Exponential fertilization of pedunculate oak (*Quercus robur* L.) seedlings: quality assessment, nutrient budgeting, and leaching dynamics

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Abstract

Pedunculate oak (*Quercus robur* L.) seedlings received one standard (S) and four exponential (E) rates of fertilizer ranging from 0.1 to 1.0 g nitrogen plant^{-1} season^{-1} during their first bareroot growing season in Co. Carlow, Ireland. Height, root collar diameter, and dry weight differences between treatments were expressed as relative height increase (RHI), relative diameter increase (RDI), and relative dry weight increase (RDWI), respectively. Treatment had a significant impact on seedling RHI ($p<.0001$) and RDI ($p<.0002$), with fertilized seedlings being taller and stouter than control seedlings receiving no fertilizer; however, differences across fertilizer treatments occurred in RDI only. Treatment also had a significant impact on seedling RDWI ($p<.0304$). A vector nomogram of relative change in above-ground plant dry mass, nitrogen content, and nitrogen concentration indicated that all rates of fertilizer applied in the study may not have been sufficient for optimal seedling growth. Soil nitrate concentrations plotted over time indicated that higher fertilizer treatments were capable of increasing the amount of nitrate in the soil available to seedlings despite heavy amounts of precipitation. However, the nitrate budget indicates that nitrate losses were proportional to the fertilizer rate applied leading to higher losses at the higher rates.

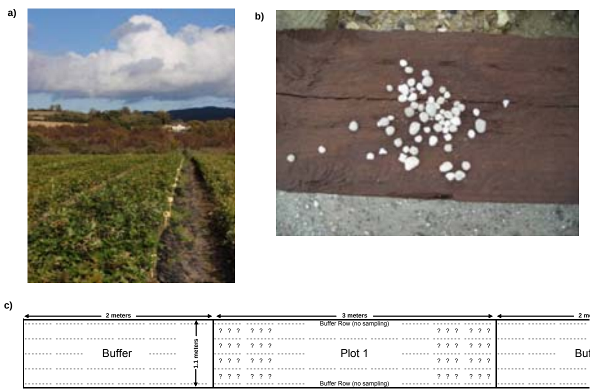

Figure 1. a) Treatment plots during a sunny day at Ballintemple Nursery. b) Sulfa CAN™ fertilizer granules which were applied to seedlings via hand broadcasting into each respective plot . c) Plot layout showing buffers and soil sampling points indicated by (?).

Introduction

Conventional fertilization regimes of most forest nurseries (including those in Ireland) involve supplying seedlings with periodic applications of a constant rate of fertilizer addition throughout the growing season. (E) fertilization (whereby fertilizer rates are incrementally increased in relative proportion to seedling size) has been shown to improve fertilizer nutrient use efficiency for species of both conifers and oaks in North America. Using this method, smaller (younger) seedlings receive less fertilizer while demand is low and larger (older) seedlings are fertilized at higher rates in accordance with increasing ability to use nutrients. (E) fertilization results in improved fertilizer use efficiency, thereby decreasing nutrient leaching and environmental contamination as was recently observed for white pine (*Pinus monticola* Dougl. ex D. Don) in a container nursery (Dumroese et al. 2005). With this fertilization method, it is also possible to induce luxury nutrient uptake through application of relatively high fertilizer rates later in the season (i.e., nutrient loading), which results in production of seedlings that are both morphologically and physiologically superior to those grown under conventional methods (Birge et al. 2006) and have improved growth upon outplanting (Salifu et al. 2008).

Materials and Methods

Site information, fertilizer rates, and plot layout

Pedunculate oak acorns were sown at the Coillte Ballintemple Nursery, Co. Carlow (52˚ 44´ N 6˚ 42´ W, 100 m) in late October of 2007. The nursery soil is classed as a coarse sandy loam of pH 5.7. Organic matter is between 6-8% and sand, silt, and clay fractions are 66, 19, and 15% respectively. After germination in the spring of 2008 the seedlings within the 1.1 × 3 m plots of the selected nursery bed were thinned via pruner clipping at ground level to a uniform density of 100 seedlings/m^2. The seedlings began to receive five different fertilizer applications beginning 29/5/08 and every two weeks thereafter until 25/7/08. Specific rates applied are outlined in Table 1. The (E) fertilizer rates at each application were determined via the exponential (E) function, $N_T = N_s\ (e^{rt}-1)$ (Timmer, V.R. & Aidelbaum, A.S. 1996). The fertilizer applied was Sulfa CAN™ (calcium ammonium nitrate) which contains 26.6% N and 5% Sulphur. Following fertilizer application each plot was irrigated with 26 L of water to ensure granules were dissolved into the bed before the subsequent soil coring which occurred 2 weeks following each application. Treatment plots were separated with 2 m buffers within the beds. The experiment was a randomized complete block design (RCBD) consisting of 4 replicate blocks.

Table 1. Fertilizer delivery schedule.

Nursery fertilization (N g plant^{-1})	Fertilizer delivery method
0	Conventional (C)
0.1	Exponential (E)
0.18	E
0.18	Standard (S)
0.5	E
1.0	E

Figure 2. a) Plot showing granules at 4th fert. application of 0.1 E treatment. b) Height of seedling receiving 1.0 g N at end of season.

Data collection and analysis

Height and root collar diameter data were collected on 4 and 3 different occasions, respectively, starting prior to fertilization. Seedlings were destructively sampled for dry weight determination and nutrient analysis prior to fertilization and again in late September. Data analysis was conducted using the mixed model analysis procedure (PROC MIXED) in SAS® (Version 9.1, SAS Institute, Inc., Cary, NC, USA).

Results

The 0.5 (E) treatment resulted in the greatest RDI and RDWI (Figure 3). N content increased with increasing fertilization rates, but P and K contents decreased at the highest rate (Figure 4, top). All treatment's N content, N concentration, and seedling dry weight increased relative to the control treatment (Figure 4, bottom).

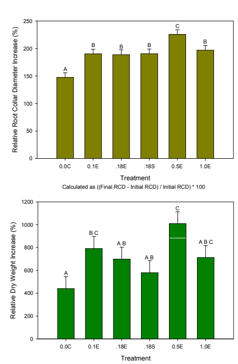

Figure 3. RDI (top) and RDWI (bottom) for six fertilizer treatments.

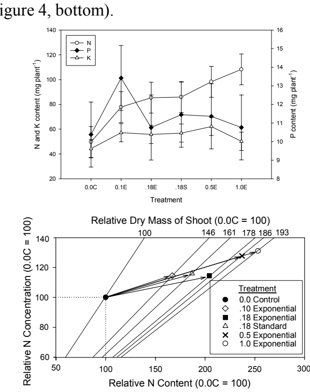

Figure 4. Seedling N,P, and K content (top) and vector nomogram (bottom).

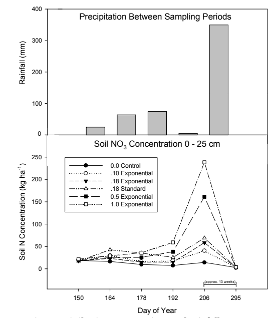

Figure 5. Soil NO_3 concentrations and rainfall amounts.

Table 2. Changes in soil properties and nutrients by treatment and over time (top). Soil N budget for one growing season (bottom).

Treatment	Organic Matter (%) 150*	Organic Matter (%) 206	Organic Matter (%) 295	P (ppm) 150	P (ppm) 206	P (ppm) 295
0 C	3.18 † ‡	3.38	3.30	120.75 A	111.00 A B	102.00 B
.10 E	3.33	3.35	3.48	130.25 A	115.75 A B	108.25 B
.18 E	3.15 A	3.35 AB	3.53 B	122.00 A	106.00 B	105.25 B
.18 S	3.13 A	3.38 AB	3.50 B	126.00 A	115.50 A	95.50 B
0.5 E	2.95 A	3.38 B	3.38 B	120.25 A	114.50 A B	101.75 B
1.0 E	3.08 A	3.53 B	3.20 A	117.00 A	104.50 A B	100.50 b

Treatment	Mg (ppm) 150	Mg (ppm) 206	Mg (ppm) 295	pH 150	pH 206	pH 295
0 C	146.25 A	168.75 B	146.25 A	7.15 A	7.38 B a	7.38 B a
.10 E	155.00	158.75	143.75	7.20 A	7.33 A B a	7.35 B a
.18 E	150.00	153.75	143.75	7.13 A	7.10 A b	7.33 B a
.18 S	142.50 A B	148.75 A	125.00 B	7.10 A	7.20 A B a b	7.25 B a
0.5 E	143.75 A B	156.25 A	132.50 B	7.20 A B	7.05 A b	7.23 B a
1.0 E	142.50 A B	155.00 A	118.75 B	7.23 A	6.80 B c	7.00 C b

† Means within the same row not followed by capital letters, or followed by the same capital letter are not significantly different at α = 0.05.

‡ Means within the same column not followed by lowercase letters, or followed by the same lowercase letter are not significantly different at α = 0.05.

* Julian Date

	Treatment 0.0 C	0.1 E	.18 E	.18 S	0.5 E	1.0 E
1 Initial Soil NO_3-N	30.5 †	35.9	30.2	33.0	31.4	34.8
2 Applied N	0.0	100.0	180.0	180.0	500.0	1000.0
3 N Mineralization	6.6	6.6	6.6	6.6	6.6	6.6
4 Plant N Uptake	31.8 A	64.2 A B	70.4 A	71.4 A	86.6 A	92.6 A
5 Residual Soil NO_3-N	5.3	9.6	4.8	6.5	7.4	7.8
6 Apparent N Loss (6 = 1 + 2 + 3 - 4 - 5)	0.0 A	68.6 B	141.6 C	141.8 C	444.0 D	941.0 E

† Means within the same row not followed by letters, or followed by the same letter are not significantly different at α = 0.05.

The 0.5 (E) and 1.0 (E) treatments continually raised soil NO_3 concentrations despite heavy amounts of precipitation early in the season (Figure 5). Soil organic matter increased in the .18 (E), .18 (S), and 0.5 (E) treatments, P concentration decreased in all treatments, Mg was highest prior to the last fertilizer application in all treatments, and pH was lowest in the 0.5 (E) and 1.0 (E) treatments prior to the last fertilizer application (Table 2, top). Apparent N loss was substantial and dependent upon the total amount of fertilizer applied. Apparent N losses for the .18 (E) and .18 (S) treatments were not significantly different (Table 2, bottom).

Future Directions

Root-growth-potential (RGP) will be used as a predictor of seedling performance upon outplanting. Fertilizer rates beyond 1.0 (E) will be applied next season to determine the sufficiency, nutrient loading, and optimum rates of fertilizer required by pedunculate oak.

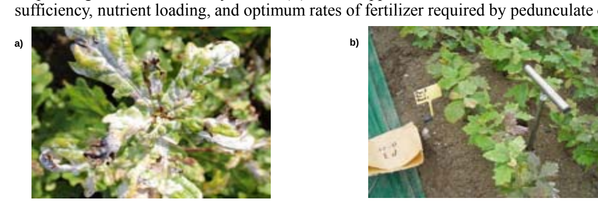

Figure 5. a) Mildew on seedling in study caused by cool temperatures and prolonged moist conditions. b) Collection of soil sample.

Conclusions

No significant RHI differences were seen across fertilizer treatments. RDWI was low for (C) and (S) seedlings, but high for 0.5 (E) seedlings compared to other treatments

Treatment differences in RDWI and RDI, but not RHI may have resulted from lateral growth due to poor apical dominance in pedunculate oak which was encouraged by thinning within the plots.

Lack of significant morphological response to (E) nutrient loading has been noted in other studies (Birge, et al., 2006; McAlilster & Timmer, 1998). However, improved outplanting performance of seedlings in the later study was noted for (E) loaded seedlings

Fertilizer treatment rates did not exceed the deficiency range for pedunculate oak. Apparent N losses were great and related to the amount of N applied. Applying the standard rate of fertilizer exponentially did not result in less N loss. Soil pH declined at higher fertilizer rates.

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