Construction Damage Assessments: Trees and Sites

by Dr. Kim D. Coder, University of Georgia October 1996

A key component in assessing development impacts on trees is the systematic evaluation of damage. Many types of damage occur repeatedly over a site, and from site to site. This constant and repetitive damage comes from fundamental anti-tree and tree-illiterate activities. Under scrutiny of a systematic assessment, these patterned damage forms can be prevented or minimized. Some types of damage (one-time, one-spot, chance occurrences) can be assessed but are difficult to prevent. By attempting to categorize damage, patterns can be recognized and steps taken to minimize tree injury and site degradation. Please note that many development activities and the continued presence of good tree quality are mutually exclusive (spacially and temporally). Decisions must be made early in the planning process to maintain tree quality of life and minimize injury.

As development activities occur on a site, continually monitor damage to tree quality and site resources. Develop a damage class assessment to quantify managerial responses and to project expected tree life-spans and losses. Expected tree reactions to construction damage vary from: immediate and out-right death; single-year decline and death; multiple-year decline and death; and, decline with major living mass loss. The latter two are the most common expectations among residual trees, and the most difficult to prove a cause-and-effect relationship with construction activities.

One method of summarizing construction damage into a number of classes is provided below in order of decreasing severity and likelihood. Assessment tools are provided to allow a precise and objective means to gauge damage. No assessment tool replaces an experienced, tree-literate professional observer.

Class 1 -- General root system destruction
- A) rooting area loss (surface area and volume) -- TOOL #1, #2, #3
- B) critical rooting distance violations (trenching) -- TOOL #4, #5
- C) open soil surface area loss -- TOOL #6

Class 2 -- Root collar and structural support root damage -- TOOL #7, #8
- A) root plate area and the zone of rapid taper (ZRT)
- B) exposed large structural roots

Class 3 -- Mechanical / structural damage to stem -- TOOL #9
- A) chemical or fire damage
- B) wood damage
- C) bark disruption
- D) hardware / signage damage

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Class 4 -- Soil surface problems (top 12 inches) -- TOOL #10, #11, #12, #13, #14

A) compaction / fills / cuts / rutting
B) soil, equipment, or material storage
C) soil erosion / water availability changes
D) natural litter loss / soil surface crusting
E) micro-climate changes

Class 5 -- Wind load changes (tree failures under wind loading) -- Note that this class affects edge or island trees where clearing or thinning has left trees prone to windthrow. This is the only damage class not necessarily a result of direct mechanical or soil damage.

Class 6 -- Major branch damage (number of cuts and heartwood exposure) -- TOOL #15

Class 7 -- Health decline (PHC) -- TOOL # 16 & #17

A) tree damage exposure values and timing
B) recovery times

Class 8 -- Instituting obstructions -- changes in surroundings that will modify growth success and management activities now and into the future (growing space interference – new lines, barriers, hardscapes, buildings, trees)

As each tree and site area are being assessed for damage, potential actions should be developed that attempt to solve short-term and long-term site problems. These actions should rest in one or more of the following five management areas:

1. Immediate safety of people and protection of property;
2. Minimize liability risks developing over time (risk management);
3. Protection of tree and site assets;
4. Managed appreciation in value of tree and site assets;
5. Modification of current goals, objectives, and management plans.

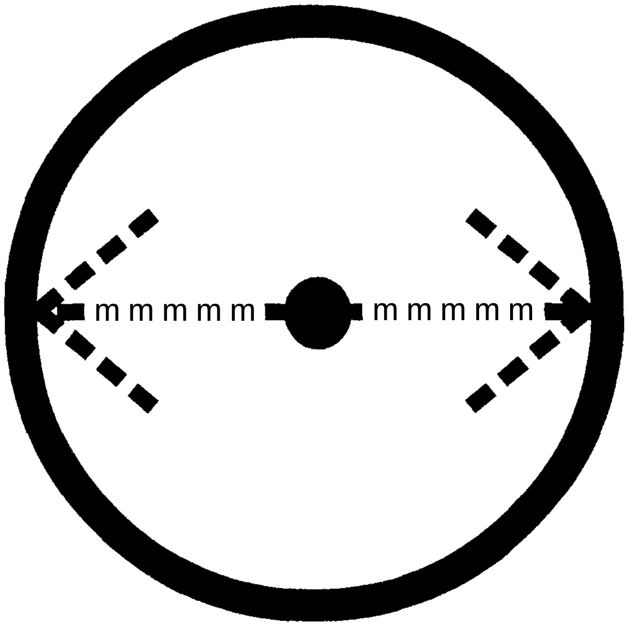
Decisions would include changing design, construction, and management plans, tree removal, planting, site or tree treatments, and/or reexamination of site resources and management objectives at a later time.

Damage assessment forms should include individual tree and site reviews, as well as an overall site damage form which stratifies the area by intensity of activity and damage extent. These records can assist in diagnosis and amelioration processes in the future. They also can be a guide for prescribing immediate treatments.

Included here are a number of tools for helping determine the extent and severity of damage. Each must be modified by species, site, circumstances, and management objectives as determined by an experienced assessor. These tools are designed to protect tree quality and minimize damage. As such, they are biologically conservative over a five year time span. Continued tree growth and reactions to change, constant or declining site resources, and disruption of either by management activities can compound long-term (>6 years) problems not reviewed here. Structural damage and chronic stress problems remain with a tree for its life.

TOOL #l

920 square feet of healthy soil per square foot of tree's cross-sectional area



2.5 X DIAMETER OF TREE (inches) = CRITICAL ROOTING DISTANCE (feet)

TOOL #2:
JOINT ROOTING AREAS

Soil area overlap values per tree based upon site-occupancy values (2.5 X diameter inches) for use where trees share soil space in linear, island or clump plantings.

number of equal size trees neighboring tree A	allowed area overlap values with tree A
2	40%
3	30%
4	20%
5	10%
>6	0%

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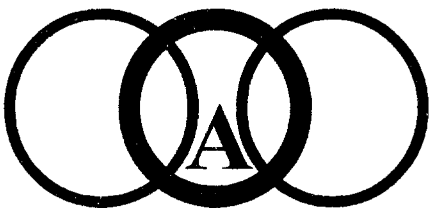
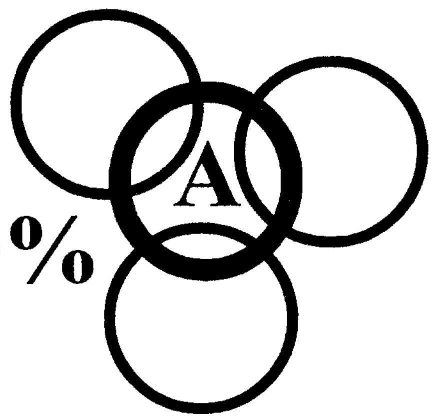
TOOL #2:
Diagram of joint rooting area overlaps for 2,3,4, and 5 neighboring trees.

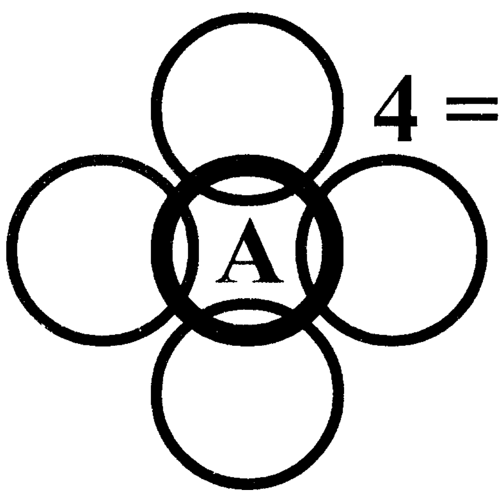


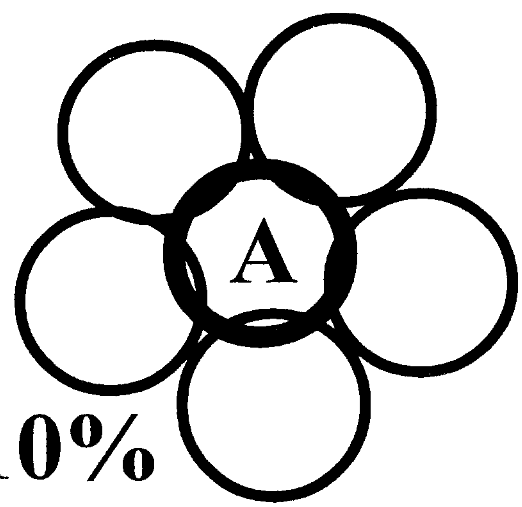
2 = 40%

3 = 30%



4 = 20%





5 = 10%

6 = 0% **OVERLAP**

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TOOL #3:
CRITICAL ROOTING DISTANCE TO MINIMIZE TREE DAMAGE

Root colonization area and limit of disruption based upon tree diameter at 4.5 feet above the ground (DBH). Do not trespass or work closer to the tree trunk than the critical rooting distance. (Table values calculated using 920ft² of biologically healthy soil area per square foot of tree cross-section).

TREE DIAMETER (inches)	CRITICAL ROOTING DISTANCE (feet of radius)
1	1.25
2	2.5
3	4
4	5
5	6
6	9
7	9
8	10
9	11
10	13
11	14
12	15
13	16
14	18
15	19
16	20
17	21
18	23
19	24
20	25
21	26
22	28
23	29
24	30
25	31

TREE DIAMETER (inches)	CRITICAL ROOTING DISTANCE (feet of radius)
26	33
27	34
28	35
29	36
30	38
31	39
32	40
33	41
34	43
35	44
36	45
37	46
38	48
39	49
40	50
45	56
50	63
55	69
60	75
65	81
70	88
75	94
80	100
85	106
90	113
95	119
100	125

TOOL #4

-- WALKING TOWARD TREE --

PERCENT OF ROOTING AREA DISRUPTED

1/5	2/5	3/5	4/5	5/5	proportion of critical rooting area radius
36	64	84	96	100%	= circular area
20	30	37	44	50%	= one side

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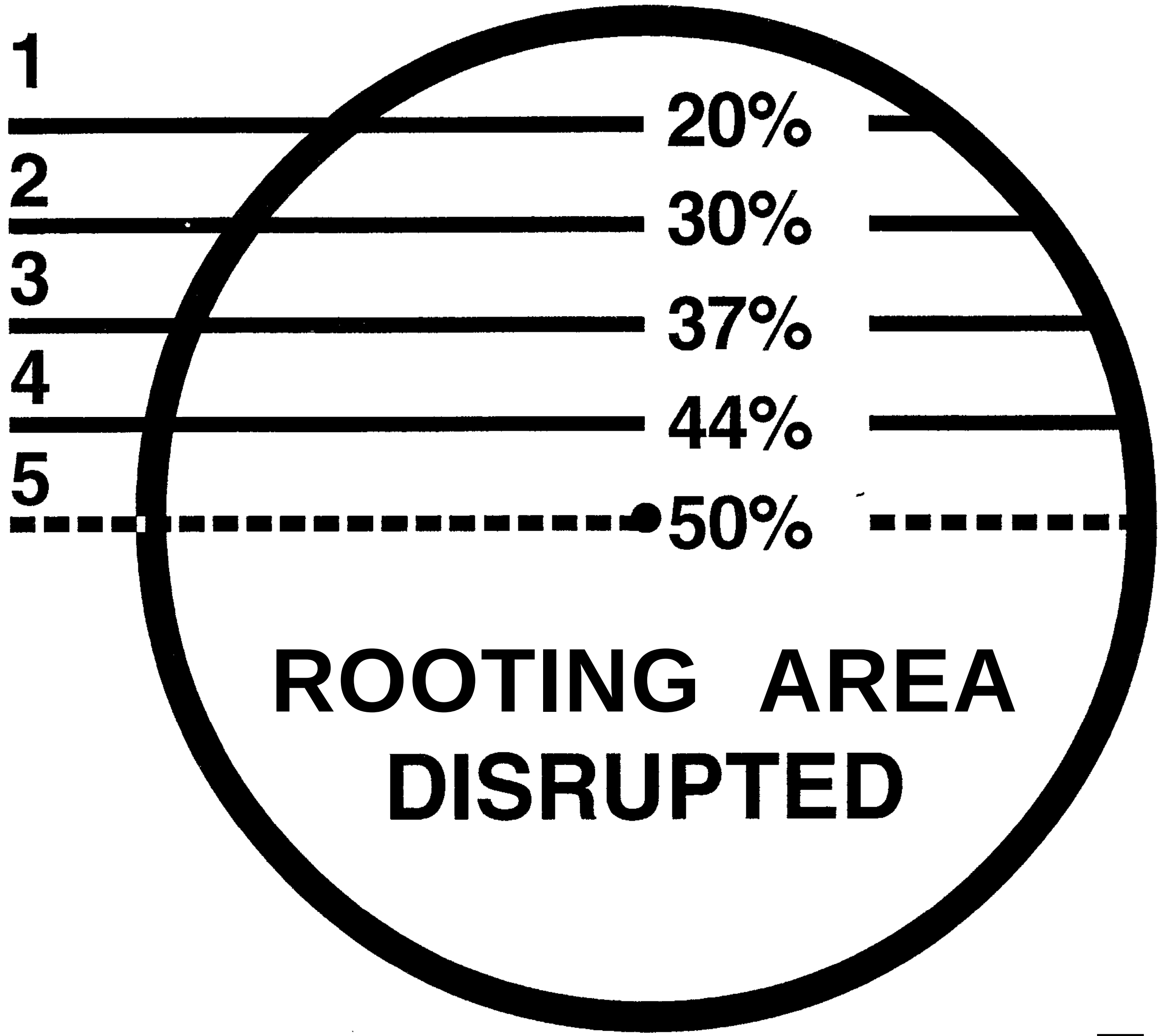

TOOL #5

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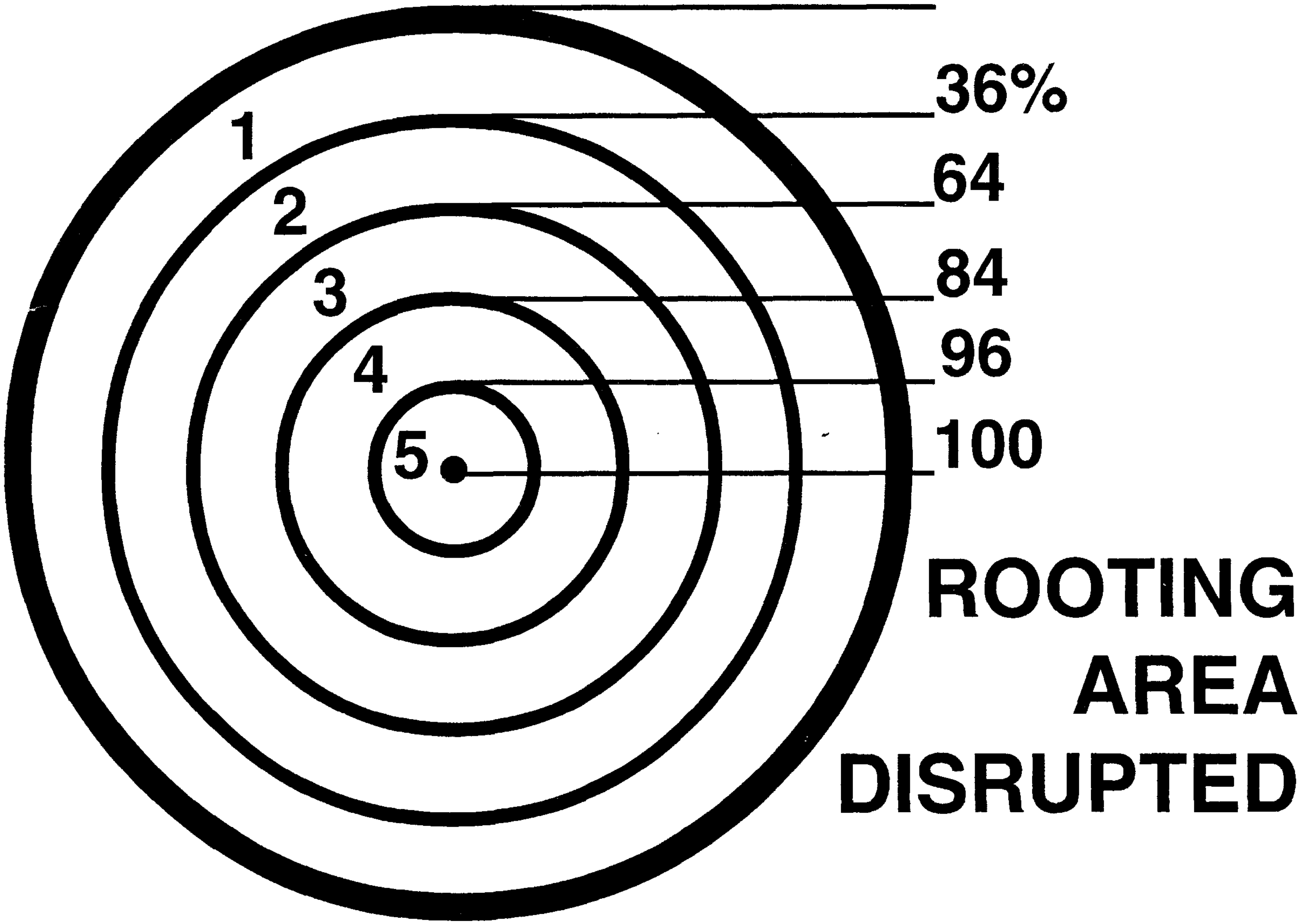

TOOL #6

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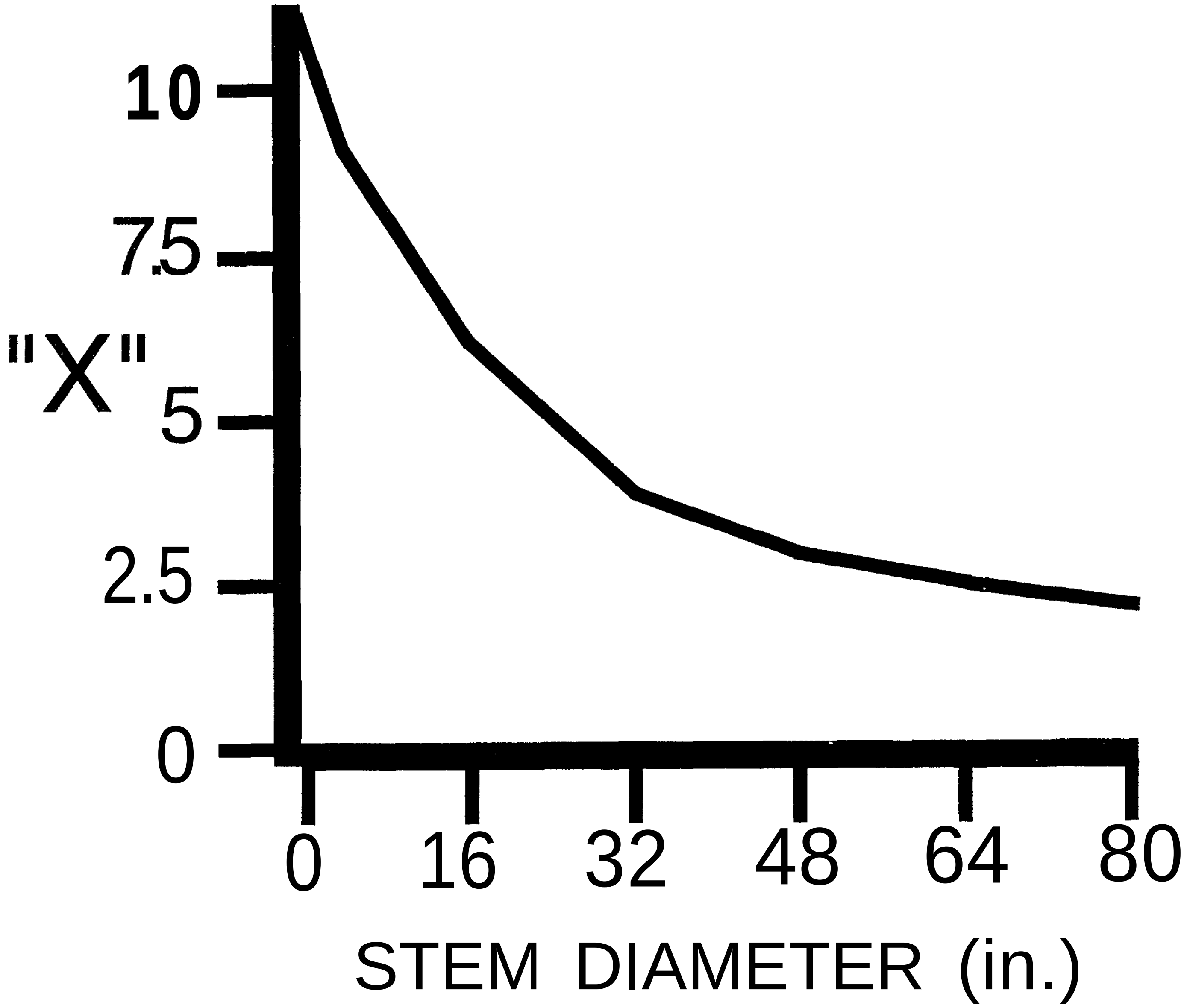
TOOL #7

ROOT PLATE RADIUS (in.)

(stem diameter (in.) times "X")



(after Mattheck et.al., 1993)

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TOOL #8:
STRUCTURAL CRITICAL ROOTING DISTANCE TO MINIMIZE CATASTROPHIC TREE FAILURE

Root plate size (i.e. pedestal roots, zone of rapid taper area, and roots under compression) and limit of disruption based upon tree diameter at 4.5 feet above the ground (DBH). Significant risk of catastrophic tree failure exists if structural roots within this given radius are destroyed or severely damaged.

TREE DIAMETER (inches)	STRUCTURAL CRITICAL ROOTING DISTANCE (feet of radius)
1	1
2	2
3	2
4	3
5	3
6	4
7	4
8	5
9	5
10	6
11	6
12	7
13	7
14	7
15	8
16	8
17	8
18	8
19	9
20	9
21	9
22	9
23	9
24	10
25	10
26	10
27	10
28	10
29	10
30	10
31	10
32	10
33	10
34	10
35	10
36	10
37	11
38	11
39	11
40	11
45	11
50	12
55	12
60	13
65	13
70	14
75	14
80	15
85	15
90	16
95	16
100	16

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TOOL #9: EXTENT AND SEVERITY OF MECHANICAL INJURIES

Determine and record the following items in the field —

1. Diameter of stem or branch at site of recent injury:
   A. If the stem / branch area that includes the injury area has little or no taper along its longitudinal axis then measure the mid-injury diameter of the stem / branch. (midDIAMETER)
   B. If the stem / branch area that includes the injury area has significant taper along its longitudinal axis, from injury top to bottom, then measure the diameter of the stem / branch at the top and bottom of injury. (topDIAMETER & bottomDIAMETER.)

2. Dimensions of the new injury:
   A. Total linear height or length (along longitudinal axis) of injury on stem / branch. (injuryHEIGHT)
   B. Total linear width (perpendicular to longitudinal axis) of injury — not circumference of injury area. (injuryWIDTH)
   C. Depth of injury at deepest point (as best as can be determined or estimated). (inj uryDEPTH)

3. Estimate number of annual rings and tissue types breached in the injury.

4. Location of the injury section in the tree.

5. Species of tree -- attempt to gauge effectiveness and efficiency of tree reactions to injury.

To determine the DAMAGE ASSESSMENT VALUE for a tree:

STEP 1A: Determine stem / branch whole segment volume (no taper) =
injuryHEIGHT * 0.785 * $(\text{midDIAMETER})^2$

STEP 1B: Determine stem / branch whole segment volume (significant taper) =
injuryHEIGHT * 0.262 * $(\text{topDIAMETER})^2$ +
0.785 * $(\text{bottomDIAMETER})^2$ +
SQUARE ROOT (0.616 * $(\text{topDIAMETER})^2$ * $(\text{bottomDIAMETER})^2$).

STEP 2: Determine injury segment volume (ellipsoidal shape factor) =
0.5 * injuryHEIGHT * injuryWIDTH * injuryDEPTH.

STEP 3: Determine DAMAGE EXTENT SCORE =
(VOLUME of injury segment (STEP 2) / VOLUME of whole segment (STEP 1)) * 100

STEP 4: Determine DAMAGE SEVERITY SCORE. Estimate the number of annual rings and tissue types breached in an injury.

Select one description that most fully matches the depth of the injury:

1. Bark to xylem (score = 0)
2. Expanded growing points, one, or two year old xylem (score = 1)
3. Three to seven year old xylem — 100% sapwood (score = 2)
4. Seven year old xylem to end of sapwood — 100% sapwood (score = 5)
5. Heartwood (score = 11)
6. Existing damage-modified heartwood and discoloration / decay columns (score = 23)

STEP 5: Determine injury location in the tree.

1. Root collar / stem base area — two feet out and four feet up (score = 7)
2. Root plate area — zone of rapid tapering (ZRT) of pedestal roots or roots that support the tree under compression — see TOOL #7 & #8 (score = 6)
3. Stem base of the live crown (score = 5)
4. Stem / trunk (score = 4)
5. Injury into reaction wood on basal l/4 of the length of primary scaffold branches — upper side tension wood in angiosperms / lower side compression wood in non-angiosperms (score = 3)
6. Ground contact / rain splash / direct irrigation wetting area (score = 2)
7. South and southwest exposure with full sun (score = 1)

Location numbers l-5 are unique positions and are non-additive (See Figure). Locations 6 and 7 are additive with other location scores. These scores comprise the DAMAGE LOCATION SCORE.

STEP 6: DAMAGE ASSESSMENT VALUE =
DAMAGE EXTENT SCORE +
DAMAGE SEVERITY SCORE +
DAMAGE LOCATION SCORE

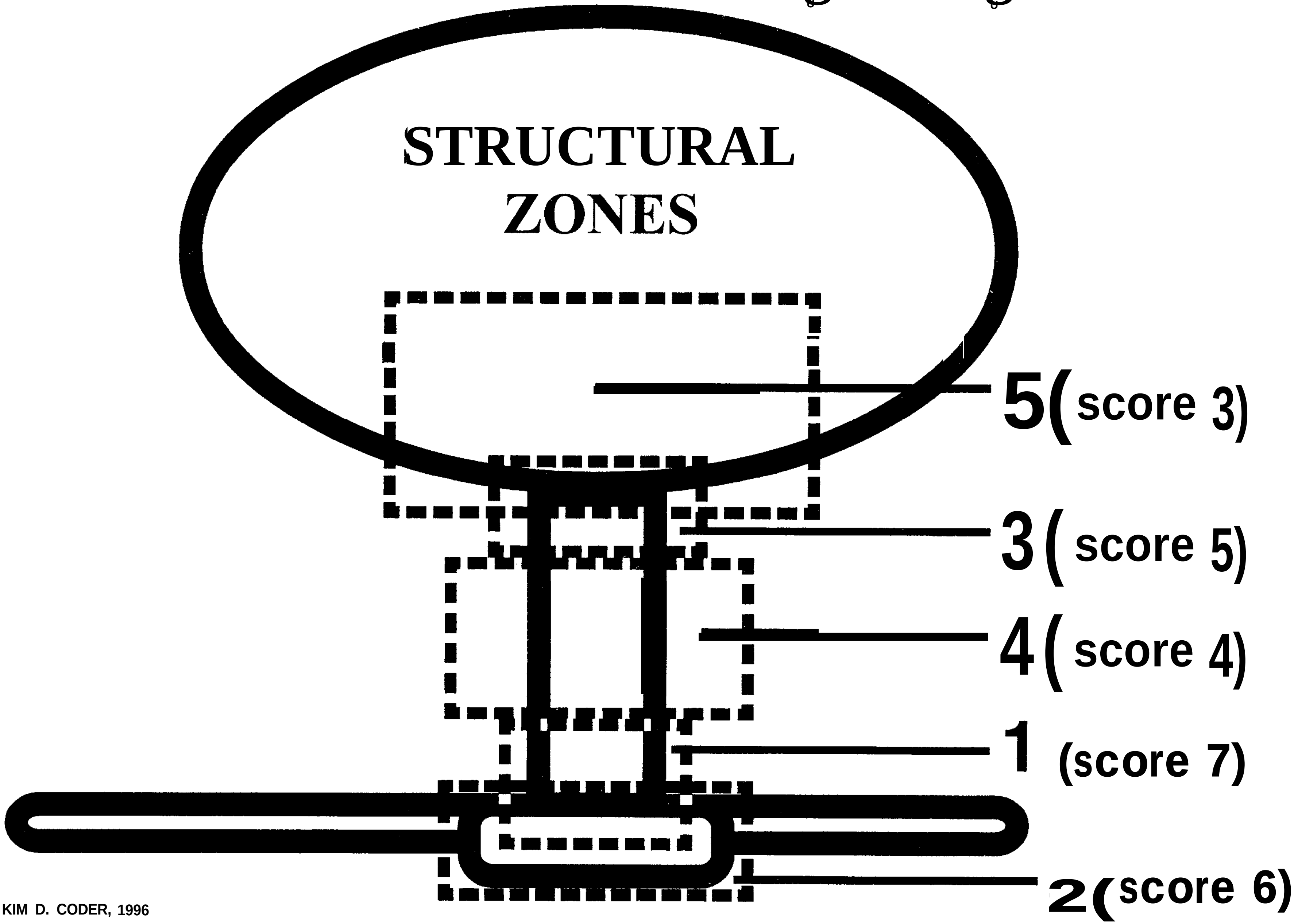
Species and individual tree differences play a critical role in setting management objectives for an area and acceptance thresholds / tree removal decisions using the DAMAGE ASSESSMENT VALUE. For long-term tree quality, suggested threshold values for increasing managerial notice should occur at 15, 22.5, and greater than 30. Removal should be considered at a DAMAGE ASSESSMENT VALUE of 3 1 and above.

Please see the following publications for further information on this assessment procedure:

Coder, Kim D. 1996. Assessing the Extent and Severity of Mechanical Injury in Trees. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-37. Pp.4.

Coder, Kim D. 1996. Construction Damage: Tree Damage Exposure Values and Recovery Times. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-36. Pp.6.

TOOL #9: Injury locations with additional scores for assessing damage.



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TOOL #10: SOIL COMPACTION

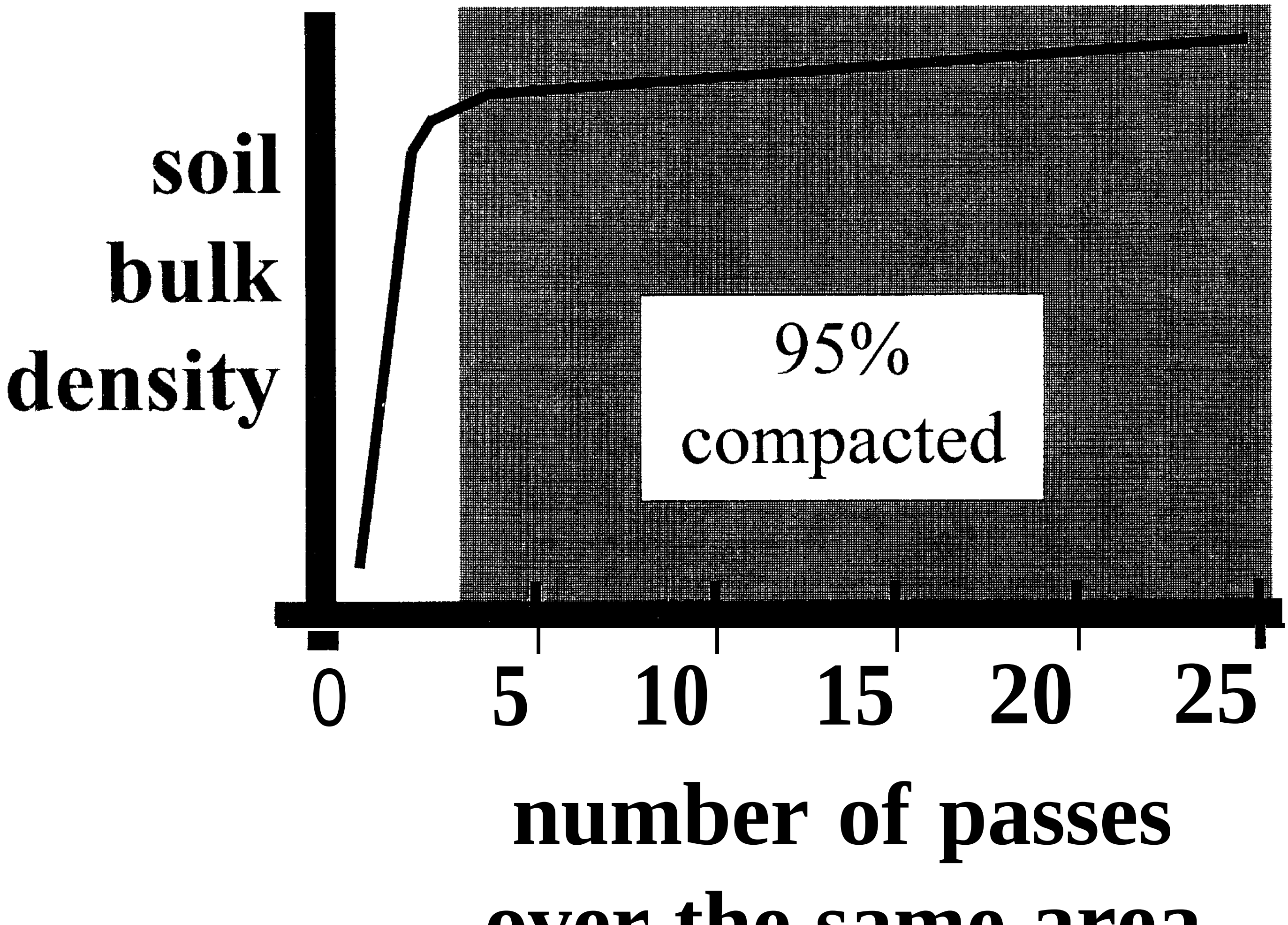
Soil physical attributes, by soil texture class, where root growth becomes significantly limiting.

soil texture	root-limiting bulk density g/cc	root-limiting % pores normally filled with air
sand	1.8 g/cc	24 %
fine sand	1.75	21
sandy loam	1.7	19
fine sandy loam	1.65	15
loam	1.55	14
silt loam	1.45	17
clay loam	1.5	11
clay	1.4	13

General root growth limits --
A) physical limit of root growth is soil density > 1.7 g/cc bulk density
B) pore space and aeration limit of root growth is < 15% of pore space filled with air

TOOL #11

SOIL COMPACTION VALUES



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TOOL #12: SOIL FILLS

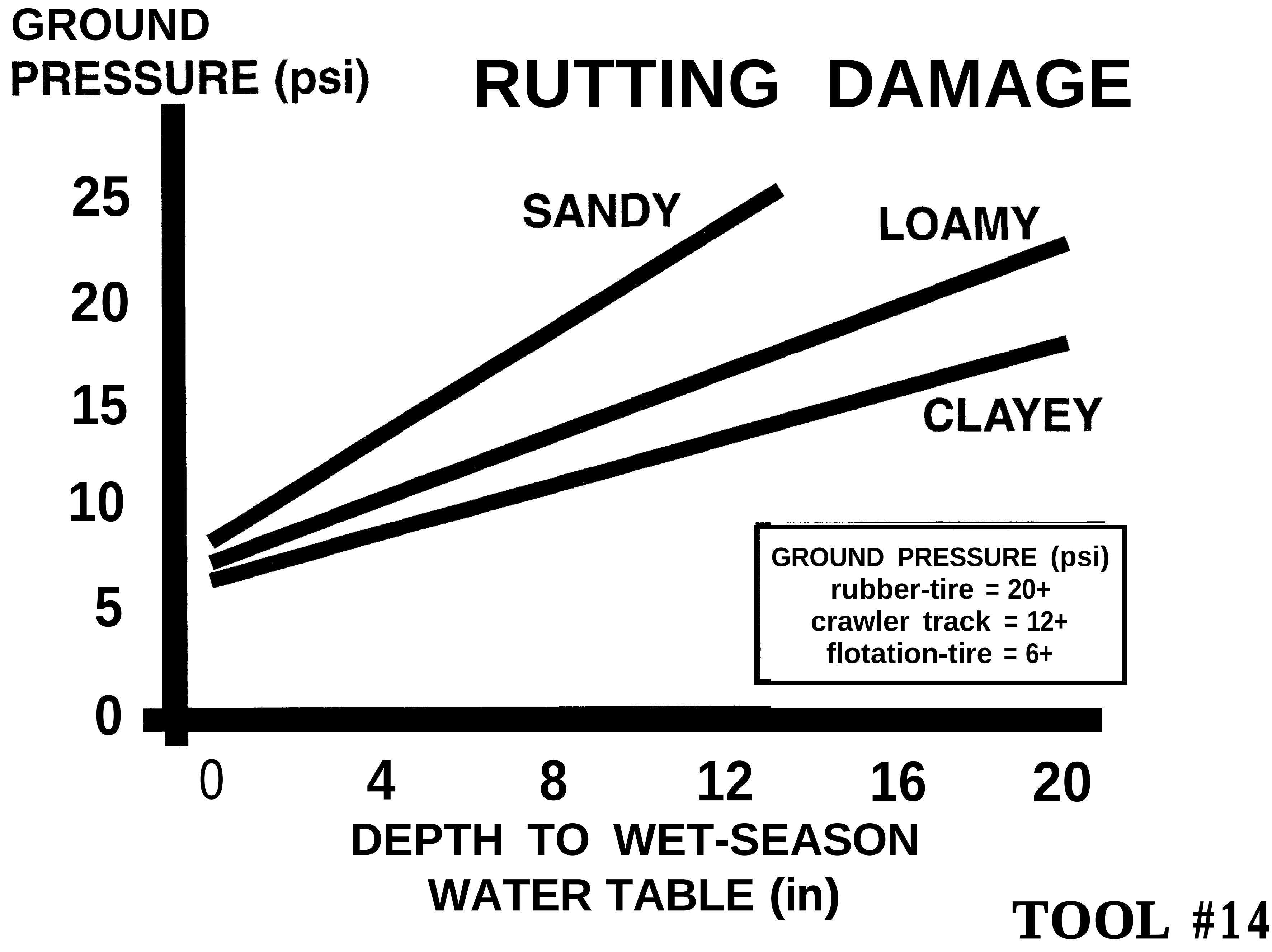
Approximate amount of soil fill, by texture class, that can be applied before having significant negative impacts on tree root health and growth. (These are highly variable values depending upon crusting, compaction, aeration/drainage, native soil attributes, residual structure, application method, organic matter content, and other compounding soil / site problems.) All types and quantities of fill can lead to root suffocation and other acute and chronic problems that permanently damage the tree. Judging the threshold of potential damage is a professional decision beginning with site management objectives.

soil texture	initiation of root damaging soil fill	massive root damaging soil fill
sand	8 inches (20cm)	24 inches (61cm.)
fine sand	6 (15)	18 (46)
sandy loam	4 (10)	12 (30.5)
fine sandy loam	3 (7.6)	9 (23)
loam	2 (5)	6 (15)
silt loam	1.5 (3.8)	4.5 (11)
clay loam	1.5 (3.8)	4.5 (11)
clay	1 (2.5)	3 (7.6)

TOOL #13: SOIL CUTS

Approximate amount of soil removal, by texture class, that can be taken away before having significant negative impacts on tree root health and growth. (These are highly variable values depending upon compaction, aeration/drainage, native soil attributes, residual structure, removal method, organic matter content, and other compounding soil / site problems.) All soil removal can mechanically disrupt root tissue leading to acute and chronic problems that permanently damage the tree. Judging the threshold of potential damage is a professional decision beginning with site management objectives.

soil texture	significant root damaging soil removals	
sand	10 inches	(25cm.)
fine sand	8.5	(22)
sandy loam	7	(18)
fine sandy loam	5.5	(14)
loam	4	(10)
silt loam	3	(7.6)
clay loam	3	(7.6)
clay	2	(5)



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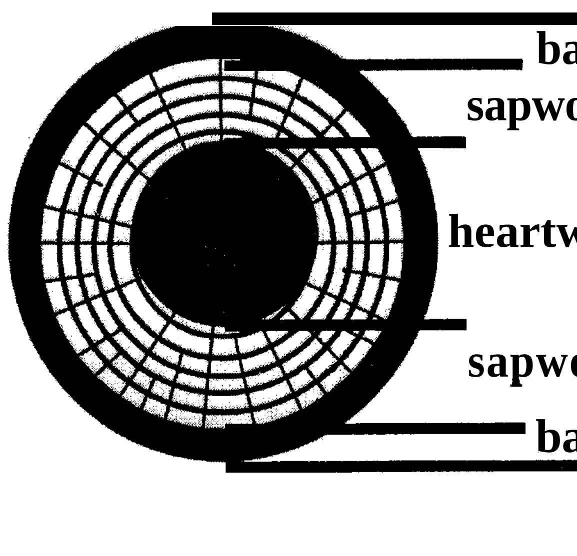
TOOL #15: MAJOR BRANCH DAMAGE

Construction damage to major branches is judged after the injuries have been properly cleaned-up and a standard pruning cut is made. Only after the final pruning cut is completed can full branch damage be assessed. Additional damage can occur after the construction injury as a result of improper pruning tools, techniques, and skills. In this assessment system it is assumed that proper standard pruning practices will be followed. Within standard pruning practices, heartwood and decay column exposure will be used to estimate damage to the health and structure of the tree now, and into the future.

This assessment system provides a user with the maximum number of cuts per wound damage class that should be made without significant and permanent damage to the tree. The basis of this system is examination of the cross-section of the living base of any properly pruned branch. It is critical that assessors differentiate between heartwood, sapwood, and chemically altered wood areas (decay, discoloration, and defensive responses)

Types and number of branch pruning cuts remaining after the tree is cleaned-up from construction damage (significant injury and liability risk exist in the damaged tree):

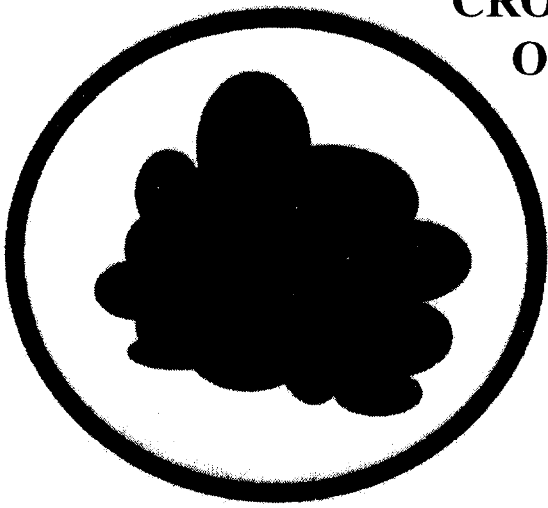
wound name	**maximum number allowed**
massive	1
major	3
large	7
standard	15
minor	31



-- definitions on next page --

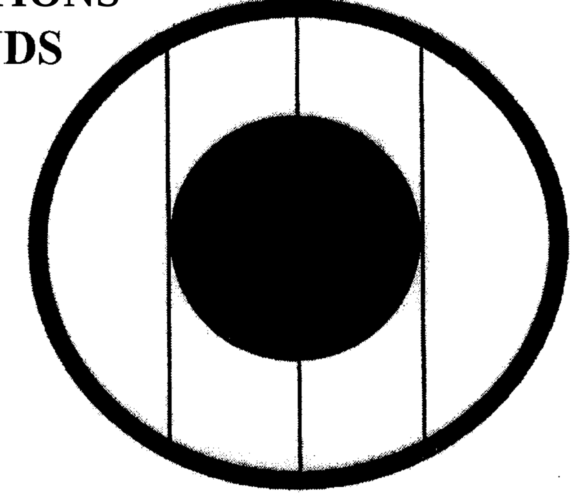
For further information please see:
Coder, Kim D. 1996. Assessing Pruning Wound Damage. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-30. pp2.

CROSIS-SECTIONS OF WOUNDS



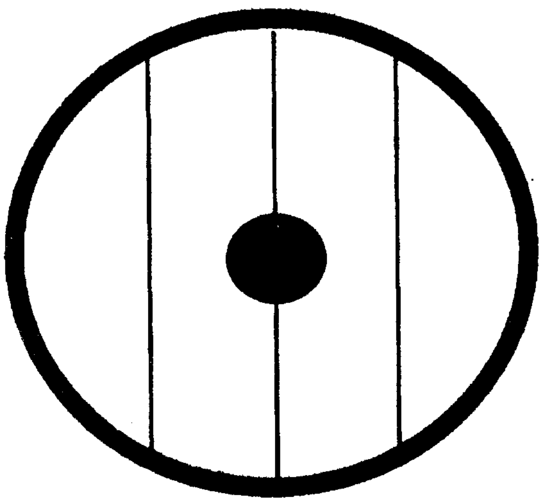
MASSIVE

ALREADY DEVELOPED DECAY AND DISCOLORATION BOUNDARIES



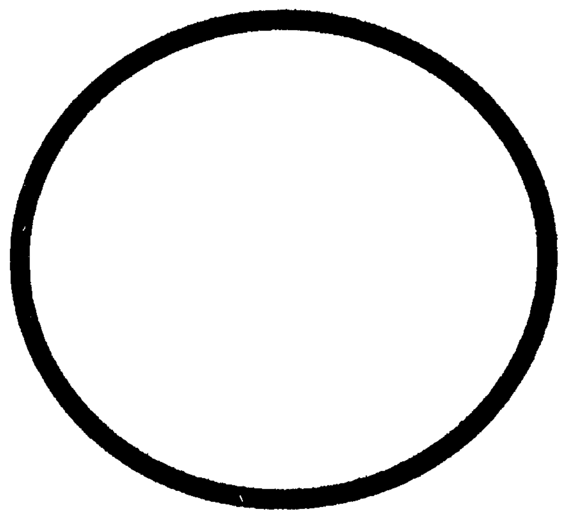
MAJOR

HEARTWOOD EXPOSURE (>1/4 DIAMETER IN HEARTWOOD)



LARGE

HEARTWOOD EXPOSURE (<1/4 DIAMETER IN HEARTWOOD)

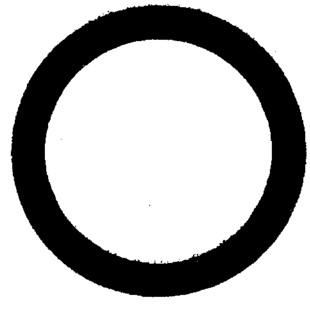


STANDARD

SAPWOOD EXPOSURE

MINOR

SAPWOOD EXPOSURE ACROSS LAST TWO ANNUAL RINGS AND POINT BARK PENETRATIONS



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TOOL #16:
TREE DAMAGE EXPOSURE VALUES

One of the most important aspects of assessing construction damage to trees is the amount of time development activities occur on a site. Both the absolute time span and the timing of damage in comparison to tree growth patterns are critical to assessing damage and estimating recovery times. Use of a construction damage timing table is both a method of training new assessors and a means of quantifying the potential extent of damage to trees.

This assessment process develops a "Tree Damage Exposure Value." This Exposure Value is determined by establishing a time-line for beginning and ending construction activities on a site. Components of the Tree Damage Exposure Value include the number of different tree growth seasons the construction activities have spanned, which season construction activities began within, which season construction activities ended within, and how many full years have been involved in the construction process.

Below is given an example time-line for calculating potential damage exposure timing for trees on construction sites.

	Four Tree Growth Seasons			
YEAR #1	dormancy	first portion of growing season	second portion of growing season	senescence
YEAR #2:	dormancy	first portion of growing season	second portion of growing season	senescence
YEAR #3:	dormancy	first portion of growing season	second portion of growing season	senescence
YEAR #4:	dormancy	first portion of growing season	second portion of growing season	senescence
YEAR #5:	(etc.)			

TREE DAMAGE EXPOSURE VALUE =

(SEASON INFLUENCE NUMBER +

SEASONAL STARTING PENALTY NUMBER +

SEASONAL ENDING PENALTY NUMBER) X

MULTIPLE-YEAR PENALTY FACTOR.

TREE DAMAGE EXPOSURE VALUE COMPONENTS

1) SEASON INFLUENCE (whole or part of season affected by construction)

full year (GS 1 +GS2+SENC+DORM)	= 25
dormant season (DORM)	= 1
full growing season (GS l+GS2+SENC)	= 24
first portion growing season (GS 1)	= 12
second portion growing season (GS2)	= 9
senescence season (SENC)	= 3

2) SEASONAL STARTING PENALTY (season when construction began)

dormant season (DORM)	= 0
first portion growing season (GS 1)	= 6
second portion growing season (GS2)	=4
senescence season (SENC)	=2

3) SEASONAL ENDING PENALTY (season when construction ended)

dormant season (DORM)	= 0
first portion growing season (GS 1)	= 6
second portion growing season (GS2)	= 0
senescence season (SENC)	= 0

4) MULTIPLE-YEAR PENALTY (unreactive / dormant period lay-overs)
-- multiply the summed results of preceding three steps by (1.05^{years})

examples:
2 years = 1.05^2 = 1.10
3 years = 1.05^3 = 1.16
4 years = 1.05^4 = 1.22

5) YOU HAVE NOW COMPLETED THE FOLLOWING FORMULA:

TREE DAMAGE EXPOSURE VALUE =
(SEASON INFLUENCE NUMBER +
SEASONAL STARTING PENALTY NUMBER +
SEASONAL ENDING PENALTY NUMBER) X
MULTIPLE-YEAR PENALTY FACTOR.

For further information:

Coder, Kim D. 1996. Assessing Construction Damage: Tree Damage Exposure Values and Recovery Times. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-36. pp.6.

Calculated Tree Damage Exposure Values

To determine a Tree Damage Exposure Value, begin at the top of the table and identify when construction activeties began on the site (by tree growth season). Next move downward in the appropriate starting column until you reach the row representing the end of construction activities on the site. The number presented is the relative "Tree Damage Exposure Value." Abbreviations: DORM = dormancy season; GS1 = first portion of growing season; GS2 = second portion of growing season; SENC = senescence season.

CONST. ENDS	**CONSTRUCTION BEGINS** YEAR 1 DORM	YEAR 1 GS1	YEAR 1 GS2	YEAR 1 SENC
YEAR 1 DORM	1			—
YEAR 1 GSI	18	24		—
YEAR 1 GS2	22	27	13	—
YEAR 1 SENC	25	30	16	5
YEAR 2 DORM	29	34	19	7
YEAR 2 GS1	48	54	39	26
YEAR 2 GS2	52	57	42	30
YEAR 2 SENC	55	61	45	33
YEAR 3 DORM	59	65	60	36
YEAR 3 GS1	80	86	70	57
YEAR 3 GS2	84	89	73	60
YEAR 3 SENC	87	93	77	64
YEAR 4 DORM	93	99	94	68
YEAR 4 GS1	115	121	104	90
YEAR 4 GS2	118	124	107	94
YEAR 4 SENC	122	128	111	98

TOOL #17:
TREE RECOVERY TIMES

Once the construction damage exposure timer (TOOL # 16) has been used to determine relative tree damage from construction activities, tree recovery times should be calculated. Recovery time begins when construction activities end on a site. Landscape disruption and installation are the final parts of construction on a site and can be extremely damaging, especially to any mature trees present. When the last machinery has left the site, and the landscape and hardscape are completly installed, recovery time can begin.

Recovery timing uses the same time-line and four seasons of tree growth as the construction tree damage exposure value (TOOL #16). For each tree growth season affected by construction activities, a specific length of recovery should be observed. From the moment of injury, the recovery timing begins. Because of tree biology, recovery time periods are not additive, but run **CONCURRENTLY** as each tree growth season is affected and grown past.

Recovery times for each tree growth season impacted by construction activities.

A) Dormant season (DORM) = 1 year

B) Senescence season (SENC) = 2 years

C) Second portion of growing season (GS2) =
3 years plus time to the end of growing season

D) First portion of growing season (GS 1) -- diffuse porous =
3 years plus time to the end of growing season

E) First portion of growing season (GS 1) -- ring porous / gymnosperms =
4 years plus time to the end of growing season

For further information:

Coder, Kim D. 1996. Assessing Construction Damage: Tree Damage Exposure Values and Recovery Times. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-36. pp.6.