UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-20-77C

September 2020

Tree Nitrogen Content & Growth

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Nitrogen stress and deficiency in trees can initiate early senescence and abscission of leaves. This process remobilizes nitrogen compounds within tissues to be shed and pulls nitrogen back into twig, branch, and stem areas behind shed leaves. Approximately 60% of nitrogen in a tree is remobilized and reallocated on an annual basis.

The internal living environment of a tree carefully stores and uses nitrogen materials. Nitrogen, for the most part, remains portable and transportable to where needs are greatest and conservation most sure. Nitrogen is a valuable prize for a tree, once captured it is carefully protected from loss.

For example, Figure 1 provides the average relative amounts of nitrogen in above ground parts of four temperate hardwoods. Most of the nitrogen content of a tree's above ground parts is positioned within leaves. The nitrogen content within the periderm is primarily within the secondary cortex. Figure 2 shows one example of relative nitrogen distribution and annual changes within a tree. Note the soil organic matter in the tree / soil system represents 82% of all reduced nitrogen present. Figure 3 is another similar example of relative amounts of reduced nitrogen within a tree, and how changes occur during a year on an average site.

In The Pool

Another way to visualize nitrogen in trees is to compare carbon stock (CHO) versus nitrogen content proportions. The tree maintains three compartments or pools for carbon and nitrogen:

1) fine roots (0.5% of total tree weight, 35% of tree nitrogen);
2) leaves and buds (0.5% of total tree weight, 50% of tree nitrogen);
3) storage reserves (99% of total tree weight, 15% of tree nitrogen).

Average tree nitrogen contents (dry weight basis) under an intensively managed landscape regime are: 2.25% leaves; 1.25% stem; and, 1.75% roots. An appropriate nitrogen percent measured in woody angiosperm tissue to use as a target is ~1.75%. Gymnosperm tissue target is ~1.3% nitrogen in tissue.

A strong combined carbon and nitrogen balance in a tree will: maintain good vigor; improve tree reactivity to changes; decrease effectiveness of pests; and, decrease the chances of environmental damage to a tree. Changing the balance among these three carbon and nitrogen compartments can radically change tree growth dynamics. For example, nitrogen enrichment can decrease both internal and external nitrogen fixation, reduce symbiotic associations, and advance pests.

Think Trees

The unique features of trees and their interactions with nitrogen, allow a tree health care provider to better care for tree and site resources. Specific tree features manipulated by health management include: shoot/root ratios; skin/core aspects; and, growth rate concerns. Each of these features affect and are effected by nitrogen availability in a tree and on a site. A number of physiological and pest effects in trees can be synthesized to provide an understanding of whole tree nitrogen.

Shoot / Root Balance

Nitrogen up-take and use in a tree have been examined using shoot/root models. The most tested and effective is called a Thornley model. To recognize resource allocation patterns in trees between shoot and root (approaching a functional balance), only four components are required: sapwood shoot mass, sapwood root mass, photosynthesis rate, and nitrogen uptake rate. Figure 4.

Trees attempt to balance shoot mass and photosynthesis rates against root mass and nitrogen uptake. A tree will adjust living mass of roots or shoots to correct any deficiency in photosynthesis rates or nitrogen uptake rates. Carbohydrate shortages and/or nitrogen increases will initiate more shoots — nitrogen shortages and/or carbohydrate increases will initiate more roots.

Balancing Disaster

Both benchmark processes (and associated tissue masses) in the Thornley model must always be functionally balanced across a tree. For example, as nitrogen absorption declines, what nitrogen remains is concentrated more in roots and used preferentially. This leads to less shoot growth and more root growth. Even before growth is noticeably reduced, a tree is reallocating nitrogen to vital processes. One vital need is for absorbing roots where more rapid turn-over is occurring as nitrogen concentrations fall.

With nitrogen enrichment, root growth declines and shoot growth increases. In addition, added nitrogen causes a decline in starch storage and an increase in transport sugars. Increased sugar contents and additional nitrogen availability generate improved access and attack conditions for pests.

Skin / Core Games

Nitrogen needs of a tree are affected by many circumstances. One of the most significant, but often overlooked conditions changing nitrogen requirements, is the fundamental perennial growth form of a tree. When trees are young, their whole mass is filled with living cells with significant nitrogen demands. As trees age, they begin to shed inefficient parts and tissues, concentrating nitrogen into those tissues that provide positive benefits to the whole organism. The shedding process includes branch self-pruning, leaf and twig abscission, and heartwood formation.

Parts of a tree, including inner core areas, are shed to minimize total respiring mass of a tree. This concept of a living active skin over a dead core has been successfully tested in trees. Figure 5. Trees have a much smaller living mass than outward size would suggest. Constant nitrogen loads (or increasing loads) after a tree has reached its full site respiration load and begins to shed can be wasteful of the nitrogen resource added and disrupt effective tree functions. The skin / core model well represents tree reactivity to internal and external changes in resources.

Nitrogen Demands

The skin / core model of tree growth can be used to approximate the living mass of a tree and its nitrogen demands. The skin / core ratio can be estimated by calculating the mass of nitrogen in a tree (an estimate of the skin portion) divided by an estimate of the remaining mass of a tree (the core estimate). This process has shown young trees have skin/core ratios of 1.0, while older trees with branch shedding and heartwood development approach a skin/core ratio value of 0.66, or less. The results of the skin / core model shows nitrogen demand is not represented by a tree's entire mass, but by some exterior, living, nitrogen using portion of that mass. Nitrogen additions should be tuned to actual living mass needs.

Growth Rate Changes

Another critical feature of nitrogen requirements in a tree involves annual growth rates and timing of growth periods. Because of its rarity in nature, nitrogen will be taken-up in the best and most expedient way possible. Sometimes nitrogen uptake occurs at the cost of other processes, regardless of growth and time of the growing season. Nitrogen is most important for actively growing tissues, but it is also needed for maintenance activities. The growth rate of a tree is both a cause and effect of nitrogen uptake and use.

Trees continue to grow, but eventually reach biological and physical limits to total living mass on any particular site. Figure 6. At this point, growth rates (percentage rate of growth) begin to decline. Annual increment radial thickness declines for trees even if the same total amount of wood is being produced. The same amount of wood grown over a larger surface spreads out growth and decreases annual increment (growth ring) width. Figure 7. As site resources are gathered and controlled, less resources may be available, greatly decreasing growth rates and nitrogen needs. As absolute growth rates decline, nitrogen requirements decline.

Have An Episode

Nitrogen requirements in a tree also are affected by episodic growth of different tree parts. Although generic in their nature, seasonal growth models can help clarify nitrogen requirements in different areas of a tree over the year. Those tissues actively growing with significant carbon supplies, can most readily assimilate any nitrogen additions. Figure 8. This period is just after full leaf expansion.

Minimizing waste of nitrogen resources, preventing competitors and pests from utilizing available nitrogen, and ensuring a tree can effectively handle added nitrogen are all critical management features. Use nitrogen enrichment when total biological costs / benefits are lowest for a tree. In addition, be sure nitrogen enrichment activities do not damage surrounding natural resources or reach untargeted organisms or areas.

Whole Tree Reactivity

Whole tree reactions to significantly increased nitrogen levels through enrichment include increased growth, size, and amino acid content. There is a resulting interaction between increased pest effectivness and decreased production of defensive materials within a tree. Generally, shoots are emphasized over roots and food storage. Figure 9. Whole tree reactions to nitrogen shortage is not simply opposite to high nitrogen reactions. Tree reactions to nitrogen shortages include decreases in most growth except for absorbing roots. Figure 10. Food storage is given priority.

tree part	relative tree nitrogen concentrations
leaf	68%
branch	9%
stem	9%
sapwood	6%
heartwood	3%
periderm	14%

Figure 1: Average relative nitrogen distribution in above ground parts for four species of hardwoods (dogwood, red maple, red oak, yellow-poplar).

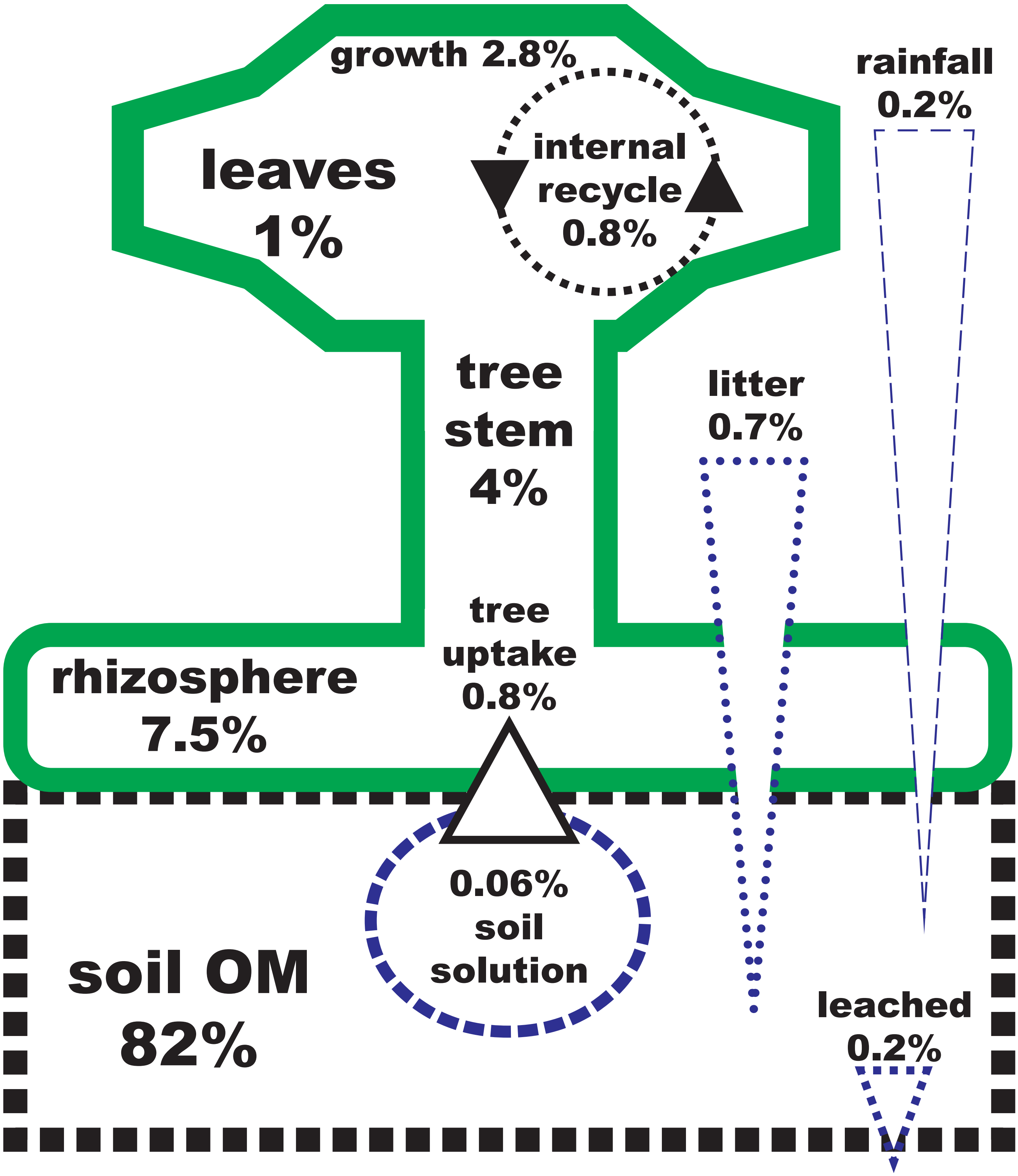

Figure 2: Relative reduced nitrogen distribution and annual changes within a tree / soil system with soil organic matter (OM) set at 82% of site's reduced nitrogen pool.

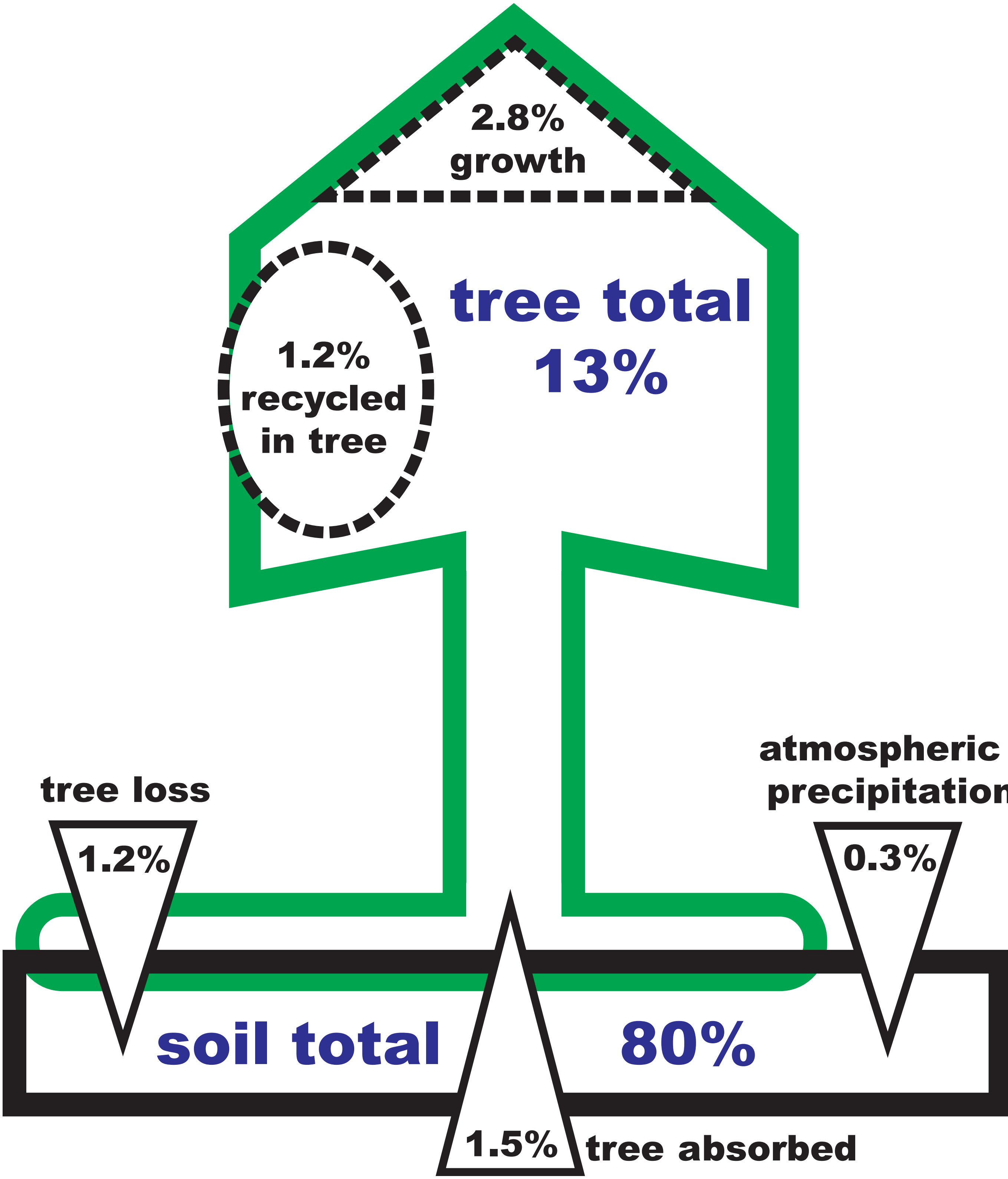

Figure 3: Relative reduced nitrogen distribution and annual changes within a tree / soil system.

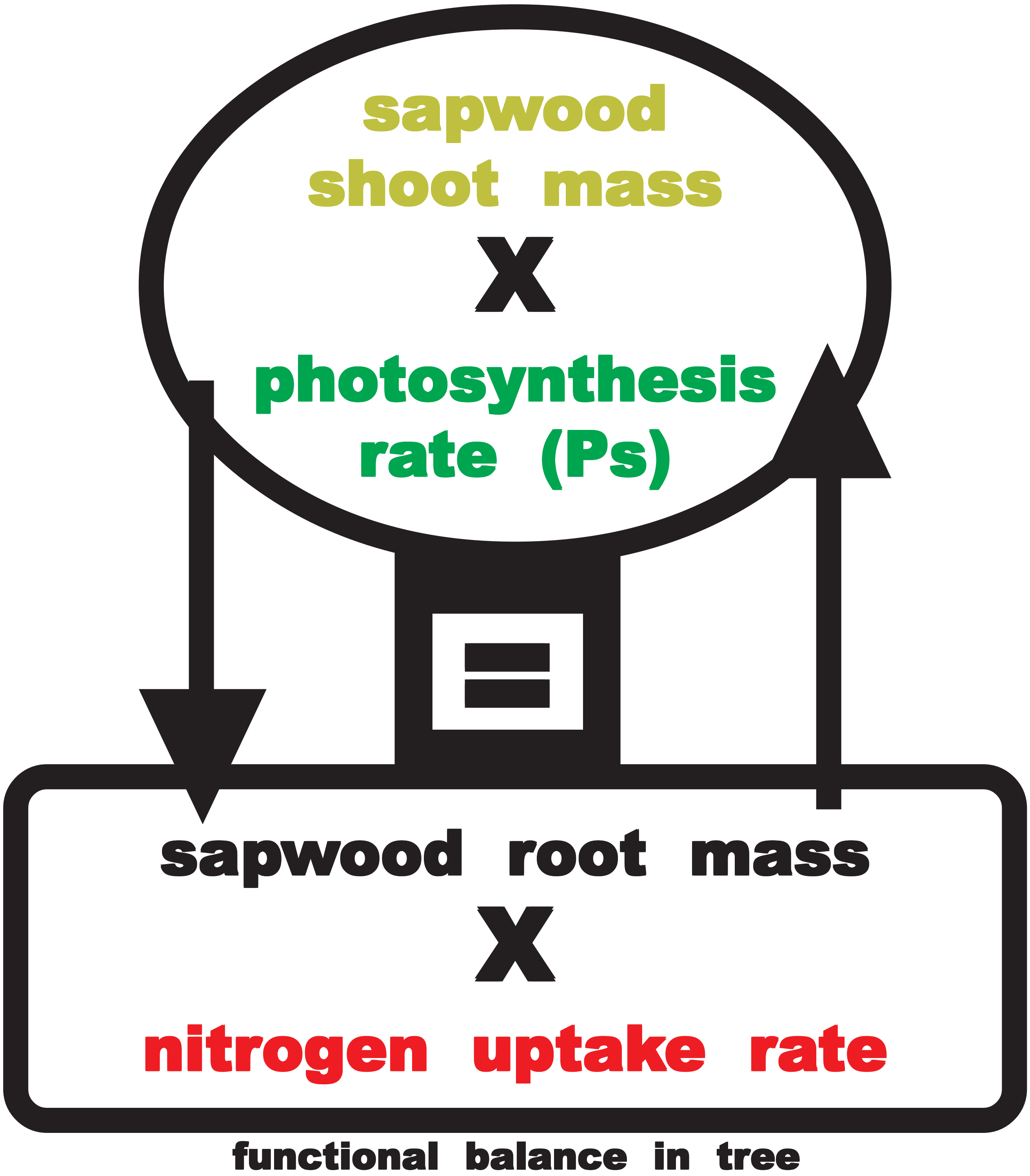

Figure 4: A Thornley model of functional balance between living components of shoot and root systems within a tree, dependent upon interacting nitrogen uptake rate and photosynthetic rate.

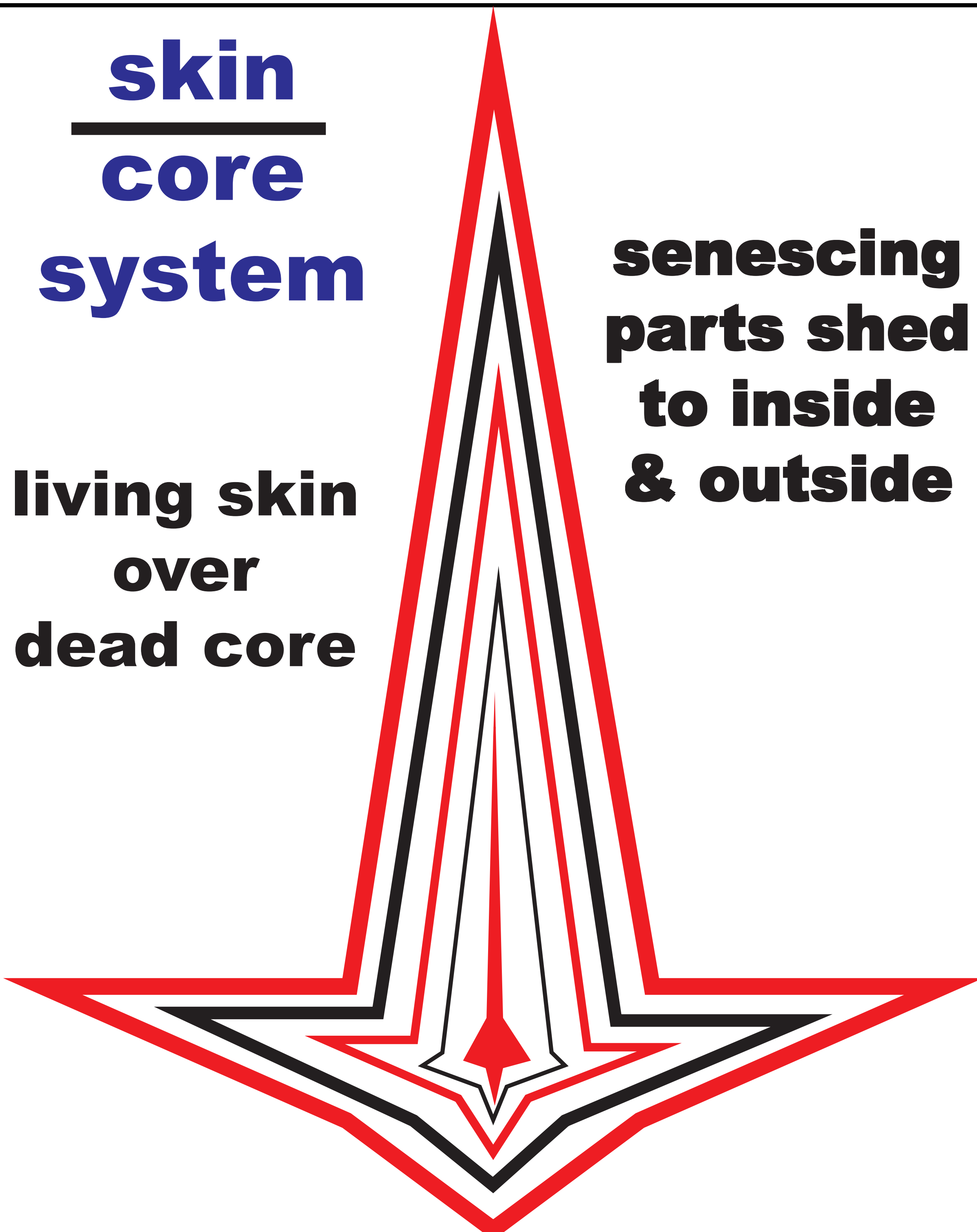

Figure 5: Tree annual growth is a thin sheath of living tissue over a framework of previous growth increments. More exterior sapwood area is functionally proportional to productivity, and inversely proportional to tree stress.

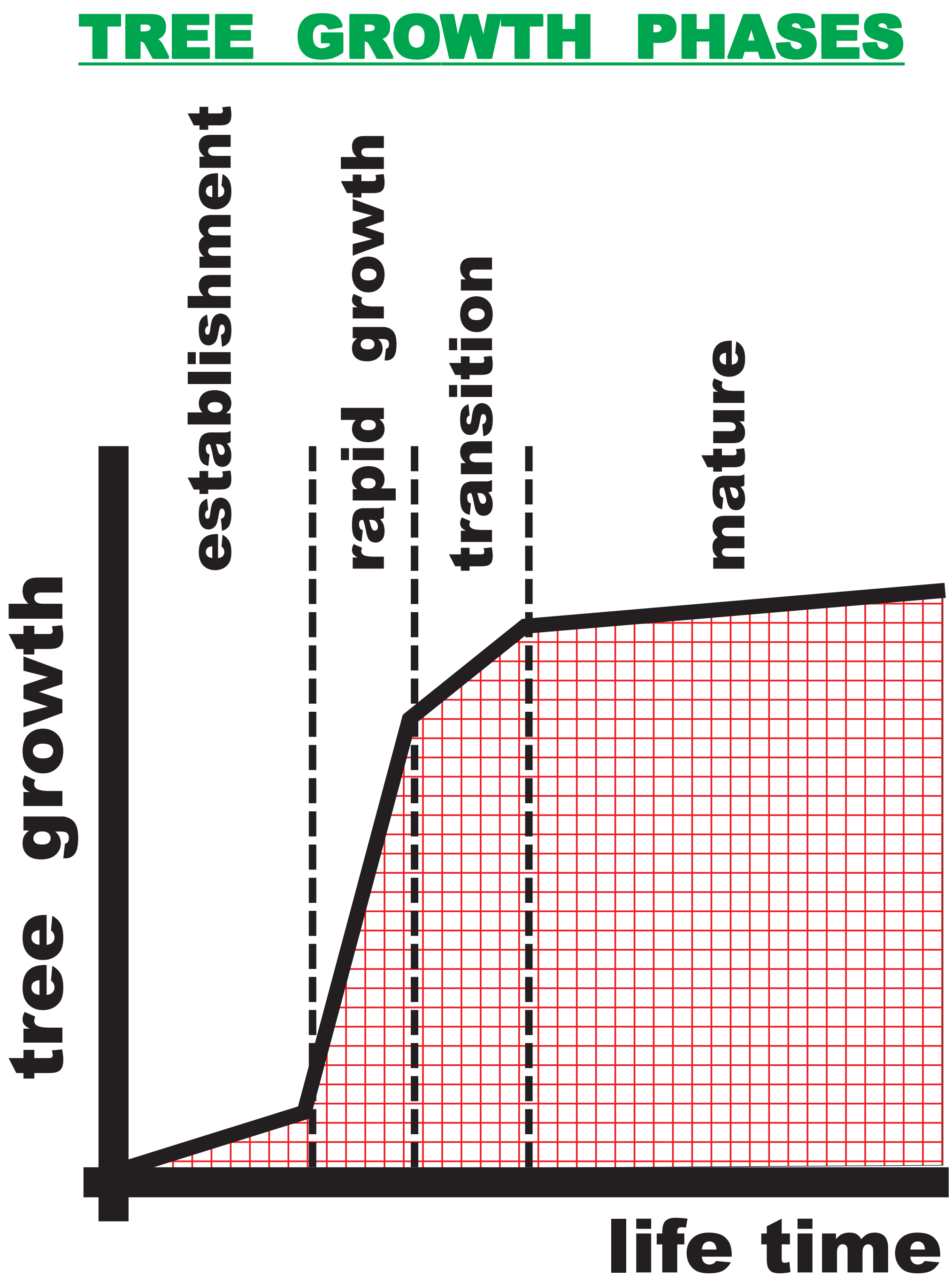

Figure 6: Tree growth phases over its life.

DBH	R1	R1.5	R2	R2.5	R3	R4	R5	R7.5	R10	R12.5	R15	R17.5	R20
6 in	16 in^2	11	8.6	7.0	5.9	4.5	3.6	2.5	1.9	1.5	1.2	1.1	0.9
7	19	13	10	8.3	7.0	5.3	4.3	2.9	2.2	1.7	1.4	1.2	1.1
8	22	15	12	9.6	8.0	6.1	4.9	3.3	2.5	2.0	1.6	1.4	1.2
9	25	17	13	11	9.1	6.9	5.5	3.7	2.8	2.2	1.9	1.6	1.4
10	28	20	15	12	10	7.7	6.2	4.1	3.1	2.5	2.1	1.8	1.6
11	31	22	17	13	11	8.4	6.8	4.5	3.4	2.7	2.3	2.0	1.7
12	35	24	18	15	12	9.2	7.4	5.0	3.7	3.0	2.5	2.1	1.7
13	38	26	20	16	13	10	8.0	5.4	4.1	3.2	2.7	2.3	2.0
14	41	28	21	17	14	11	8.7	5.8	4.4	3.5	2.9	2.5	2.2
15	44	30	23	18	15	12	9.3	6.2	4.7	3.7	3.1	2.7	2.3
16	47	32	24	20	16	12	9.9	6.6	5.0	4.0	3.3	2.9	2.5
17	50	34	26	21	17	13	11	7.0	5.3	4.3	3.5	3.0	2.7
18	53	36	28	22	19	13	11	7.5	5.6	4.5	3.7	3.2	2.8
19	57	38	29	23	20	15	12	7.9	5.9	4.8	3.9	3.4	3.0
20	60	41	31	25	21	16	12	8.3	6.3	5.0	4.1	3.6	3.1
21	63	43	32	26	22	16	13	8.7	6.6	5.3	4.3	3.8	3.3
22	66	45	34	27	23	17	14	9.1	6.9	5.5	4.5	3.9	3.4
23	69	47	35	28	24	18	14	9.6	7.2	5.8	4.8	4.1	3.6
24	72	49	37	30	25	19	15	10	7.5	6.0	5.0	4.3	3.8
25	75	51	39	31	26	19.	16	10	7.8	6.3	5.2	4.5	3.9
26	79	53	40	32	27	20	16	11	8.1	6.5	5.4	4.7	4.1
27	82	55	42	33	28	21	17	11	8.5	6.8	5.6	4.8	4.2
28	85	57	43	35	29	22	18	12	8.8	7.0	5.8	5.0	4.4
29	88	59	45	36	30	23	18	12	9.1	7.3	6.0	5.2	4.5
30	91	61	46	37	31	23	19	13	9.4	7.5	6.2	5.4	4.7
31	94	64	48	39	32	24	19	13	9.7	7.8	6.4	5.6	4.9
32	97	66	50	40	33	25	20	13	10	8.0	6.6	5.7	5.0
33	101	68	51	41	34	26	21	14	10	8.3	6.8	5.9	5.2
34	104	70	53	42	35	27	21	14	11	8.5	7.0	6.1	5.3
35	107	72	54	44	36	27	22	15	11	8.8	7.2	6.3	5.5
36	110	74	56	45	37	28	23	15	11	9.0	7.5	6.4	5.6
37	113	76	57	46	38	29	23	15	12	9.3	7.7	6.6	5.8
38	116	78	59	47	39	30	24	16	12	9.5	7.9	6.8	6.0
39	119	80	61	49	41	30	24	16	12	9.8	8.1	7.0	6.1
40	123	82	62	50	42	31	25	17	13	10	8.3	7.2	6.3
45	138	93	70	56	47	35	28	19	14	11	9.3	8.1	7.1
50	154	103	78	62	52	39	31	21	16	13	10	9.0	7.8
55	170	114	86	69	57	43	34	23	17	14	11	9.9	8.6
60	185	124	94	75	62	47	38	25	19	15	12	11	9.4
65	201	135	101	81	68	51	41	27	20	16	14	12	10
70	217	145	109	88	73	55	44	29	22	18	15	13	11
75	233	156	117	94	78	59	47	31	24	19	16	13	12
80	248	166	125	100	83	63	50	33	25	20	17	14	13
85	264	177	133	106	89	67	53	36	27	21	18	15	13

Figure 7: Area increase in cross-sectional inches per single growth increment by tree diameter (DBH). Diameter growth rate ranges from 1.0 growth increment per inch (R1) to 20 growth increments per inch (R20).

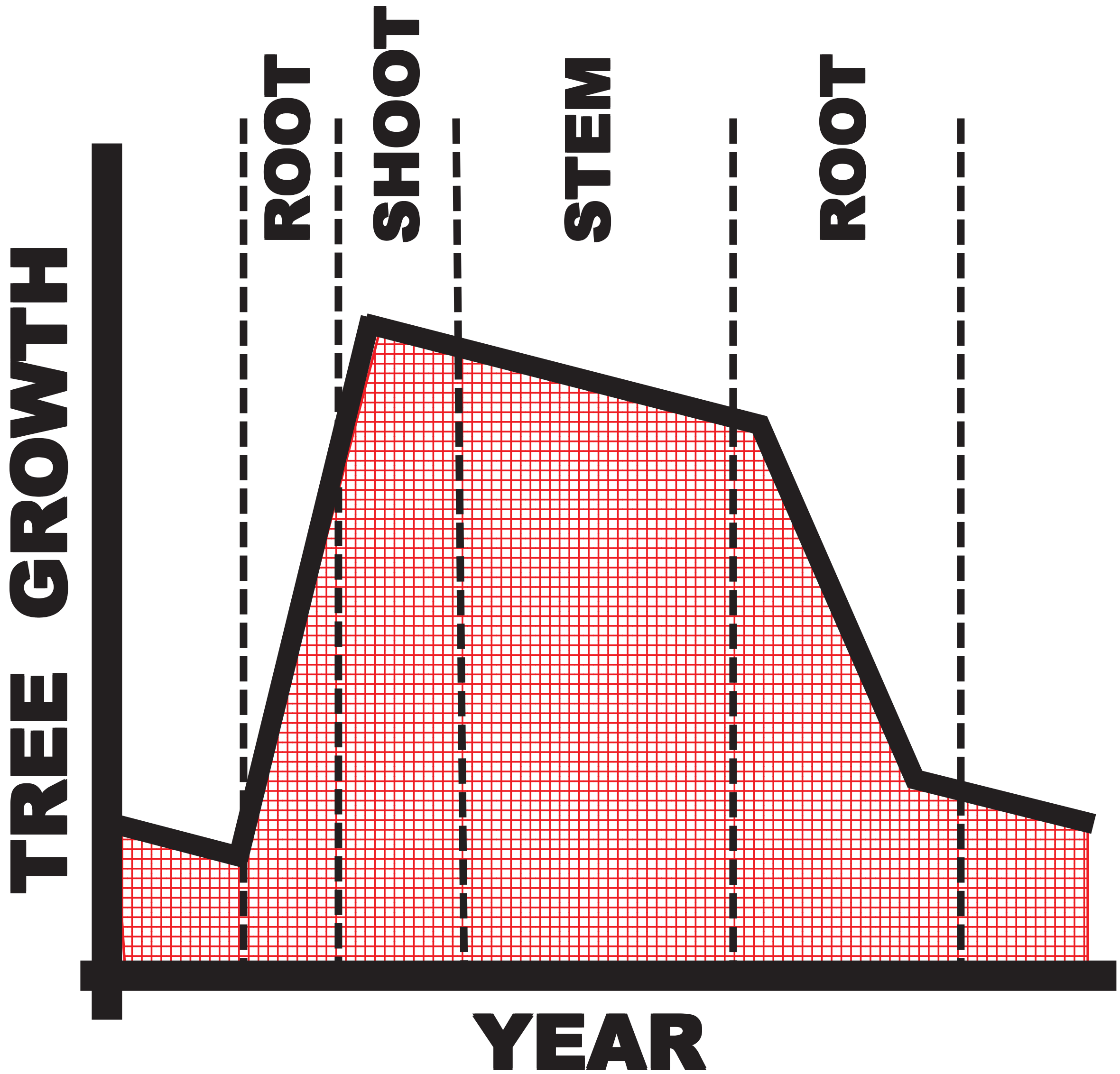

Figure 8: Generalized tree energy requiring and energy producing activities summarized over a growing season, divided among root, stem, and shoot components.

Whole Tree Reactions
INCREASED Nitrogen:

— Increased shoot size.
— More foliage growth stimulated.
— Photosynthesis & stomates sensitive to water stress.
— Lengthened growing season.
— Increased amino-nitrogen content.

— Decreased starch in whole tree.
— Increased pest effectiveness.
— Decreased defensive materials produced.
— Carbon allocation to fine roots delayed.
— Decreased carbon allocation to roots.

— Root carbon storage reduced.
— Root sugar concentrations increase.
— Decreased root reactivity to damage and stress.
— Reduced cold tolerance in root system.
— Increases stored starch use -- not always photosynthesis increase.

Figure 9: Whole tree reactions to moderate / large concentrations of nitrogen availability and uptake.

Whole Tree Reactions Nitrogen SHORTAGE:

— **Decreased overall growth of tree.**
— **Increased total storage reserves.**
— **More sulfur containing proteins made.**
— **More fine root production.**

— **Increased root weights.**
— **More carbon allocated to fine roots.**
— **Shortened time span of fine root growth.**
— **Earlier seasonal carbon storage in roots.**

Figure 10: Whole tree reactions to low concentrations / slight deficiency of nitrogen availability and uptake.

Citation:

Coder, Kim D. 2020. Tree Nitrogen Content & Growth. University of Georgia, Warnell School of Forestry & Natural Resources Outreach Publication WSFNR20-77C. Pp.14