Effect of establishment fertilization on leaf area development of loblolly pine plantation stands in the southeastern United States

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Abstract

Loblolly pine plantations in the southeastern United States are some of the most intensively managed forest plantations in the world. Within intensive management one common practice is fertilizing a stand/site at establishment. The objective of this study was to investigate the effect of establishment fertilization on the leaf area development of loblolly pine planation stands across time. Sub-objectives included comparison of fertilized stands with stands that had no intervention and examination of whether identifying fertilized stands and no intervention stands could be applied across the landscape. To account for the size of the study area and different landscape types (elevation and proximity to a coast) the study area was also stratified by hardiness zone. Additionally, the study was stratified by soil type, specifically CRIFF (Cooperative Research in Forest Fertilization) groupings. Leaf area index (LAI) is a meaningful biophysical parameter and an important functional and structural element of a plantation stand. The Landsat satellite missions provides plantation managers and scientists a way to estimate LAI over time. Google Earth Engine (GEE) provides the ability to leverage the Landsat archive to obtain LAI estimates over large areas and through time. Stand boundaries were buffered inwards 30m to minimize mixed pixels and to match the spatial resolution of Landsat. LAI was computed (using: SR * 0.3329155 - 0.00212) to create trajectories of mean Stand LAI over time for analysis.

Introduction

Leaf area index (LAI) is an important biophysical parameter used to monitor, model and manage loblolly pine plantations across the southeastern US. The Landsat platform provides the ability to obtain accurate and timely LAI estimates. The forested landscape in the southeastern United States (US) has been undergoing significant shifts in forest type and species representation. From 1952 to 2010 there was an increase of 38 million acres of planted pine and in 2016 it was reported that there were 37 million acres of planted loblolly pine in the south. Nutrient deficiencies across the south are addressed through fertilizations and other intensive management strategies. To assess the impact of fertilizations, crews have to check each stand, which is expensive and time consuming. Using satellite data we can measure fertilization impact remotely and more often. This study is looking to determine whether length of fertilization effect can be determined and if the two treatment types can be separated using remotely sensed data.

Methods and Materials

- Using ArcMap identify Stands within IP Dataset which have the following attributes:
  - Major species: loblolly pine
  - Secondary species: none
  - Year established: 1990-1999
  - Year Fertilized: within 2 years of year established or none
  - Soil code: any non-blank record
  - Year of last vegetation management: none
  - Year of last harvest: none or before year established
- The LAI model by Blinn et al. (2019) was applied in Google Earth Engine to the resulting stand shapefiles for the study area.:
  - LAI = SR * 0.3329 – 0.00212
- The mean stand winter median LAI was extracted for each year 1990-2018.
- Stands were separated by treatment type, soil CRIFF groups, and hardiness zone.
- Each stand was zeroed to its recorded establishment year and the following ten years' values were evaluated. Results show in Figure 1.

Figure 1. Treatment type comparison. Above 0 fertilized treatment group is statistically significant.

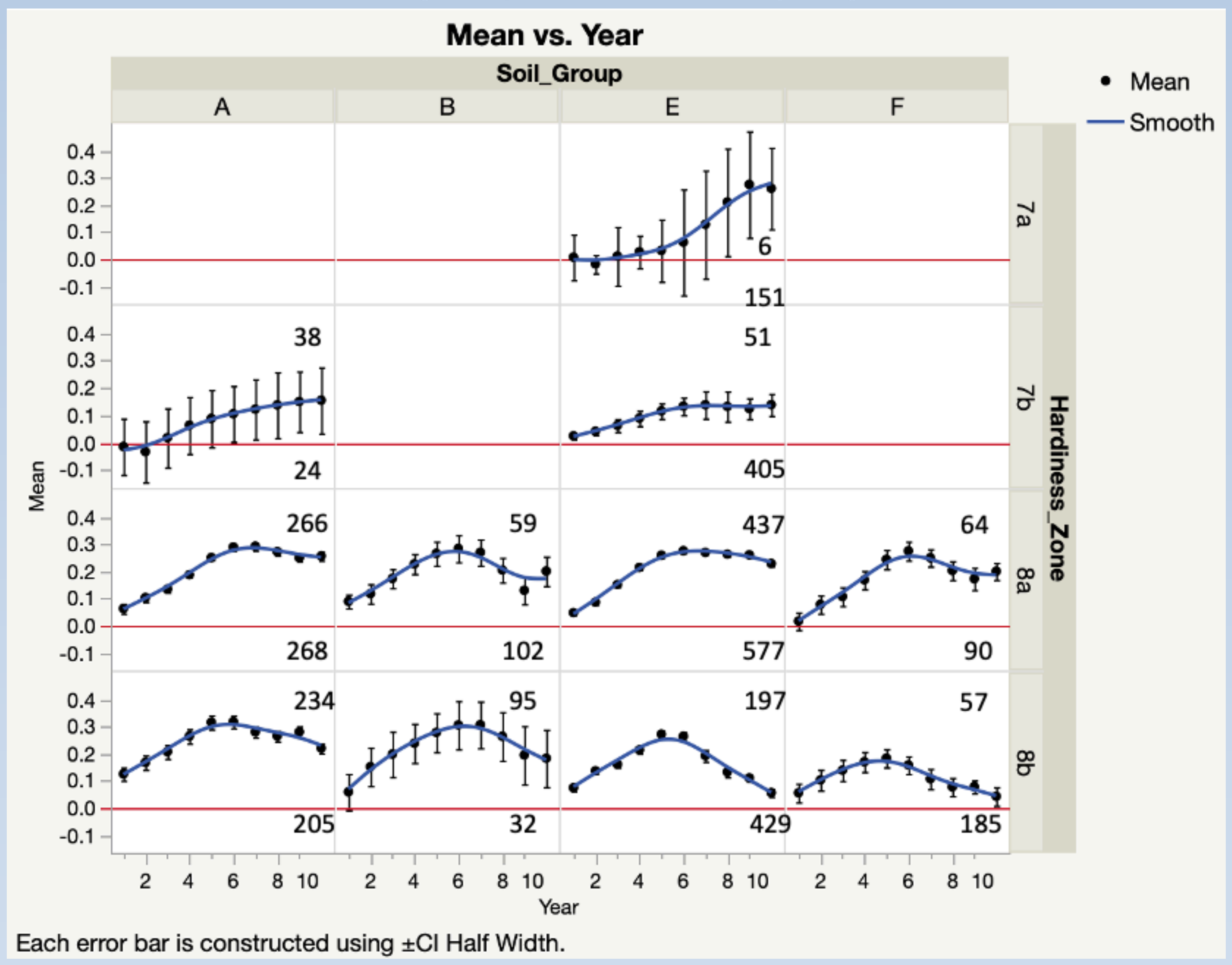


Table 1. Two selected soil type, hardiness zone combinations and statistical significance

Hardiness Zone	Soil Group	Method	Variances	t Value	DF	Pr > |t|	F Value	Pr > |F|	Mean	Lower Limit of Mean	Upper Limit of Mean	Year Significant
8a	A	Satterthwaite	Unequal	6.91	319.88	<.0001	4.69	<.0001	0.0631	0.0451	0.081	1
8a	A	Satterthwaite	Unequal	13.11	341.26	<.0001	3.7	<.0001	0.1038	0.0882	0.1193	2
8a	A	Satterthwaite	Unequal	22.23	308.9	<.0001	5.4	<.0001	0.1344	0.1225	0.1462	3
8a	A	Satterthwaite	Unequal	42.42	426.15	<.0001	1.82	<.0001	0.1877	0.179	0.1964	4
8a	A	Satterthwaite	Unequal	54.16	489.94	<.0001	1.51	0.0014	0.2512	0.242	0.2603	5
8a	A	Pooled	Equal	47.14	494	<.0001	1.21	0.1404	0.2899	0.2778	0.302	6
8a	A	Satterthwaite	Unequal	38.16	460.65	<.0001	1.37	0.0127	0.2929	0.2778	0.3079	7
8a	A	Satterthwaite	Unequal	39.59	462.84	<.0001	1.35	0.0195	0.2729	0.2593	0.2864	8
8a	A	Pooled	Equal	40.41	494	<.0001	1.15	0.2839	0.2502	0.238	0.2623	9
8a	A	Satterthwaite	Unequal	31.29	467.89	<.0001	2.05	<.0001	0.2569	0.2407	0.273	10
7b	A	Satterthwaite	Unequal	-0.26	31.592	0.7934	3.43	0.0008	-0.0133	-0.1159	0.0893	Not Significant
7b	A	Satterthwaite	Unequal	-0.26	31.592	0.7934	3.43	0.0008	-0.0133	-0.1159	0.0893	Not Significant
7b	A	Satterthwaite	Unequal	-0.58	30.069	0.5643	4.17	0.0001	-0.0319	-0.1435	0.0798	Not Significant
7b	A	Satterthwaite	Unequal	0.35	33.632	0.7252	2.76	0.0058	0.0188	-0.0892	0.1268	Not Significant
7b	A	Pooled	Equal	1.35	60	0.1827	1.86	0.0896	0.0645	-0.0312	0.1601	Not Significant
7b	A	Pooled	Equal	1.81	60	0.0746	1.61	0.1898	0.0891	-0.00911	0.1873	Not Significant
7b	A	Pooled	Equal	2.27	60	0.0266	1.91	0.0766	0.1063	0.0128	0.1999	6
7b	A	Satterthwaite	Unequal	2.28	32.419	0.0292	3.12	0.002	0.123	0.0133	0.2327	7
7b	A	Satterthwaite	Unequal	2.35	31.721	0.0249	3.38	0.001	0.1385	0.0186	0.2584	8
7b	A	Satterthwaite	Unequal	2.77	35.269	0.0088	2.38	0.018	0.1508	0.0405	0.2611	9

Figure 2. Study area states & stand extent across study area.

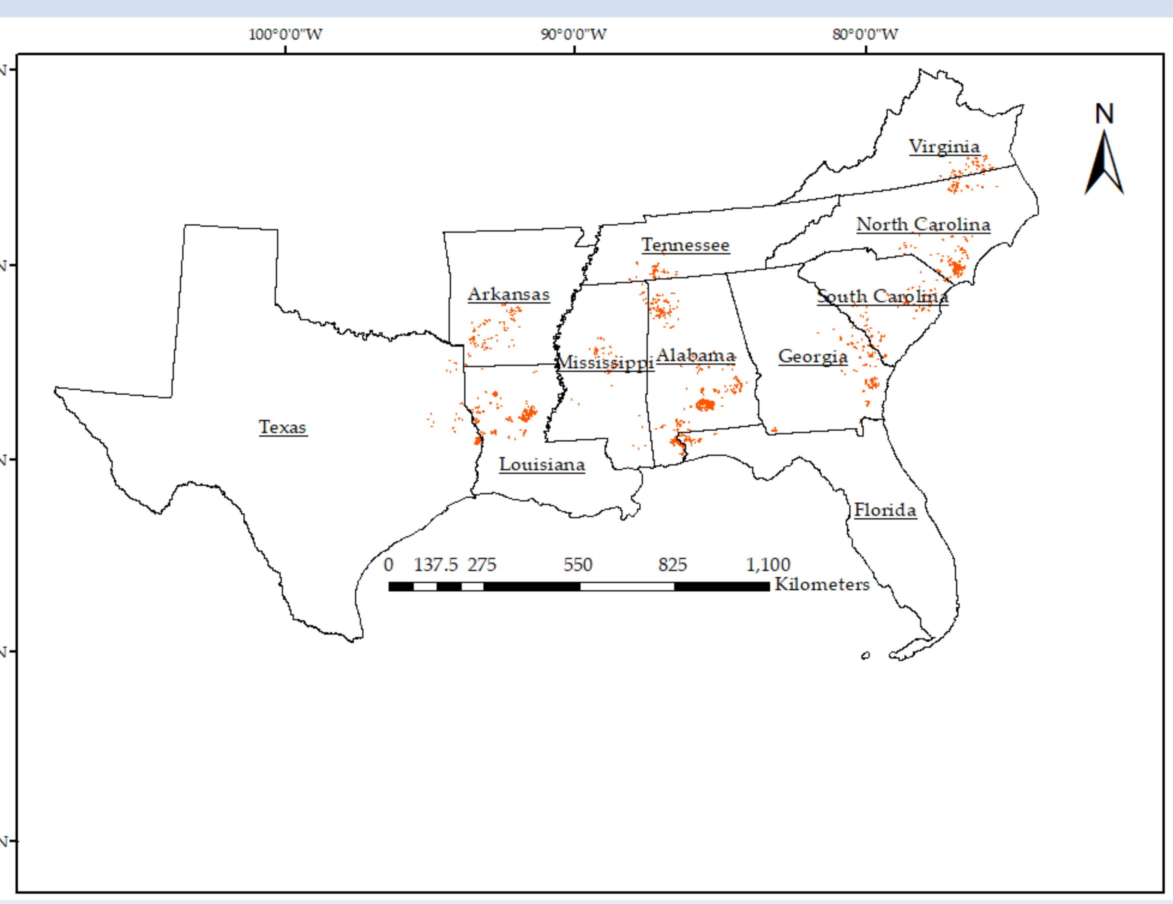


Figure 3. Extent of hardiness zone across study area.

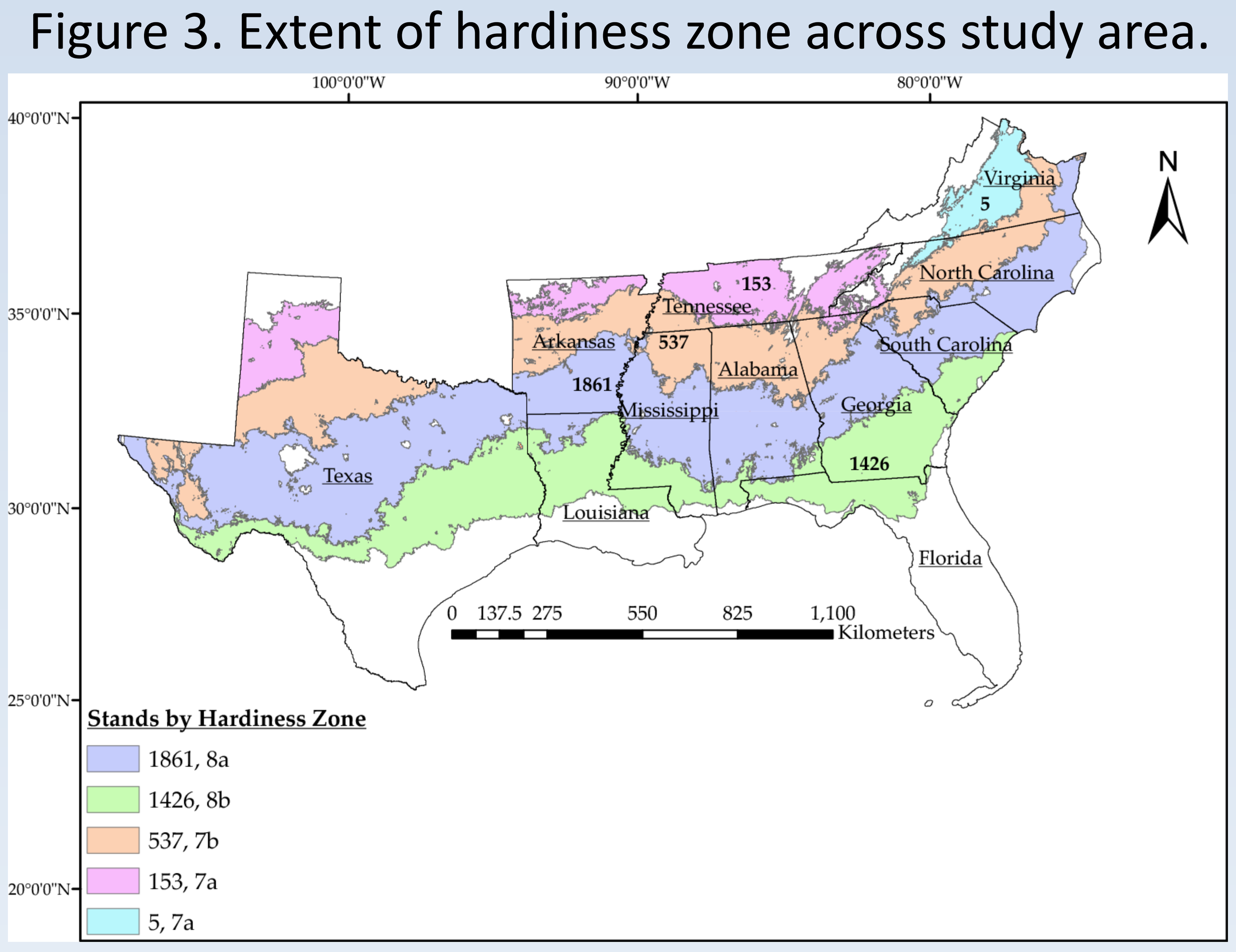
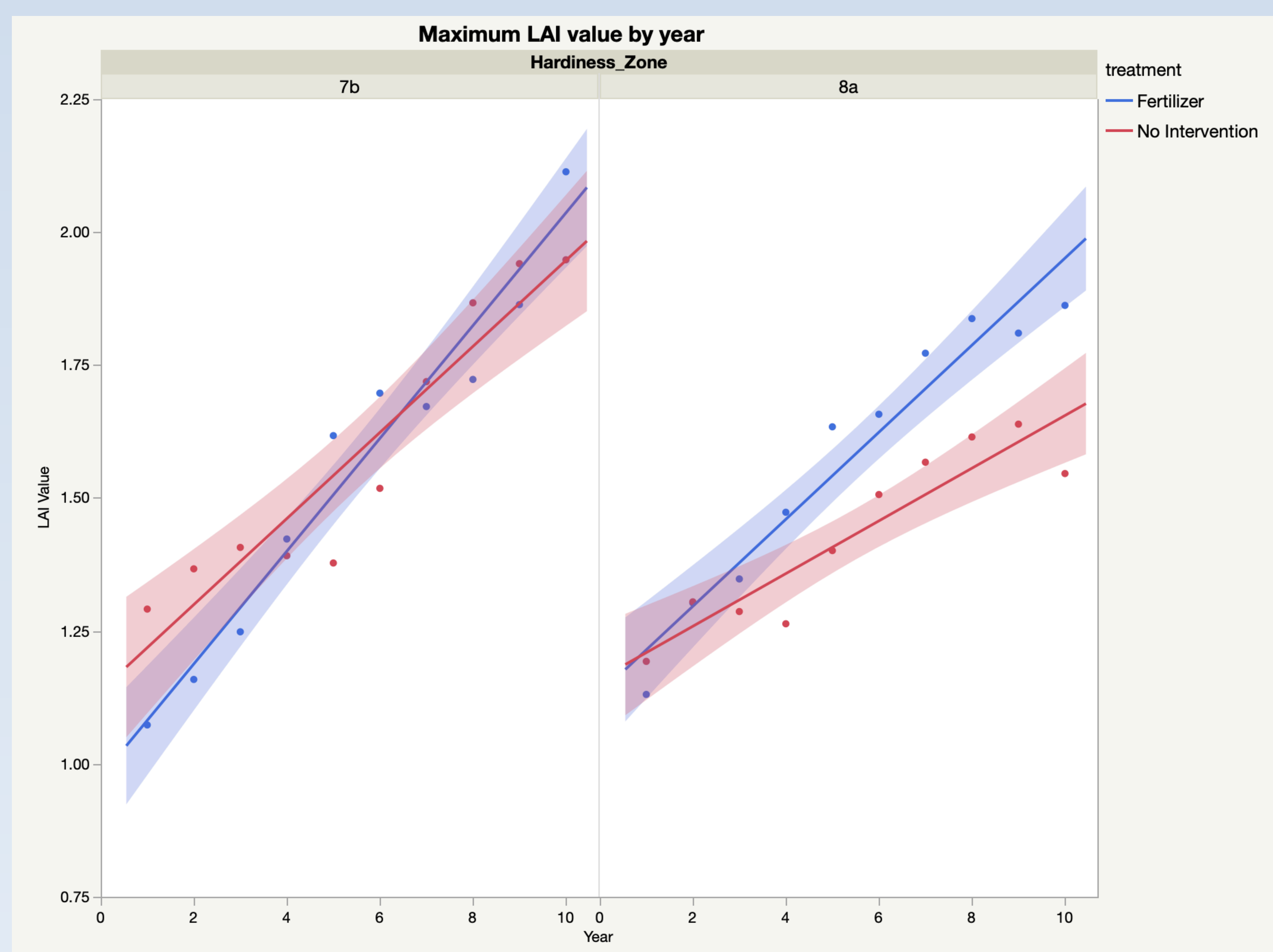


Figure 4. 7b and 8a soil type A max LAI value by year.



Results

Figure 1 shows the fertilized stands above zero and the no intervention stands below zero. Across all soil types and hardiness zones, there is a statistically significant difference between treatment types, with fertilized stands preforming better across time. For hardiness zones 8a and 8b, fertilized stands seem to peak in their difference between year 6 and 8. This is in line with research stating that fertilizer effects last up to 8 years. In figure 2, the extent of the stands can be discerned across the study area and in figure 3, the area of each hardiness zone can be determined. Hardiness zones 7a and 7b in figure 3 are relatively small across the study area and when compared to figure 2 it can be seen why there are fewer stands in those zones, as it is on the edge of loblolly's native range. For example, Arkansas stands seem to follow the line of separation between hardiness zones 7b and 8a, with most if not all stands falling in hardiness zone 8a. In hardiness zones 7a and 7b, the year of significance did not appear until year 7 or year 6 (table 1), where all other soil hardiness zone combinations were significant at year one (except 8aF was significant at year 2). Figure 4 is showing the maximum LAI value by year for the two hardiness zone soil type combinations show in table 1.

Discussion

We find that Google Earth Engine can access the Landsat archive to conduct reliable and reproducible analyses over time and over large areas, such as this study's area. Through experimentation, we found that if someone wanted to evaluate a single stand for growth over time, that it would be possible to get all values for the pixels in that stand for each year. This study could be repeated on different species types and in different locations, as long as the right metrics were used for species and region.

When compared to field trials, this study is a much larger sample both in area and number of stands. Using remote sensing, a researcher is no longer limited to single stand treatment trials and long lead times. If treatment type and timing is known, remote sensing can evaluate the effects over time, when using a biophysical parameter with researched ties to the species being evaluated such as LAI and loblolly pine.

Using a method such as this, it may be possible to predict when a stand has utilized the nutrients provided by the establishment fertilization. This way companies with large land holdings could assess which stands need additional fertilization treatments or at least which stands need further evaluation as to why their growth is not progressing as expected.

One further study could evaluate site index as it relates to remotely sensed LAI. Would it be possible to predict site index based on known treatment type, whether or not it was fertilized, what soils are present on the site and which hardiness zone the site is in?