

Controlled Release Fertilizers and Fertigation in Nursery Pot Production of Quercus Species

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Abstract

The COVID-19 pandemic and ensuing lockdowns led to an increase in revenue and production for green industry products in early 2020. An evaluation of fertigation (liquid feed, quick release) and controlled release fertilizers (CRFs, slow release) were applied to container-grown (7 gallon) live oak (*Quercus virginiana*) and Nuttall oak (*Quercus nuttallii*) trees (100% Liquid feed, 0% CRF, 67% Liquid feed, 33% CRF, 33% Liquid feed, 67% CRF, 100% Liquid feed, 0% CRF). Live oak trees fertilized with CRFs had increased stem calipers (>30%). Nuttall stem caliper and height were significantly increased by 62% and 58%, respectively, with substrate incorporation of CRFs. Live oak tree height was increased by 35% and stem caliper when CRFs were incorporated.

Keywords

Plant Nutrition, Nursery Management, Plant Fertility

1. Introduction

Fertilization is one of the most important cultural practices for plant quality, especially for seedlings produced in containers in which the limited volume hinders their growth [1]. Fertilization can accelerate shoot and root growth of plants, modify tissue nutrient contents and hence the available reserves, improve post-transplant rooting and growth capacity, and increase resistance to water stress, low temperature and disease [2]-[4]. This also applies to ornamental production, not just for reforestation purposes, to provide customers with a high-quality product that will adapt and overcome the challenges of transplanting in an urban landscape. The use of soil may be applied to lessen the need for fertilizing, but this practice is unreliable and can provide varied results which are not good for businesses wishing to compete and provide consistently high-quality products. Therefore, the use of

bark-based media has become more widely accepted because the results are more consistent even though a grower must manage the media components more than soil [5]. Container growing practices are used for the same reasons in that conditions can be more easily controlled by the grower to create the highest quality product through good management. In containers, the root systems of a crop are confined to the limited volume provided by the container and so an efficient fertilization program should be implemented. Adequate nutrition is needed to provide an optimal supply of nutrients while avoiding deficiencies and excess waste.

Fertigation is the practice of applying fertilizer solutions with irrigation water, typically through a micro sprinkler or a drip system [6]. Fertigation is a specialized agricultural management technique combining fertilizers and irrigation water in a single process. This method is commonly used in the nursery industry to efficiently and precisely deliver nutrients to plants, ensuring optimal growth and health. Fertigation allows nursery managers to deliver essential nutrients directly to the root zone of plants through the irrigation system. This precise method ensures that plants receive sufficient nutrients they need for healthy growth, minimizing waste and reducing the risk of over-fertilization. These systems are often automated, allowing growers to carefully control the timing and dosage of fertilizers. This helps to conserve water by delivering nutrients in conjunction with irrigation. Nursery operators can tailor fertigation programs to the specific needs of different plant types, growth stages, and environmental conditions [7]. This flexibility is crucial for nurseries that produce a wide range of plant species, each with its own nutritional requirements. Fertigation promotes healthier plant growth by ensuring that nutrients are readily available to the plants. Fertigation systems can reduce the need for costly labor applied fertilizer applications, which can be labor-intensive and costly [8]. This can result in cost savings for nursery operators by reducing labor requirements and increasing overall operational efficiency. These systems can also monitor and adjust the pH and electrical conductivity (EC) of the irrigation water, ensuring that the nutrient solution is within the desired range for optimal nutrient uptake by the plants. Monitoring equipment can be easily installed to manage these systems. However, as with any method, there are also negative aspects that come with positive aspects. Cost comes into play primarily whenever a grower at a nursery decides on how to grow a quality product. The upfront cost of creating an irrigation system that can provide adequate water and be used for fertigation can be costly, especially for smaller operations where it may be cheaper to have workers apply fertilizer by hand [9]. The cost of water-soluble fertilizers can be comparatively cheap compared to other sources, but the constant need to provide a consistent availability of nutrients available to crops can add up. This is varied by the nutritional needs of the species being grown. Water-soluble fertilizers can leach through a container system with the addition of any additional water since they are in a soluble form. Nitrate present in liquid fertilizer formulations is more likely to enrich drainage water as it is already dissolved [10] [11]. Nutrient leaching is a wasted economical input since most of the water-soluble fertilizer does not get

absorbed by a crops root system. Estimates of up to 60% of N in a water-soluble fertilizer do not get utilized by the crop which is being fertigated leading to excess N leaching and runoff from nurseries dissolved [10] [11]. Therefore, the need for efficient N management within these systems is critical to meet production goals while reducing the economic and environmental costs of excess N [12].

A solution to excess leaching and reduction of efficiency could be manufactured fertilizers called controlled release fertilizers (CRFs). These fertilizers have become more popular in recent years [13]. CRFs play a significant role in the nursery industry by providing a gradual and consistent availability of nutrients to plants over an extended period. These fertilizers are engineered to release nutrients based on environmental factors such as temperature, soil moisture, and microbial activity. This precision allows for tailored nutrient release, which can be especially beneficial in nurseries with diverse plant species, each having unique nutrient requirements. These specialized fertilizers are designed to release nutrients slowly, matching the plant's growth rate and reducing the need for frequent fertilizer applications. Controlled-release fertilizers are typically coated or encapsulated with inorganic or organic materials that control the rate, pattern, and duration of plant nutrient release. Polymer-coated urea exemplifies CRFs [14] [15]. These fertilizers control the release of nutrients with semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble, low-molecular-weight compounds, or by other unknown means [16]. CRFs typically come in the form of prills. Controlled release fertilizers are formulated to release nutrients gradually over weeks or even months. This extended-release period ensures that plants receive a steady supply of essential nutrients throughout their growth cycle, reducing the need for frequent reapplication. Controlled release fertilizers provide a consistent supply of nutrients, promoting more uniform plant growth and reducing the risk of nutrient imbalances. The slow-release nature of CRFs reduces the frequency of fertilization, resulting in reduced labor costs and lower expenses associated with fertilizer application [17]. Nursery operators can allocate resources more efficiently since they don't need to apply fertilizers as frequently. Since CRFs release nutrients as plants need them, there is minimal nutrient pollution. This increased efficiency benefits both the plants and the nursery's profit. These fertilizers are environmentally friendly because they minimize the risk of nutrient runoff, which can lead to water pollution [18]. By reducing the need for frequent fertilization, CRFs contribute to sustainable nursery practices. CRFs may provide an inexpensive and simplistic method to supply nutrients to tree seedlings in low-technology nurseries while allowing relative control of the supply during the growing period [19]. Additionally, their field of application could be widened with the simultaneous use of products with different rates of release [20] or combined with fertigation [21]. Nursery operators can choose from various types of CRFs with different release patterns and nutrient formulations to match the specific needs of their plant varieties and growing conditions. Nurseries can use CRFs to extend the availability of nursery stock, allowing for longer selling seasons and

better inventory management. This flexibility allows customized fertilization programs. Not all CRFs are the same, and research should be done on them to better tailor them to the species intended to be grown by a nursery. Despite similar longevity ratings, the intensity and pattern of nutrient release can be significantly different among polymer-coated CRF products [22]. The choice of CRF product and application rate must be suitable for the species and nursery growing conditions [23]. Though just like in fertigation, there are disadvantages with the use of CRFs. One disadvantage of CRFs is that, despite long durations of fertilizer release, proportionally greater quantities of nutrients are often released during the beginning of culture [22] when plants are small and nutrient requirements are low. This can rapidly exhaust the fertilizer and promote high salinity levels at this stage, which may cause root damage and limit seedling growth [24]. Damaged seedlings take much longer to recover from such incidents compared to older specimens and therefore would cost a nursery more money in damages. Though, CRFs release nutrients slowly and in a controlled manner, reducing the risk of fertilizer burn, which can occur when conventional, quick-release fertilizers are applied in excess. Although controlled release fertilizers may have a higher initial cost compared to traditional fertilizers, their extended nutrient release can lead to long-term cost savings due to reduced fertilizer applications and labor requirements.

Nevertheless, the application of solid fertilizers to the substrate, particularly controlled-release fertilizer (CRF), represents a good alternative to fertigation under certain conditions. Similar growth rates have been observed in trials in which both types of fertilization were compared [25]. Application of controlled release fertilizer (CRF) at time of planting has been shown to enhance nutrient uptake and stimulate above-ground growth for several hardwood species within the Central Hardwood Forest region of the USA [26]. A larger quantity of CRF tests are conducted in the central and northern regions of the USA. Weather conditions, especially in states such as Louisiana, can be highly unpredictable and involve a huge quantity of precipitation (>60 in) in the South compared to other regions of the USA. Seedling responses to common post-transplant environmental stresses, may be altered by the CRF application such that, dependent upon site and environmental conditions, seedlings may exhibit positive, negative, or neutral responses to fertilization [26]. Environmental and field condition interactions with CRFs and how that affects the growth of plants have not been studied well [27]. CRFs are slowly becoming more popular for giving consistent results but more studies are required on their interactions under different conditions and how they fare using fertigation in production. Studies may improve recommended rates or other methods of use to improve efficiency. This could lead to proof that the use of fertigation with CRFs may provide additional benefits that the two methods themselves do not provide alone.

Fertigation and CRFs are commonly used in ornamental crop production in the nursery industry [6] [13]. Nurseries that focus on tree production use fertigation to supply adequate nutrition to their product. Fertigation allows nursery managers

to deliver essential nutrients directly to the root zone of plants through the irrigation system. CRFs are engineered to release nutrients based on environmental factors such as temperature, soil moisture, and microbial activity [16]. The objective of this experiment was to test the efficiency of CRFs versus fertigation and combinations of the two by comparing the growth associated with those treatments and asking the question if a combination of the two could provide increased growth.

2. Materials and Methods

A study (Table 1) was initiated in February 2021 consisting of four treatments to compare the effect of growth fertigation, CRFs, and combination of both on the two oak tree species in the experiment. Treatment 0 received 100% fertigation as a control, Treatment 1 received 67% fertigation and 33% CRF, Treatment 2 received 33% fertigation and 67% CRF, and Treatment 3 received 100% CRF. The fertilizer for fertigation was Peters 20% (N)-20% (P₂O₅)-20% (K₂O) and the fertilizer used for a CRF was Osmocote 15% (N)-9% (P₂O₅)-11% (K₂O), 12-to-14-month release. Fertilizers were calculated and measured to provide 3 lbs N/yd³ per growing season. This rate of N was determined using the product labels to give a medium-high rate of fertilizer. All treatments were amended with 8 lbs dolomitic lime/yd³ and Micromax at 1 lb/yd³ to cover the basis of the nutritional needs among the trees in the experiment. Tree liners grown in individual cells and measuring on average 8 inches above the soil level. All tree liners were grown in 7-gallon containers and received the same barked-based media mix (3: bark, 1: sand, 1: peat). Drip irrigation was used on all trees to provide daily irrigation as needed. Precipitation in Baton Rouge, Louisiana for 2021 was greater than average and weather for 2022 was far less than average.

Table 1. Fertilizer sources and rates using CRF or liquid feed (fertigation) in the 2021 and 2022 LSU Hill Farm live oak and nuttall oak studies.

Treatment 0.	100% Liquid feed, 0% CRF
Treatment 1.	67% Liquid feed, 33% CRF
Treatment 2.	33% Liquid feed, 67% CRF
Treatment 3.	0% Liquid feed, 100% CRF

Live oak (*Q. virginiana*) and nuttall oak (*Q. nuttallii*) species were chosen due to their popularity in the nursery trade. This also provided the ability to test evergreen and deciduous species that were closely related that would have different nutritional needs. Trees were transplanted as liners, young plants grown in individual tree cells, in March 2021 for the initial experiment and again in March 2022 to repeat the experiment. Tree growth parameters for height (in.) and caliper/width (mm) were measured and assigned to fertilizer treatments using random assignment to reduce variability. Oak tree plants were randomized by species and arranged in a RCBD. Both trials were established at the LSU Hill Farm Horticulture Teaching Facility in Baton Rouge, LA (30.41°, -91.17°). At the end of every month throughout the 10-

month experiment, data was collected from the trees to establish rate of growth through measuring height (in.) at the apex bud and caliper/width (mm) at 6 inches above the soil line to show the effect that the different treatments had on the trees. Data was collected each month and means statistically compared using Duncan's Multiple Range Test. Plant tissue nutrient analysis (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Mo and Zn) was analyzed by the LSU Soil Testing Lab. Nutrient analysis was initiated by harvesting plants tops at the termination of the project, and dried at 60°C. One gram of ground plant material was transferred into a 20 ml scintillation vial and placed in an oven at 50°C for 1 h to remove residual moisture. Vials were transferred to desiccators for 1 h to further remove moisture and cool the sample to room temperature. The caps of each sample were tightened upon removal from the desiccators to prevent moisture from re-entering. All elements were analyzed by placing 0.5 g of tissue into a 50 ml tube (SCP Scientific digiTUBE). Funnels were placed in each tube, and samples were placed into an automatic digester (Thomas Cain, DEENA) for digestion using nitric acid. During the digestion, the samples are heated for 6 s at 60°C and 2.2 ml of distilled water is added. After 2 m, 5 ml nitric acid (SCP Science, 67% to 70% HNO₃, reagent grade) was dispensed into each tube, and the temperature was increased 10°C every 10 m from 60°C to 110°C. The temperature was increased to 125°C and held for 45 m, and then held for 50 m at 128°C, and cooled for 2 m. One ml of hydrogen peroxide (Macron Fine chemicals, 30% solution) was dispensed into each tube, cooled for 5 m and reheated for 5 m to 128°C. One ml of hydrogen peroxide was dispensed, and another 1 ml of hydrogen peroxide was dispensed into each tube. The samples were cooled for 5 minutes and heated for 30 minutes at 122°C, cooled for 6 seconds to 20°C and cooled for 1 more minute. The volume of each sample was brought to 20 ml using distilled water. Samples were removed from the digester and vacuum filtered using a 1.0-micron Teflon membrane filter (SCP Science) into another 20 ml tube. ICP (inductively coupled plasma) spectroscopy was performed for the elements P, K, Ca, Mg, S, Al, B, Cu, Fe, Mn, Mo, Na, and Zn using a Spectro Arcos according to the LSU Soil Testing and Plant Analysis Lab's AgMetals procedure. The instrument was calibrated using one blank and 6 standard samples. Samples were run in sets of 60 (2 blanks included) with two National Institute of Standards and Technology (NIST) peach samples and an internal standard for every 20 samples. The data was verified to ensure it was within the tolerant ranges of the NIST and internal standards. Nutrient levels were reported as % (dry weight) for macronutrients and ppm (mg/kg dry weight) for micronutrients. Data was statistically analyzed using a Proc GLM at the 0.05 level. The experiment used 80 trees total, 40 per species, with 10 replications per treatment per species establishing a RCBD using random assignment to reduce variability with 20 blocks. Mean separation was analyzed using a Duncan Multiple Range Test at the 0.05 level.

3. Results and Discussion

There were significant statistical differences at the 0.05 level using a Proc GLM

between treatments. CRFs increased the growth for both height and caliper of *Q. virginiana* trees as shown in (Figures 1-2). Initially within the first 2 months, there was no difference in the growth of the tree with either caliper (mm) or height (in.). As the growing season for the trees continued, all treatments containing CRFs began to have increased growth compared to the fertigation treatment alone (Figures 1-2). This led to a significant difference between the treatments. Furthermore, as growth began to slow at the end of the year with decreasing temperatures, the three CRF treatments further differentiated as Treatments 2 - 3 continued to grow past Treatment 1 leading to a significant difference (Figures 1-2). At the end of the growing season, Treatment 0 (100% fertigation)

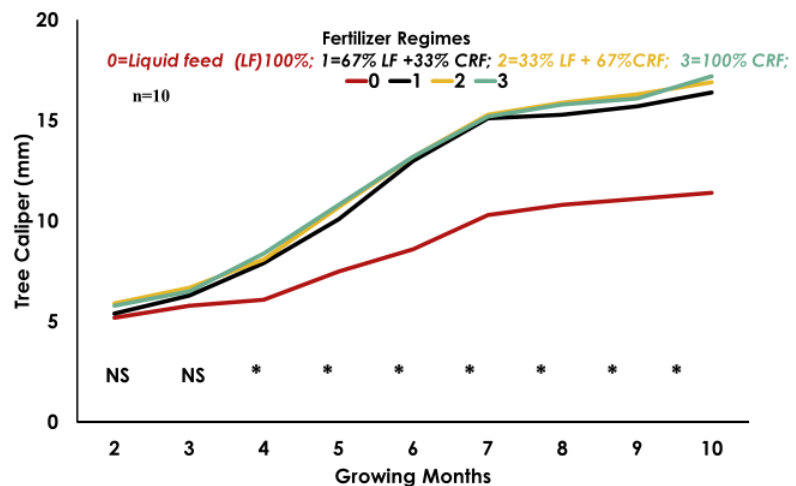


Figure 1. Live oak caliper (mm, diameter of stem) measured after a 10-month growing season (February to October) and fertilized with liquid and/or controlled released fertilizers in 2021 and 2022. NS = Not significant at the 0.05 level; * = Significantly different at the 0.05 level.

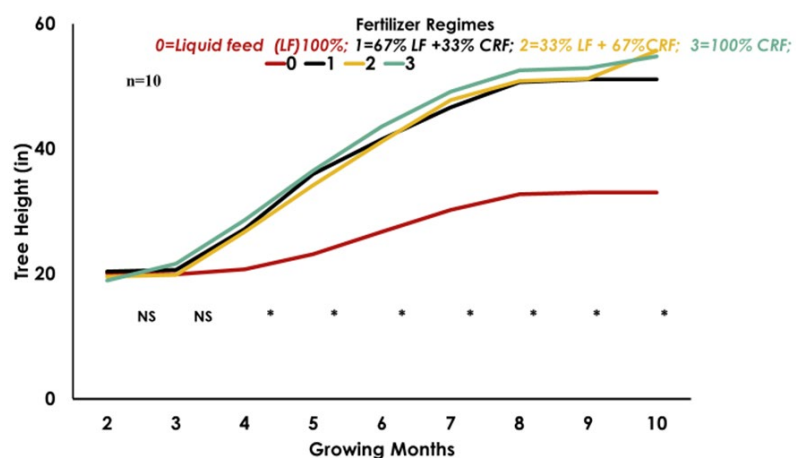


Figure 2. Live oak height (in., soil surface to apex) averages measured after 10-monthgrowing season (February to October) and fertilized with liquid and/or controlled released fertilizers in 2021 and 2022. NS = Not significant at the 0.05 level; * = Significantly different at the 0.05 level.

produced short unsalable trees while Treatments 2 - 3, which had little to no significant differences between each other, with vigorous commercially salable trees (Figure 3). Live oak leaf tissue resulted in significantly lower levels for the 100% fertigation treatment. Not only were N tissue levels lower than other treatments, but below lower threshold levels for optimum growth. This is consistent with previous research reporting more prevalent N leaching through the container. It is possible that lower N levels could have been a limiting growth factor resulting in smaller stem caliper and tree height.

Like the results for live oak, the results for nuttall oak showed a significant difference between the treatments. In Figures 4-5, a similar trend is shown in growth the nuttall oaks had when compared to the growth of the live oaks. There were no differences after 2 months of growth between the various treatments. After 4 months, however, a clear difference formed as the growing season

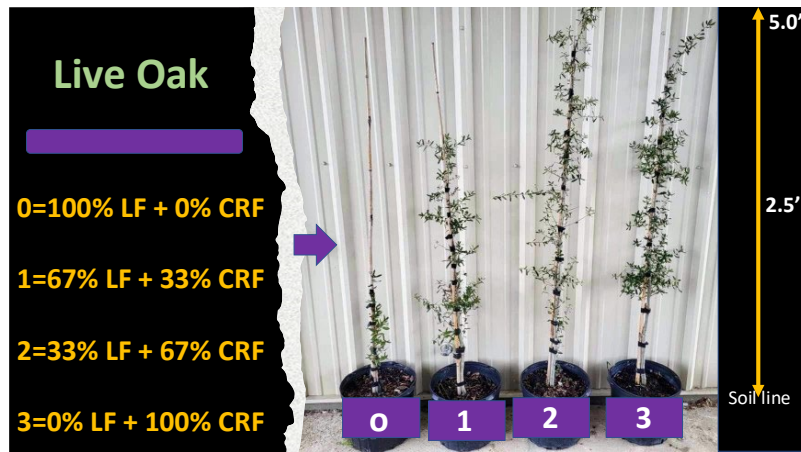


Figure 3. A visual representation of live oak treatments after 10 months of growth in 2022.

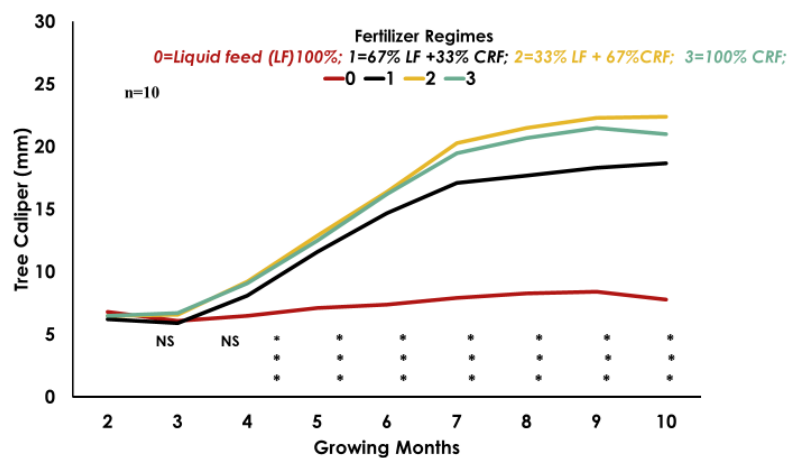


Figure 4. Nuttall oak caliper (mm, diameter of stem) was measured after a 10-month growing season (February to October) and fertilized with liquid and/or controlled released fertilizers in 2021 and 2022. NS = Not significant at the 0.05 level; * = Significantly different at the 0.05 level.

continued into the year. All three treatments containing the CRF performed significantly better than the treatments that contained only water-soluble fertilizer (fertiligation). By the end of the growing season, there was a significant difference. Treatments 2 - 3 performed the best and Treatment 0 (100% liquid feed) performed the worst. Beyond month 2, Treatment 0 had little or no growth. Treatment 2 also had a positive significant difference over treatment 3. Nuttall oaks were selected to visually represent the differences between the treatments (Figure 6).

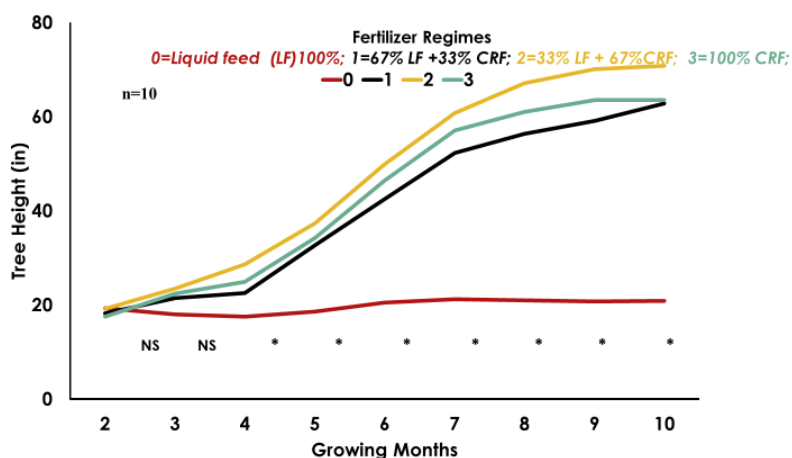


Figure 5. Nuttall oak height (in., soil surface to apex) measured after a 10-month growing season (February to October) and fertilized with liquid and/or controlled released fertilizers in 2021 and 2022. NS = Not significant at the 0.05 level; * = Significantly different at the 0.05 level.

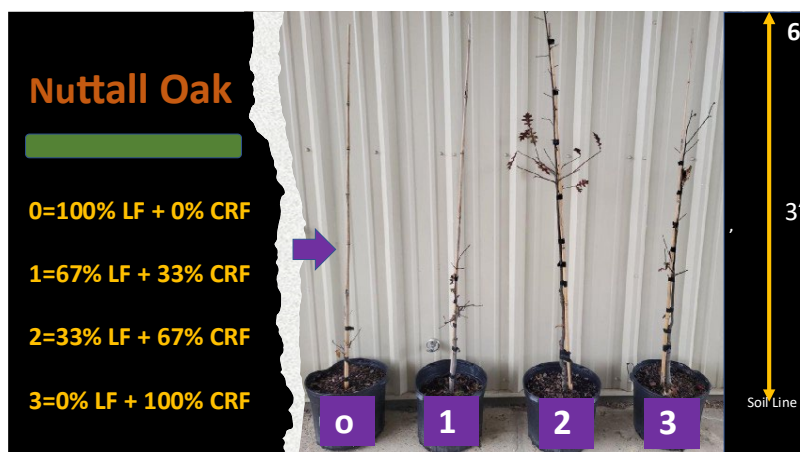


Figure 6. A visual representation of nuttall oak treatments after 10 months of growth in 2022.

4. Conclusion

The two-year experiment conducted in Baton Rouge, LA, during 2021 and 2022, provided valuable insights into the comparative effectiveness of Controlled Release Fertilizers (CRFs) and fertigation to produce oaks within a nursery setting,

under high rainfall conditions. CRFs implemented as part of a nurseries fertilization program clearly produced taller trees with greater caliper results. CRFs allowed all treatments with them to outperform the one treatment that lacked them. CRFs consistently provided an adequate supply of nutrients to the oak trees throughout both years of the experiment. This gradual nutrient release matched the plants' growth requirements and ensured that they received essential nutrients even during periods of heavy rainfall. Oak trees treated with CRFs exhibited more consistent and uniform growth patterns over the two-year period. This consistency is crucial for nursery operators aiming to produce high-quality nursery stock with uniform characteristics. Why did the fertigation perform poorly compared to the other treatments? The answer is water-soluble fertilizers are more likely to leach out of containers during irrigation or any addition of water through such events as precipitation. Louisiana has abundant annual rainfall, averaging > 60.0 inches. As precipitation enters the container system, the already easy to move water-soluble fertilizers are then moved out of the container at a much higher rate than just with the already supplied drip irrigation [11]. With rainfall being a nearly daily occurrence, water-soluble fertilizers are not present for a long enough period to allow for absorption by the trees from their root systems. The experiment's location, characterized by high rainfall, posed a challenge for fertigation due to the difficulty of accurately adjusting nutrient applications in response to variable weather conditions. CRFs, on the other hand, were not affected as much by sudden changes in rainfall and continued to provide nutrients steadily. In an arid environment, or at least one with less precipitation (*i.e.*, greenhouses), the fertigated fertilizers would have a longer period to be absorbed by the trees. This is not the situation in the Southern USA, so CRFs would be needed to produce a high-quality product and ensure crop survival. It can be speculated that Treatment 2 performed the greatest, having 67% of its N from CRF and 33% from fertigation. Why did this happen? A smaller steady supply of N with the occasional "burst" of N from fertigation stimulated the root system to pick up increased rates of N which in turn stimulated growth of the trees. The presence of CRFs being more constant would also potentially increase soil content of the salts since the fertilizer from fertigation would more easily be leached out of the system. The salts in turn could alter the soil physics and chemistry to hold onto other elements not supplied by the fertilizers as well as alter pH to be more optimum for growth since the water used has a more basic pH. What does this mean for growers in Louisiana? The use of CRFs significantly reduces the labor and operational costs associated with fertilization. With fertigation, frequent monitoring and adjustments were required due to the variable rainfall patterns. In contrast, CRFs required fewer applications and less maintenance, resulting in cost savings [17]. CRFs may be a cheaper and more effective fertilizer overall. The main cost of CRF use would come in the purchase of the fertilizer itself and the labor to incorporate it in the field. Fertigation costs would include the cost of the fertilizer, which would need to be constantly added into the system and the building of an irrigation system to allow for ferti-

gation. Therefore, a greater amount, weight wise, of fertilizer would be required for a yearly fertigation system compared to the one-time application of CRFs. Labor and materials to build irrigation systems to support fertigation would come at a hefty price in today's market. As noted, water-soluble fertilizers are very prone to leaching compared to CRFs having fertilizer leach out of the system [6]. In a region experiencing high rainfall, concerns about nutrient runoff and water pollution are particularly relevant. CRFs, with their controlled and slow-release characteristics, proved to be environmentally responsible by minimizing nutrient runoff. In the end, CRFs may be the cheaper option and if not, it would provide crops with some nutrition reaching during the unexpected events and unreliability of weather which may cause increased leaching with heavy precipitation. CRFs demonstrated their long-term viability as a sustainable fertilization method for oak production in a nursery setting. Their extended nutrient release allowed for better planning and management of resources, contributing to the overall success of the nursery operation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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