two plant strains were monitored with replications and data combined. All replications were treated with the same fertilizers, and water was measured and applied uniformly to each pot. Measurements were taken on the vegetative production between week 2 and week 6 of the crop. Substrate moisture and soluble salts (EC) were measured in the growing plants with a Pulse Meter (Blue Lab) at about one-week intervals over a period of four weeks. The leachate volume and EC (using a conductivity meter) were measured after four different watering events.

The averaged data comparing the substrates are summarized and presented in the graphics in this section of the report. Note that this information is distilled from "field sampling," and that the data show trends and effects but do not provide statistical probabilities and exact precision regarding the differences of the treatments.

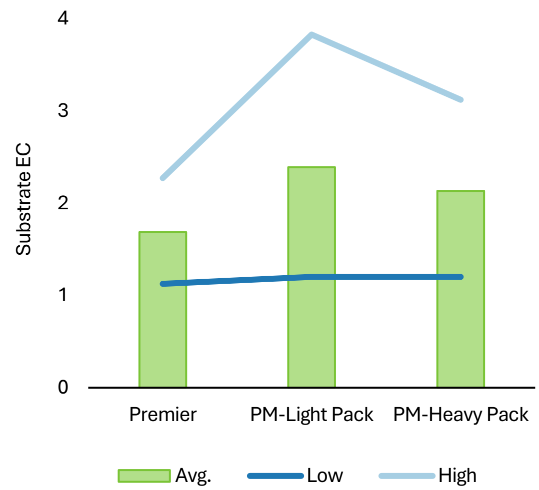
***Nutrients Retained***

Measurements of soluble salts in the substrate are presented here as electrical conductivity (EC) as measured using the Pulse Meter. Each EC unit in this study represented approximately 775 ppm of total soluble salts (mostly nutrients). The lows were about 1.2 in all three blends. The highest measured in the Premier blend was 2.3 and 3.8 for the light pack modified PM1. The heavy pack modified PM1 had a lower high EC of 3.1. That is likely due to the higher density of substrate material and thus less room for nutrient solution. On average, the Premier blend provided nutrients at an EC level of 1.7, while the lightly packed PM1 provided the most nutrients with an EC of 2.4 (vs 2.1 for heavily packed PM1). These data lead to the suggestion that up to 41% higher nutrient-holding (nutrient buffering) properties are present in the PM1 (Figure H).

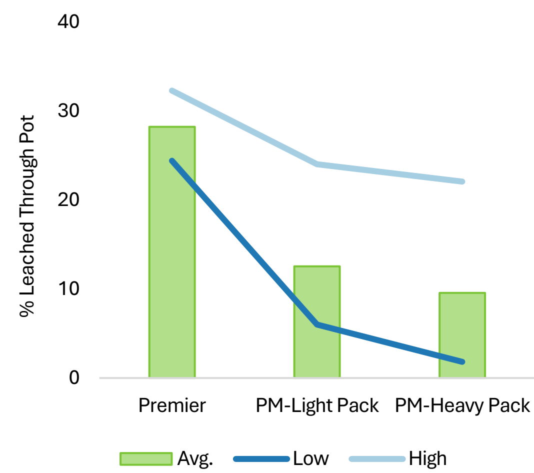
***Leachate Quantification***

Wide differences were observed in the leachate. The modified PM1 allowed less than half of the water leave through the bottom of the pot than the ProMix (Figure I). While the ProMix blend yielded 28% leachate, the light packed PM1 yielded about 13% run-off, and the heavy pack yielded about 10%. In other words, in this trial and under the same uniform solution applications, the PM1 had one-third to one-half the wasted nutrient solution of the ProMix. Note that the moisture held within the substrate was greater in both PM1 treatments, and that the crop was larger in the PM1 blends and likely drew more solution between applications. This provides evidence that PM1 provides greater fertilizer savings.

*H. Substrate Electrical Conductivity Comparison following Fertigation*




*I. % Fertilizer Solution Leached*




***Nutrient Utilization Quantification***

Since the volume of nutrient solution applied was the same for all pots, a comparison of the relative efficacy of nutrient holding and application by each substrate can be normalized by multiplying the volume by the concentration to get a normalized utilization factor. The EC leachate measurements (in ppm) were divided by 775 to obtain the normalized comparative EC units as measured by the Pulse Meter. This total normalized nutrient loss factor can then be used to compare the efficacy of the tested blends (Figure J). Lower units of loss mean higher utilization. The efficiency was much greater for the PM1 blends. The heavily packed PM1 showed about 2.5 times greater utilization of total nutrients than the ProMix, while the light pack showed about 2 times better efficiency compared to ProMix.

***Substrate Nutrient Buffering Assessment***

The ability of a substrate to hold nutrients aginst leaching provides a good measure of buffering in the substrate. Comparing the EC levels measured within the substrates with the EC measured in the leachate provides allows for comparative assessment of nutrient buffering ability between substrates. In order to make direct comparisons, the leachate EC values (in ppm) were divided by 775 to obtain normalized comparative EC units comparable to those measured by the Pulse Meter. These normalized EC values were when compared to determine the nutrient buffering ability of each blend (Figure K).

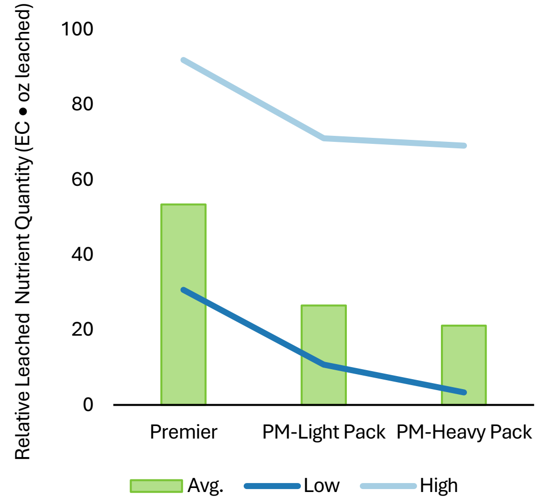
Highly buffered blends show higher substrate EC levels compared to leachate EC levels. However, lower leachate EC levels also indicate better use efficiency of applied nutrients. In this study, comparison of substrate and leachate EC values indicate that PM1 blends retained nutrients better against leaching. This was indicated by higher substrate EC levels on average. The ProMix blend had higher leachate EC levels, indicating a lower ability of the substrate to retain nutrients and provide efficient fertilizer use.

These data are from actual production rather than from a pure research project. The data demonstrate that selection of substrates significantly impacts crop and nutrient management, even in practice. That selection has important implications regarding the efficiency of nutrient use and limiting nutrient loss, both of which have become very important in this time of concern for increased sustainability and environmental stewardship. Fertilizer production is energy-intensive and generates high emissions, and nutrient loss creates far-reaching problems in critical waterways and sensitive ecosystems. Therefore, reductions in both the use and loss of applied nutrients are beneficial directly to growers and to society as a whole.

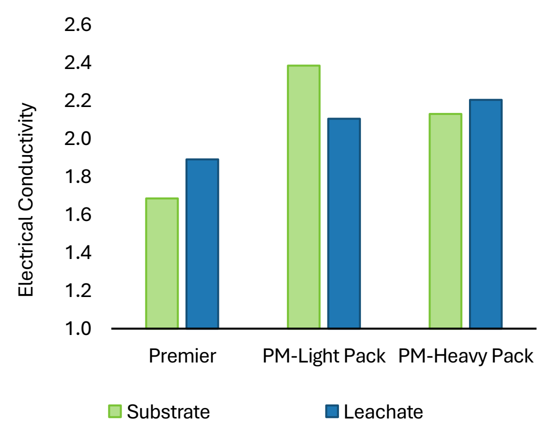
## Summary of Observations on PittMoss Fertilizer Efficiency Benefits

Considering the controlled observations made to date, it is clear that there is greater plant utilization and reduced loss of fertilizer from blends containing at least 30% PittMoss fibers. In order to summarize the

*J. Total Unitized Nutrient Loss (Means Normalized with Pulse/775)*




*K. Electrical Conductivity in Substrate and Leachate of 3 Different Growing Blends (Mean Normalized Pulse/775)*




observations, the comparative measured results are presented in Table 1. The numbers have been normalized such that the PittMoss PM1 blend results function as a point of reference. The results for PittMoss PM1 are assigned 100% normal utilization, then the nutrient utilization and loss of other substrates with the same crops are quantitatively compared to PM1. This normalization then provides a measure of the increase or decrease in efficiencies realized by other substrates compared to PM1 in the various research projects and crops tested.

As it has been previously discussed, substrate performance was expressed as milligrams of fertilizer to produce 1g of fresh weight or dry weight when using a given substrate. Table 1 presents fresh weight comparisons as seen at Dr. Bethke's Michigan

Research Greenhouse and the University of Arkansas. It lists the fresh and dry weight comparisons. To further shed some light on the reasons for the responses, physical data measured by the staff at the facility while growing cannabis are also included, along with normalized values for comparison of the substrate and leachate EC values obtained in that study.

### *Research Greenhouse Data Discussion*

Comparing the relative fertilizer use efficiencies for fresh weight production in the three mixes (PittMoss PM1, ProMix BX with mycorrhizae, and Fox Farm Happy Frog), six crops were produced under careful measurement of fertilizer applications (see *Nutrient Management Research Projects at Dr. Bethke's Michigan Research Greenhouse* section for exact methodology). Those data were normalized using PM1 as a 100% standard of fertilizer use. The amount of fertilizer used to grow 1g of fresh weight in PittMoss PM1 was then compared to that required by both the ProMix BX and Happy Frog blends.

As shown in Table 1, ProMix BX required anywhere from 12% more fertilizer when growing sunflowers up to 171% more fertilizer when growing kale. ProMix BX averaged 71% greater need for fertilizer over all crops compared to PittMoss PM1. At no time did the ProMix BX yield more fresh weight per milligram of fertilizer applied than the PM1. Likewise, when measuring fresh weight responses in the Fox Farm Happy Frog substrate, fertilizer demand ranged from 74% greater for basil production up to 214% more demand for cucumbers. On average, the Fox Farm Happy Frog required 118% more fertilizer to yield the same quantity of fresh weight as PittMoss PM1.

A similar response was observed in dry weight measurements but varied somewhat from the responses in fresh weight. The ProMix BX data showed 11% more fertilizer required for producing dry weight in sunflowers and 212% more fertilizer for basil when projecting for the same dry weight attainment as compared to PittMoss PM1. Overall, the ProMix BX required an average of 42% more fertilizer to achieve the same dry weights as PM1. The Fox Farm Happy Frog did not fare well at all. Its best response was with zinnias, where "only" a 72% increased need in applied fertilizer was required as compared to the PM1. The most pronounced and worst response overall appeared when growing cucumbers in the Fox Farm Happy Frog bark-based mix. The data shows that it would take 373% more fertilizer to produce the same dry weight in cucumbers compared to PittMoss PM1. It should be noted that this number seems excessive and may represent an error or special interaction; however, it does follow the trend demonstrated in the fresh weight fertilizer projections for cucumbers grown in the Happy Frog substrate.

### *University of Arkansas Data Discussion*

When comparing fertilizer efficiency of ProMix BX to the PM1 at the University of Arkansas, the best efficiency realized by the ProMix BX was 111% of the efficiency in the PM1. Thus, it would take 11% extra fertilizer in the ProMix BX to achieve the same results when growing the Calibrachoa "N" as was needed in the PM1. The worst performance of the ProMix BX was identified when growing New Guinea impatiens, where the data indicate it would require 99% more fertilizer (essentially double) to achieve the same plant size as achieved by PM1. The average over all crops trialed at the University of Arkansas showed that ProMix BX would likely require about 46% more fertilizer than PittMoss PM1 to achieve the same level of plant growth.

### *Cannabis Production Data Discussion*

Presented in Table 1 are physical properties representing features related to nutrient absorption, leaching, utilization, and buffering. Table 1 shows a summary of measurements by the grower demonstrating why PittMoss fibers in a growing media (in the case of PM1, PittMoss is incorporated at a rate of 30%) provides better nutrient efficiency and plant performance. As shown in the table, ProMix would require 32% more applied fertilizer to obtain the same substrate nutritional concentration as PittMoss PM1. It would take 125% more fertilizer to equal the estimated utilization of applied fertilizer in growing the cannabis, and the ProMix leached 143% more fertilizer than the PM1. Overall, an average of 83% more fertilizer was projected for the use of ProMix when growing cannabis when compared to PM1.

## Conclusion

As shown in this report, it is reasonable to project that anywhere from 32% to 135% percent less fertilizer can be required when incorporating at least 30% PittMoss into a blend. This series of studies has clearly demonstrated that substrate choice plays a large role in fertilizer use efficiency. Choosing a substrate that uses fertilizer more efficiently can have real impact on the amount of fertilizer required for marketable crop production, ultimately impacting a grower's bottom line as well as our shared environment.

**Table 1: Summary of Normalized Fertilizer Efficiencies in Comparison to PittMoss PM1 Containing 30% PittMoss Fiber. PM1 performance metrics (indicated in the leftmost column) were utilized as the baseline. Figures for ProMix BX and Happy Frog indicate the percentage of additional fertilizer required to achieve the same level of each performance metric achieved in PM1. For example, this table indicates that ProMix BX requires 108% more fertilizer to achieve the same fresh weight in Zinnias grown in PM1.**

| Performance Metric | PittMoss PM1 (%) | ProMix BX (%) | FF Happy Frog (%) |
|---|---|---|---|
| **Research Greenhouse - Fresh Weight** | | | |
| Zinnias 4.5" | 100 | 208 | 203 |
| Kale 3.5" | 100 | 271 | 210 |
| Cucumbers 3.5" | 100 | 124 | 314 |
| Basil 3.5" | 100 | 136 | 174 |
| Tomatoes 6 Liter | 100 | 176 | 206 |
| Sunflowers 6" | 100 | 112 | 202 |
| ***Average*** | ***100*** | ***171*** | ***218*** |
| **Research Greenhouse - Dry Weight** | | | |
| Zinnias 4.5" | 100 | 148 | 172 |
| Kale 3.5" | 100 | 126 | 166 |
| Cucumbers 3.5" | 100 | 133 | 473 |
| Basil 3.5" | 100 | 212 | 245 |
| Tomatoes 6 Liter | 100 | 123 | 179 |
| Sunflowers 6" | 100 | 111 | 173 |
| ***Average*** | ***100*** | ***142*** | ***235*** |
| **University of Arkansas Project - Fresh Weight** | | | |
| Calibrachoa N | 100 | 111 | * |
| Calibrachoa B | 100 | 155 | * |
| NG Impatiens | 100 | 199 | * |
| Dwarf Tomatoes | 100 | 117 | * |
| ***Average*** | ***100*** | ***146*** | |
| **Cannabis Production - Fertilizer Use Efficiency Estimates** | | | |
| Cannabis | | | |
| Nutrients Absorbed | 100 | 132 | * |
| Percent Run Off | 100 | 243 | * |
| Apparent Utilization | 100 | 225 | * |
| Nutrient Buffering | 100 | 132 | * |
| ***Average*** | ***100*** | ***183*** | |

* No data available from this study