FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

ASSESSMENT OF ROOTS – NGARUAWAHI, WAIHI & FEILDING TOPPLING TRIALS

J.A. Turner & J.D. Tombleson

Report No. 53 November 1998

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INTRODUCTION

Influence of Root Form on Incidence of Topple

Toppling occurs in young trees two to three years of age. Toppling beyond this age is generally referred to as windthrow. The incidence of toppling is becoming more common particularly with the large areas of new planting being established on exposed, fertile ex-farm sites throughout New Zealand. Toppling can result in reduced tree selection for a suitable final crop and can also result in swept butt logs and reduced value of the crop at harvest.

A Model of Toppling

A static tree failure model indicates that a tree is likely to topple when the overturning moment[1] caused by the wind exceeds the maximum resistive moment that the tree roots can provide (Figure 1) (Petty and Swain 1985; Moore and Somerville 1998). The overturning moment in young trees is predominantly the force applied to the tree crown by the wind (Moore and Somerville 1998). The level of force applied by the wind is determined by the wind speed, crown frontal area, and drag coefficient of the crown. The maximum resistive moment is the maximum resistance offered by the root system of the tree.

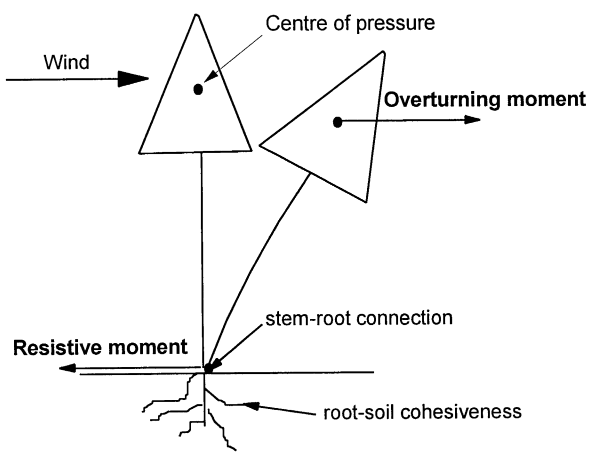

Figure 1: The overturning moment acting on a tree due to the wind acting on the centre of pressure of the tree crown (adapted from Papesch *et al.* 1997).

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[1] A moment is a "turning agent" and is defined as M = rF, where r is the perpendicular distance of the line of action of the applied force, F, from the base of the tree (Halliday and Resnick 1988).

The maximum resistive moment offered by the root system is influenced by the root systems dimensions, mass and distribution, tensile strength of roots, soil tensile strength, and root/ soil resistance (Coutts 1983). To resist the turning moment transmitted by the stem, trees need a rigid root system. This is achieved either by having a tap root from which horizontal lateral roots are attached, or by having a plate of lateral roots with sinkers growing downwards (Stokes *et al.* 1995). Coarse, woody, roots greater than 2 mm in diameter are considered essential for anchorage (Stokes *et al.* 1995).

Comparative Studies of Root Systems

Comparison of root systems between naturally regenerated and planted trees and between toppled and non-toppled trees have been carried out by a number of authors (cited in Mason 1985) in an attempt to identify components of the root system which are important in achieving anchorage in young trees. A common observation is that naturally regenerating radiata pine does not topple, while planted trees do (Chavasse 1978). This difference in stability has been related to the development of a strong taproot and well-distributed laterals in naturally regenerated radiata pine compared with poor lateral root distribution and distorted or non-existent taproots in planted trees (Wendelken 1955; Gruschow 1959; Chandler 1968; Menzies 1974; Chavasse 1978; Somerville 1979; Pfeifer 1982; Mason 1985; Mason *et al.* 1988).

Somerville (1979) compared the root systems of naturally regenerated and eleven year-old planted *Pinus radiata* grown at Eyrewell Forest, Canterbury. The naturally regenerated trees tended to form large, straight-grained tap roots, while the planted trees formed few tap roots and smaller diameter sinkers which often fractured at the base of the stem when under stress.

Pfeifer (1982) compared the root systems of straight (non-toppled) and swept (toppled) nine year old *Pinus contorta*. Straight trees were found to possess a uniform radial arrangement of lateral support roots. Swept trees lacked a well defined tap root and an even distribution of laterals. The root systems of planted and naturally regenerated *P. contorta* were also compared, again identifying an even distribution of lateral support roots and a well defined tap root in naturally regenerated trees, while tap roots were almost absent in planted trees.

Mason (1985) compared pairs of toppled and stable 2 to 3 year-old radiata pine, and identified significant differences in the Menzies' taproot score (Figure 7) and the number of sinkers > 2 mm, between toppled and non-toppled trees. Toppled trees had poorer taproot form and fewer structural sinker roots.

Mason *et al.* (1988) compared 1.5/0 and 1/0 *Pinus radiata* seedlings and found that those that exhibited poorer root form were more prone to topple, even when planted deeper and with larger mean root: shoot ratios, than planting stock with better root form. The unstable stock type scored significantly poorer in the Menzies' Taproot Score (number of sinkers > 2 mm in diameter), and core distortion score (which measures the extent to which lateral roots are wrapped around the root bole of the tree (Mason & Cullen 1986)).

Root: Shoot Ratio

A static tree failure model suggests the ratio of root biomass to shoot biomass is also an important factor influencing tree stability. A tree with a large "sail" area and small root system (low root: shoot ratio) may topple more readily as the overturning moment caused by the wind on the large crown will easily exceed the maximum resistive moment that the small mass of tree roots can provide (Figure 1) (Moore & Somerville 1998). Several authors (Lines 1971; Coutts 1983; Nielsen 1992) have associated a lowering of the root: shoot ratio with increasing juvenile instability as trees require a certain quantity and quality of roots in relation to the quantity of crown to achieve stability.

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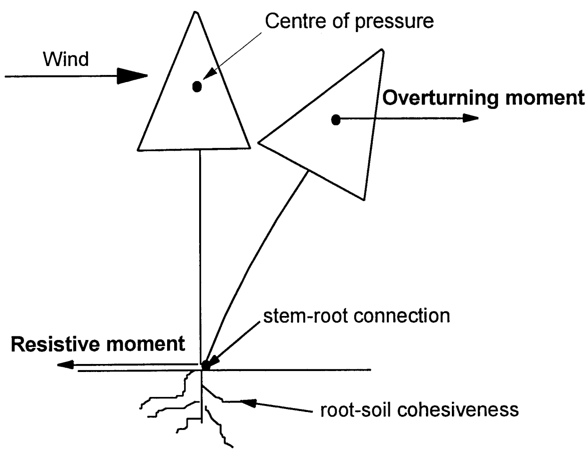

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Influence of Site Fertility

The root: shoot ratio is suspected to be influenced by site fertility, although conflicting findings exist in the literature. Chavasse (1969), in a survey of toppling in the South Island of New Zealand found very high incidences of toppling on fertile ex-farm sites. The high occurrence of topple on fertile farm sites has been linked to low root: shoot ratios[2] associated with high site fertility. Several authors have identified a decline in the root: shoot ratio with increasing site fertility. Lines (1980) summarising results from Danby (1973) of an investigation of *Pinus contorta* grown in Great Britain and aged from 3 to 8 years old found root: shoot ratio increased due to a lack of phosphate. Nambiar (1980) studied the root configuration of 10-month-old radiata pine seedlings grown in a South Australian nursery, and found nitrogen and phosphorus deficiencies increased the root: shoot ratio.

Findings counter to those made by Chavasse (1969), Danby (1973), Lines (1980), and Nambiar (1980) were made by Snowdon and Waring (1985) in a study of 4 year old *Pinus radiata* in N.S.W., Australia, grown with combinations of nitrogen, phosphorus, clover and native grasses. In this study the coarse root[2] :shoot ratio increased with increasing fertility, while the fine[2]: root ratio declined with increasing fertility. Ray *et al.* (1998) recently provided root: shoot ratio results from an investigation of the effect of fertilisation, compaction, weed control, and planting on the stability of 27 month old *P. radiata* cuttings and seedlings. In this study no effect of treatment on root: shoot ratio was evident.

Contrasting findings relating to the influence of site fertility on root: shoot ratio may in part result from differences in the method of root system measurement. It is important to differentiate between coarse roots and fine roots, particularly when investigating tree stability (Snowdon & Waring 1985; Nielsen 1992). Inclusion of the below-ground stump in calculation of root biomass may also result in the different findings, and again is an important distinction to make when studying tree stability (Nicoll *et al.* 1995). Seasonal timing of sampling in relation to the time of shoot elongation potentially influences root: shoot ratios. Differences in the period of shoot elongation among trees sampled result in changes in the relative differences in root: shoot ratio (Cannell & Willett 1976). The greatest differences in root: shoot ratio have

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[2] The ratio of the dry weight of all roots, both fine (≤ 2 mm diameter) and coarse (> 2 mm diameter), to the dry weight of above ground stem and foliage.

been shown to occur in winter/ autumn, while the least differences occur in summer/ spring (Cannell & Willett 1976). As topple tends to occur in autumn (Pfeifer 1982) root: shoot ratios sampled at this time may be relevant to tree stability of radiata pine.

Influence of genetics

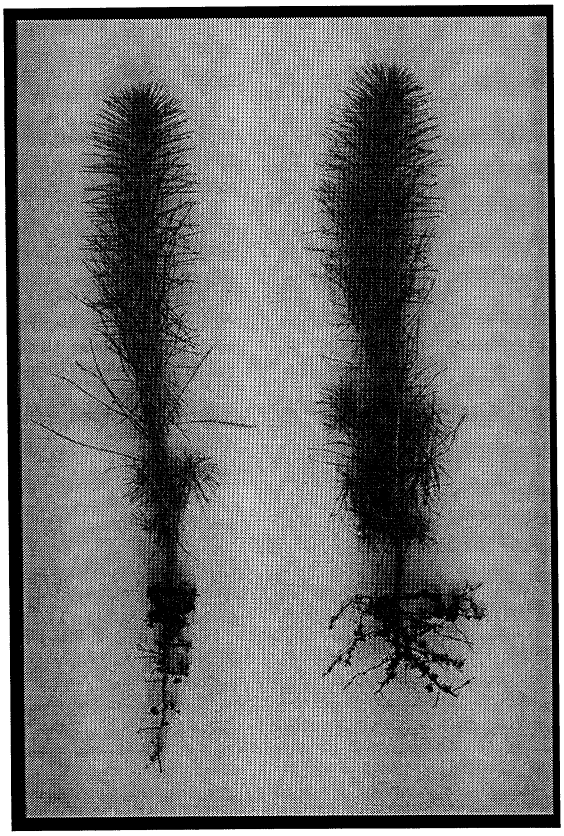
Differences in root: shoot ratios of 10 to 30% have been quantified between provenances of *P. contorta* (Cannell & Willett 1976) although this difference varied throughout the year. Large differences in total root: shoot, and root (excluding stump): shoot ratios were observed among five improved 11 year old sitka spruce clones (Nicoll *et al.* 1995). Using the root (excluding stump): shoot ratio rather than the total root: shoot ratio, changed the rankings of the clones (Nicoll *et al.* 1995).

METHODS

Trial Objective

The objective of the trials was to evaluate the stability of seedlings specifically grown in the nursery to produce well defined tap roots as shown in Figure 2. Following lifting, the lateral roots were severely trimmed using hand shears. The premise was that such root systems would readily regenerate from the tap root creating a strong, dominant and well developed tap root(s) potentially resulting in greater tree stability. Another premise was that the severely trimmed laterals will also ensure that the root system could not be distorted at planting, possibly contributing to improved stability. These treated seedlings are compared with conventionally produced seedlings which do not contain a well defined tap root as shown in Figure 2.

Figure 2: Seedling on left received a deep undercut to produce a well defined tap root in comparison to conventional nursery root conditioned seedling shown on right.



Trial design

A block design was used incorporating the following:

- 98 plots (each plot being two trees), laid out in a block comprising 14 x 14 trees (as shown in Figure 3);
- each plot comprises a conventionally root conditioned seedling (Control) and a severe lateral root trimmed seedling (Treatment);
- spacing of 4.0 x 4.0m = 625 stems/ ha;
- two surround rows planted at the same spacing as the trial.

Figure 3: Layout for the severe lateral root trimming trials.

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	T	C	T	C	T	C	T	C	T	C	T	C	T	C	X	X
X	X	C	T	C	T	C	T	C	T	C	T	C	T	C	T	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

KEY

C = Control seedling (conventionally root conditioned)

T = Treatment seedling (severe lateral root trimmed)

X = Surround seedling

Trial Locations & Descriptions

The three toppling trials were established in September 1996 on three fertile farm sites located at Ngaruawahia, Waihi and Feilding. Detailed site descriptions for each site are contained in Forest & Farm Plantation Management Cooperative Report No. 44.

Figures 4, 5 & 6 provide a general indication of site type and terrain for each trial.

Figure 4 Ngaruawahia Toppling Trial

Figure 5: Waihi Toppling trial

Figure 6: Feilding Toppling Trial

Rainfall Data

Total rainfall (mm) recorded at the closest meteorological station for each of the three sites relating to the 24 month growing period (1 June 1996 to 30 June 1998) is presented in the following Table. The Feilding site is a drier site with approximately 67% of the rainfall of the Ngaruawahia and Waihi sites.

Table 1: Rainfall data for the 24 month growing period

Location	Total Rainfall (mm)
Ngaruawahia	2462[3]
Waihi	2450[4]
Feilding	1652[5]

[3] Records from Hamilton Aero meteorological station, 31 km from trial location.
[4] Records from Palmerston Aero meteorological station, 18 km from trial location.
[5] Records from Tauranga Aero meteorological station, 40 km from trial location. Rainfall records missing from 27/5/97 to 3/6/97 were filled using data from Oropi Water Treatment Meteorological Station which provided comparable records to Tauranga Aero.

Measurements

The Ngaruawahia and Feilding trials were measured for tree height and root collar diameter at age 19 months (see Table 2 & 4). Subsequent root excavations at all sites were carried out along with the root assessments at age 23 months. The Waihi trial was measured for tree height and root collar diameter at 11 months and again at 19 months following a storm event and subsequent toppling.

Storm Events and Toppling

The Waihi site was subjected to a severe wind storm when the trees were nine months of age resulting in over 50% of the trees being toppled with an average lean of 17°. Neither the Ngaruawahia or Feilding sites suffered any toppling.

Root Excavations

A sample of 16 trees (8 Treatment & 8 Control trees) were excavated from the Waihi trial. The sample was increased to a total of 22 trees (11 Treatment & 11 Control trees) for the Ngaruawahia and Feilding sites. Trees were selected to cover the range of tree heights contained in the trial. Trees were excavated using a sharp spade. The aim was to excavate to a minimum depth and width of 30 cm to provide sufficient root material to apply the necessary assessments. Immediately following root excavation the depth of planting was measured, being from the ground level to a point just above the root plate. The stem of each root was removed just above the ground level. Root systems were then assessed for the following:

Menzies' Taproot Score	(see Figure 7)
Menzies' Lateral Root Score	(see Figure 8)
Menzies' Vertical Root Distribution Score	(see Figure 9)

Photographs of Root Systems

The lateral and tap root systems of all trees excavated from all three sites were photographed and are contained in Appendices 1 - 3. Tree root sample identification numbers are shown on the photographs and can be related to the assessment data shown for each site in Tables 2, 3 & 4.

Figure 7: Menzies' Taproot Score

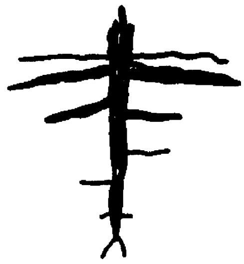
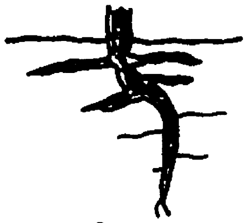
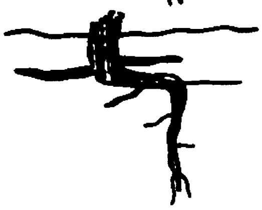
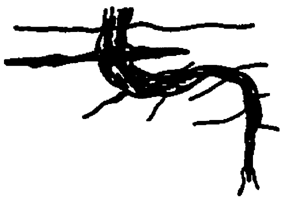
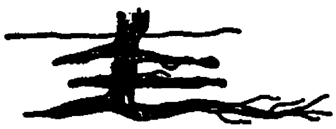
SCORE	DIAGRAM	DESCRIPTION
0		Strong, dominant, well developed taproot
2		Stunted, slightly malformed, but still a definite taproot
4		Taproot distinctly hooked
6		Taproot quite badly hooked, but downward development still present
8		Taproot severely deformed into two or more fracture zones, but growth still downward
10		Taproot does not come below a horizontal plane, or no taproot at all. Subtract one point for each strong sinker present.

Figure 8: Menzies' Lateral Root Score

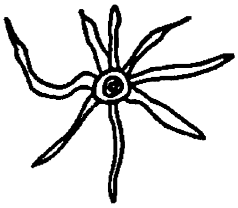
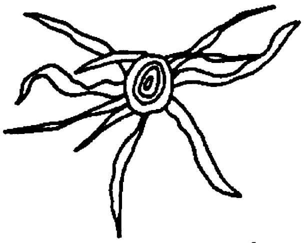
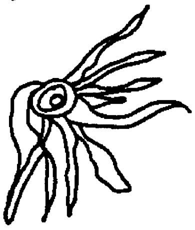
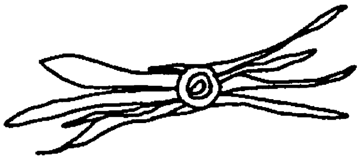
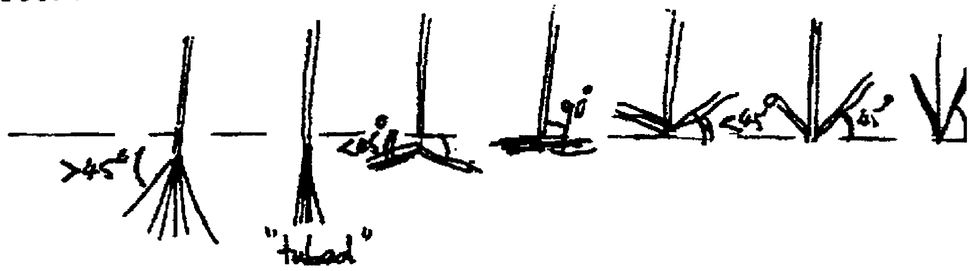
SCORE	DIAGRAM	DESCRIPTION
0		**Laterals on all four sides**
2		Laterals in three quadrants
4		Laterals in two adjacent quadrants
6		Laterals in two opposite quadrants
8		Laterals in one quadrant
10		No significant laterals in any quadrant

Figure 9: **Menzies Vertical Root Distribution Score**

(a) Vertical root distribution



Score	0	1	2	5	7	10	12

Analysis

Differences in taproot, lateral and vertical root distribution scores between the control and treatment trees at each trial were assessed using an analysis of variance (ANOVA). The sample of trees at Waihi were biased by lean with the control trees having greater average lean than the treatment trees (Table 2). To adjust for this bias the ANOVA included lean as a covariate. Differences in Menzies' taproot, lateral, and vertical root distribution scores were assessed using an ANOVA adjusted for trial treatment effects. The relationship between root form, topple and degree of lean (occurring at the Waihi trial) was also assessed using an ANOVA. This analysis was only performed for Waihi as this was the only trial to experience any significant topple.

RESULTS

Scores for each assessment method are contained in the following Tables:

Ngaruawahia	(see Table 2)
Waihi	(see Table 3)
Feilding	(see Table 4)

TABLE 2: Ngaruawahia - Summary of tree growth, lean and root assessment data

TREE NO	HEIGHT 19 -mths (m)	DIAMETER 19-mths @ 30cm (mm)	LEAN (degrees) 23-mths Root collar	ROOT ASSESSMENT Tap Root	Lateral 23-mths	Planting Depth	VERTICAL ROOT DISTRIBUTION SCORE (% ROOTS) 0	1	2	5	7	10	12
Root trim													
48	1.55	36	45	0	6	11	45	0	10	40	5	0	0
50	1.80	42	0	0	0	7	25	0	20	25	30	0	0
88	1.30	23	0	0	2	6	15	0	10	70	5	0	0
94	1.35	33	0	2	0	6	20	0	25	25	25	0	5
100	1.80	42	0	0	6	9	10	0	10	65	10	0	5
130	1.80	41	0	0	0	8	0	10	0	40	40	5	5
132	2.05	51	0	2	2	3	10	0	0	80	0	0	10
146	1.80	45	0	0	0	9	10	0	5	70	0	15	0
157	1.85	49	0	2	6	8	75	0	0	20	5	0	0
183	1.00	20	0	0	0	5	50	0	0	20	30	0	0
185	1.70	35	0	0	6	7	75	0	0	20	5	0	0
Mean	**1.64**	**38**	**4**	**1**	**3**	**7**	**30.5**	**0.9**	**7.3**	**43.2**	**14.1**	**1.8**	**2.3**
Control													
39	1.70	56	0	2	2	8	60	0	10	20	10	0	0
47	1.80	31	0	0	2	7	35	0	10	30	0	25	0
63	1.30	35	0	10	2	8	0	0	10	80	10	0	0
77	1.70	47	0	4	2	10	0	0	0	80	0	15	5
97	2.05	42	0	2	2	8	10	0	20	40	20	0	10
107	1.80	37	0	2	2	10	35	0	10	25	0	30	0
123	1.35	34	0	2	4	10	50	0	0	40	10	0	0
140	1.95	42	0	0	0	9	0	0	0	70	25	0	5
141	1.35	31	0	0	2	7	30	0	15	45	10	0	0
147	2.25	49	0	0	2	9	20	0	0	70	0	0	10
170	1.45	41	20	2	0	7	30	0	30	25	15	0	0
Mean	**1.70**	**40**	**2**	**2**	**2**	**8**	**24.5**	**0.0**	**9.5**	**47.7**	**9.1**	**6.4**	**2.7**

TABLE 3: Waihi - Summary of tree growth, lean and root assessment data

TREE NO	HEIGHT		DIAMETER	LEAN (degrees)			LEAN DIRECTION		ROOT ASSESSMENT			VERTICAL ROOT DISTRIBUTION SCORE (%ROOTS)				
	11 -mths (m)	19-mths (m)	19-mths @ 30cm (mm)	11 -mths Root collar	19-mths Root collar	19-mths @ 30cm	11-mths	19-mths	Tap Root	Lateral 19-mths	Planting Depth	0	2	5	7	12
Root trim																
17	0.87	2.00	50	36	19	7	East	East	2	0	22	20	30	20	30	0
55	0.76	1.80	30	0	0	0	North	East	0	2	14	30	30	30	10	0
79	0.58	1.82	47	0	4	4	North	East	2	2	14	30	20	25	25	0
111	0.92	2.05	45	0	1	1	North	East	0	6	15	35	10	35	20	0
129	0.95	2.05	56	13	15	8	North/E	East	0	0	15	15	25	20	40	0
135	0.52	1.35	31	0	6	6	North	East	0	2	15	40	20	25	15	0
177	0.95	1.90	50	0	25	12	North	East	0	2	9	20	20	40	15	5
195	0.82	1.92	48	12	9	4	East	West	4	2	13	40	15	20	25	0
Mean	**0.80**	**1.86**	**45**	**8**	**10**	**5**			**1**	**2**	**15**	**29**	**21**	**27**	**23**	**1**
Control																
36	0.78	1.70	46	9	20	7	East	East	4	0	11	10	35	55	0	0
50	0.80	1.65	46	34	21	0	South/E	East	2	4	14	10	20	25	25	20
62	1.18	1.97	68	17	15	15	East	East	0	2	10	30	20	15	20	15
68	0.65	2.49	47	0	0	0	North	East	2	4	13	0	55	15	0	30
90	0.95	1.80	52	18	18	4	East	East	2	2	0	50	25	25	0	0
100	0.80	1.90	53	28	28	6	East	East	4	4	10	55	35	5	0	5
118	0.83	1.75	55	0	2	2	North	East	0	6	10	30	30	20	20	0
156	0.65	1.95	38	28	25	4	East	East	4	2	10	50	15	20	15	0
Mean	**0.83**	**1.90**	**51**	**18**	**16**	**5**			**2**	**3**	**10**	**29**	**29**	**23**	**10**	**9**

TABLE 4: Fielding - Summary of tree growth, lean and root assessment data

TREE NO	HEIGHT 19 -mths (m)	DIAMETER 19-mths @ 30cm (mm)	LEAN (degrees) 23-mths Root collar	ROOT ASSESSMENT Tap Root	Lateral 23-mths	Planting Depth	VERTICAL ROOT DISTRIBUTION SCORE (% ROOTS) 0	1	2	5	7	10	12
Root trim													
14	1.75	38	0	0	2	10	15	0	30	40	15	0	0
40	0.95	20	0	0	0	11	5	0	10	75	10	0	0
60	1.3	31	0	0	0	8	20	0	5	70	5	0	0
64	1.76	46	0	2	0	7	5	0	15	80	0	0	0
66	1.65	40	0	0	2	10	5	0	25	60	10	0	0
80	1.7	49	30	2	0	9	10	0	45	5	30	5	5
86	1.95	45	0	10	0	8	5	0	30	50	15	0	0
104	1.5	36	0	0	0	8	5	0	10	80	5	0	0
160	1.3	28	0	0	2	12	5	0	20	55	15	0	5
170	1.7	39	0	0	0	3	5	0	10	80	5	0	0
192	2.3	49	0	0	0	9	5	0	10	80	5	0	0
Mean	**1.62**	**38**	**3**	**1**	**1**	**9**	**7.7**	**0.0**	**19.1**	**61.4**	**10.5**	**0.5**	**0.9**
Control													
27	0.95	23	0	2	0	6	5	0	10	50	35	0	0
35	1.60	39	0	0	0	10	5	0	5	85	5	0	0
37	1.65	32	0	10	0	10	10	0	35	20	35	0	0
57	1.95	48	45	10	0	9	5	0	15	75	0	0	5
69	1.90	42	0	2	0	6	10	0	15	60	15	0	0
89	1.70	52	0	0	0	6	10	0	25	60	5	0	0
113	2.20	47	0	0	0	7	35	0	10	50	5	0	0
123	1.60	40	0	0	0	8	10	0	20	65	5	0	0
139	1.95	41	0	6	0	9	0	0	15	80	5	0	0
163	1.60	39	0	10	0	9	10	0	10	80	0	0	0
183	2.30	56	0	10	0	8	10	0	50	40	0	0	0
Mean	**1.76**	**42**	**4**	**5**	**0**	**8**	**10.0**	**0.0**	**19.1**	**60.5**	**10.0**	**0.0**	**0.5**

Menzies' Taproot Score

Once the bias in lean between the treatment and control samples was removed there was no significant difference ($p > 0.05$) for Menzies' taproot scores between the conventionally conditioned seedlings and severe lateral root trimmed seedlings at any of the sites. Comparison of root scores between sites found no difference in taproot score.

Table 5: Menzies' Taproot Score, assessed at age 23 months. Standard errors of the average are given in brackets below the weighted average.

		Ngaruawahia		Waihi		Feilding	
Score	Description	Root Trim No. of Trees	Control No. of Trees	Root Trim No. of Trees	Control No. of Trees	Root Trim No. of Trees	Control No. of Trees
10	Taproot does not come below a horizontal line	0	1	0	0	1	4
4	Taproot distinctly hooked	0	1	1	3	0	1
2	Stunted, slightly malformed, but still a definite taproot	3	5	2	3	2	2
0	Strong, dominant, well developed taproot	8	4	5	2	8	4
	TOTAL No. of trees	**11**	**11**	**8**	**8**	**11**	**11**
	Weighted Average	**0.5**	**2.2**	**1.0**	**2.3**	**1.3**	**4.5**
	Standard Error	(0.65)	(0.65)	(0.55)	(0.55)	(1.18)	(1.18)

Menzies' Lateral Root Distribution Score

A summary of the Menzies' Lateral Root Scores are shown in Table 6. There was no significant difference ($p > 0.05$) between the conventionally conditioned seedlings and severe lateral root trimmed seedlings.

There was a significant ($p < 0.05$) difference between sites in lateral root distribution scores, with the Feilding site having superior lateral root distribution compared to the other two sites (see Table 9).

Table 6: Menzies' Lateral Root Distribution Score, assessed at age 23 months.

		Ngaruawahia		Waihi		Feilding	
Score	Description	Root Trim No. of Trees	Control No. of Trees	Root Trim No. of Trees	Control No. of Trees	Root Trim No. of Trees	Control No. of Trees
6	Laterals in two opposite quadrants	4	0	1	1	0	0
4	Laterals in two adjacent quadrants	0	1	0	3	0	0
2	Laterals in three quadrants	2	8	5	3	3	0
0	Laterals on all four quadrants	5	2	2	1	8	11
	TOTAL No. of trees	**11**	**11**	**8**	**8**	**11**	**11**
	Weighted Average	**2.5**	**1.8**	**2.0**	**3.0**	**0.5**	**0.0**
	Standard Error	(0.65)	(0.65)	(0.65)	(0.65)	(0.20)	(0.20)

Depth of Planting

A summary of depth of planting is shown in Table 7. On average the planting depth ranged from 7 to 15cm which is the required depth to provide initial stability.

Table 7: Planting Depth, assessed at age 23 months

Location	Treatment (cm)	Control (cm)
Feilding	9.0	8.0
Ngaruawahia	7.0	8.0
Waihi	15.0	10.0

Menzies' Vertical Root Distribution Score

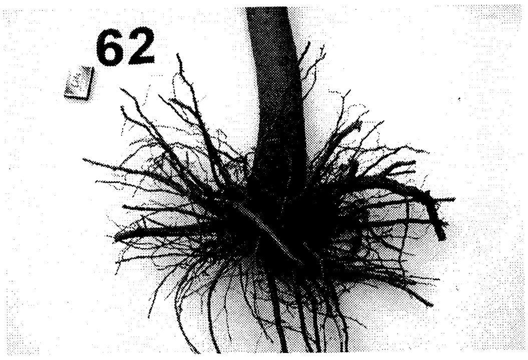
There was no significant difference ($p > 0.05$) between the conventionally conditioned seedlings and severe lateral root trimmed seedlings for the Menzies' Vertical Root Distribution Score. There were no significant differences ($p > 0.05$) for the Vertical Root Distribution Scores across the three sites (see Table 9).

The percentage of roots orientated above the horizontal was similar for the higher rainfall sites of Waihi and Ngaruawahia being 21.0% and 18.2% respectively. The drier Feilding site has only 11.3% of the roots orientated above the horizontal (see Table 8).

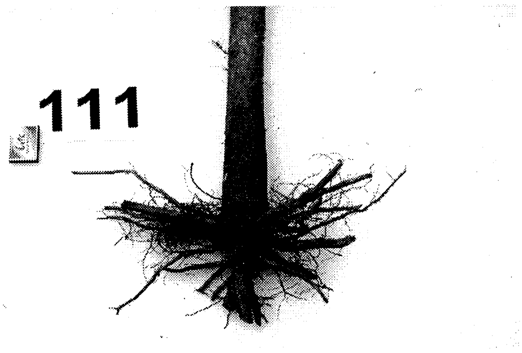
Table 8: Menzies' Vertical Root Distribution Score, assessed at age 23 months

Score	Description	Ngaruawahia % Roots	Waihi % Roots	Feilding % Roots
12	Roots at an angle greater than 45° above the horizontal	2.5	5.0	0.7
10	Roots at 45° above the horizontal	4.1	0.0	0.3
7	Roots at an angle less than 45° above the horizontal	11.6	16.0	10.3
5	Roots at the horizontal	45.5	25.0	61.0
2	Roots at an angle less than 45° below the horizontal	8.4	25.0	19.0
1	Roots tubed at an angle greater than 45° below the horizontal	0.5	0.0	0.0
0	Roots at an angle less than 45° below the horizontal	27.5	29.0	8.9
	Weighted Average Score	**4.0**	**3.5**	**4.3**

Figure 10: Example of conventionally conditioned and severe lateral root trimmed seedlings illustrating the large proportion of roots orientated above the horizontal.



Conventionally conditioned seedling



Severe lateral root trimmed seedling

Table 9: Comparison of the average Menzies' Taproot, average Menzies' Lateral, and weighted average Menzies' Vertical Root Distribution scores among the three locations adjusted for trial treatment effects. Averages with the same letter are not significantly different at the 1% level.

Location	Taproot Score		Lateral Score		Vertical Root Distribution Score	
Ngaruawahia	1.9	a	2.1	b	3.7	a
Waihi	1.2	a	2.2	b	3.7	a
Feilding	3.4	a	0.2	a	4.0	a

Relationship Between Root Form and Topple

Those trees which had toppled to any degree at Waihi, ie., lean greater than zero, had significantly poorer tap root form (p=0.0197) than non-toppled, with an average Menzies' tap root score of 2.4 compared with 0.6 for non-toppled. Taproot score alone accounted for 33% of the variation in incidence of topple. The Menzies' tap root score is also significantly correlated (p=0.0473) with the degree of lean measured at age 11 months (R^2 = 0.25). It is not possible from this data to determine whether poor taproot form is the result of topple or that topple arises from poor taproot form.

DISCUSSION

The significant differences to emerge from this study are that:

- The Feilding site has superior lateral root distributions compared to the other two sites possibly due to friable silt soils.
- Ngaruawahia and Waihi sites have approximately twice the percentage of roots orientated above the horizontal (as illustrated Figure 10) possibly because of a considerably higher and evenly distributed rainfall. To provide conclusive explanations to the differences found above, further assessments will be carried out on toppling trials established in 1997 located on a wider range of soil types.
- The small sample size (22 trees at Feilding and Ngaruawahia and 16 trees at Waihi) and the high level of variation in root morphology necessitates an increase in the sample size to a minimum of 20 trees.

CONCLUSIONS

The severe lateral root trim treatment has not resulted in a significant improvement in taproot form over conventional nursery root conditioning. There is no difference between nursery treatments in taproot score when adjusted for bias in sampling due to lean. In agreement with work by Mason (1985), taproot form has a significant influence on the incidence, and to a lesser extent degree, of topple.

The small sample size, eight trees per treatment for Waihi, eleven trees per treatment for the Feilding and Ngaruawahia sites along with the variation in root morphology mean that the results of the statistical analysis must be interpreted with a degree of caution. Assessment and analysis of further sites using larger samples, approximately 20 trees per treatment, is recommended.

Assessment and analysis of roots from sites on other soil types is required to confirm the effects found in this study.

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References

Cannell, M.G.R.; S.C. Willett. 1976. Shoot growth phenology, dry matter distribution and root: shoot ratios of prevenances of *Populus trichocarpa, Picea sitchensis* and *Pinus contorta* growing in Scotland. **Silvae Genetica 25(2)**: 49-59.

Chandler, K.C. 1968. Climatic damage to forests of the Tapanui District. **New Zealand Journal of Forestry 13(1)**: 98-110.

Chavasse, C.G.R. 1969. Instability in young stands. **Farm Forestry 11(3)**: 70-77.

Coutts, M.P. 1983. Root architecture and tree stability. **Plant and Soil 71**: 171-188.

Danby, N.P. 1973. Summary of root/ shoot ratio results of Lodgepole pine 3 to 8 years after planting. **Internal Report Forestry Commission**. Unpublished.

Gruschow, G.F. 1959. Observations on root systems of planted loblolly pine. **Journal of Forestry 57**: 894-896.

Halliday, D. and R. Resnick. 1988. **Fundamentals of Physics**. extended third edition. John Wiley and Sons, New York.

Lines, R. 1971. Provenances. Lodgepole pine. Studies of factors leading to basal bowing. In **Report on Forest Research**, H.M.S.O. London: 39-40.

Lines, R. 1980. Stability in *Pinus contorta* in relation to wind and snow. In *Pinus contorta* as an exotic species. **Proceedings of the IUFRO working party meeting 1980 on *Pinus contorta* provences (S2-02-06) in Norway and Sweden**. Swedish University of Agricultural Science, Department of Forest Genetics, Research Notes No. 30. Garpenburg: 209-219.

Mason, E.G. 1985. Causes of juvenile instability of *Pinus radiata* in New Zealand. **New Zealand Journal of Forestry Science 15(3)**: 263-280.

Mason, E.G.; A.W.J. Cullen; W.C. Rijkse. 1988. Growth of two *Pinus radiata* stock types on ripped and ripped/ bedded plots at Karioi Forest. **New Zealand Journal of Forestry Science 18(3)**: 287-296.

Mason, E.G.; A.W.J. Cullen. 1986. Growth of *Pinus radiata* on ripped and unripped Taupo pumice soil. **New Zealand Journal of Forestry Science 16(1)**: 3-18.

Menzies, M.I. 1974. Tree toppling trials at Whaka Forest. **New Zealand Forest Service, Forest Research Institute, Production Forestry Division Report No FE60** (unpubl.).

Moore, J. and A. Somerville. 1998. Assessing the risk of wind damage to plantation forests in New Zealand. **New Zealand Forestry 43(1)**: 25-29.

Nambiar, E.K.S. 1980. Root configuration and root regeneration in *Pinus radiata* seedlings. **New Zealand Journal of Forestry Science 10(1)**: 249-263.

Nicoll, B.C.; E.P. Easton; A.D. Milner; C. Walker; M.P. Coutts. 1995. Wind stability in tree selection: distribution of biomass within root systems of Sitka spruce clones. In M.P. Coutts & J. Grace (eds.) **"Wind and Trees"**. Cambridge University Press.

Nielsen, C.Ch.N. 1992. Will traditional conifer tree breeding for enhanced stem production reduce wind stability? Genetic variation in allocation of biomass to root classes and stem. **Silvae Genetica 41(6)**: 307-319.

Papasch, A.J.G.; J.R. Moore; A.E. Hawke. 1997. Mechanical stability of *Pinus radiata* trees at Eyrewell forest investigated using static tests. **New Zealand Journal of Forestry Science 27(2)**: 188-204.

Petty, J.A. and C. Swain. 1985. Factors influencing stem breakage in conifers in high winds. **Forestry 58(1)**: 75-84.

Pfeifer, A.R. 1982. Factors that contribute to basal sweep in lodgepole pine. **Irish Forestry 39(1)**: 7-16.

Ray, J.; G. Coker; B. Richardson; A. Vanner. 1998. The effect of compaction, weed control, fertilisation, and planting on the stability of *Pinus radiata* cuttings and seedlings. **NZFRI Project Record No. 6186**. (unpubl.)

Snowdon, P.; H.D. Waring. 1985. Response to some genotypes of *Pinus radiata* to clover and fertilization. **Australian Forest Research 15**: 123-134.

Somerville, A. 1979. Root anchorage and root morphology of *Pinus radiata* on a range of ripping treatments. **New Zealand Journal of Forestry Science 9(3)**: 294-315.

Stokes, A; A.H. Fitter; M.P. Coutts. 1995. Responses of young trees to wind: effects on root growth. In Coutts, M.P. & J. Grace (eds) **"Wind and Trees"**. Cambridge University Press.

Wendelken, W.J. 1955. Root development and wind-firmness on the shallow soils of the Canterbury plain. **New Zealand Journal of Forestry 7(2): 71-76.**

APPENDIX 1:

Photographs of the Ngaruawahia root samples

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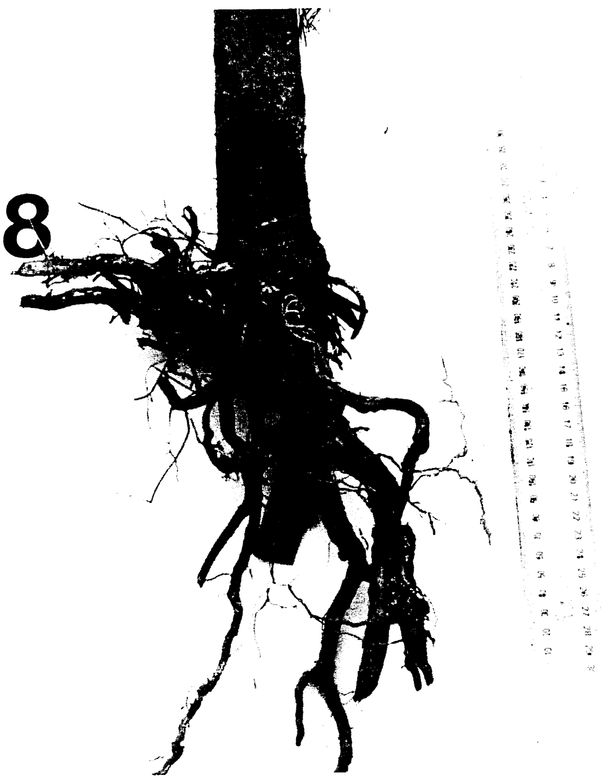

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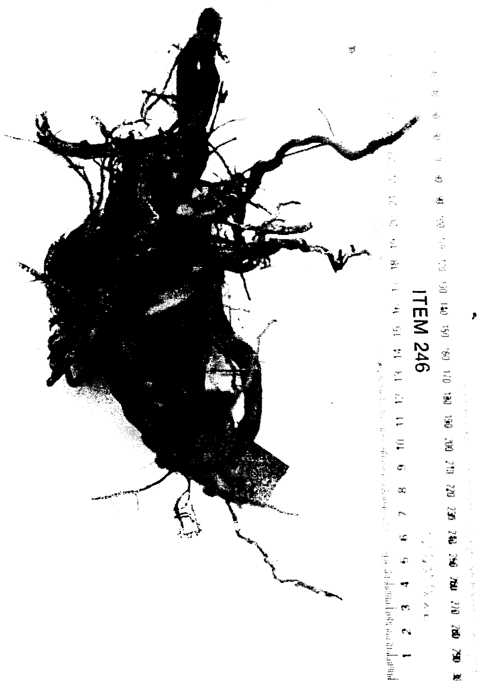

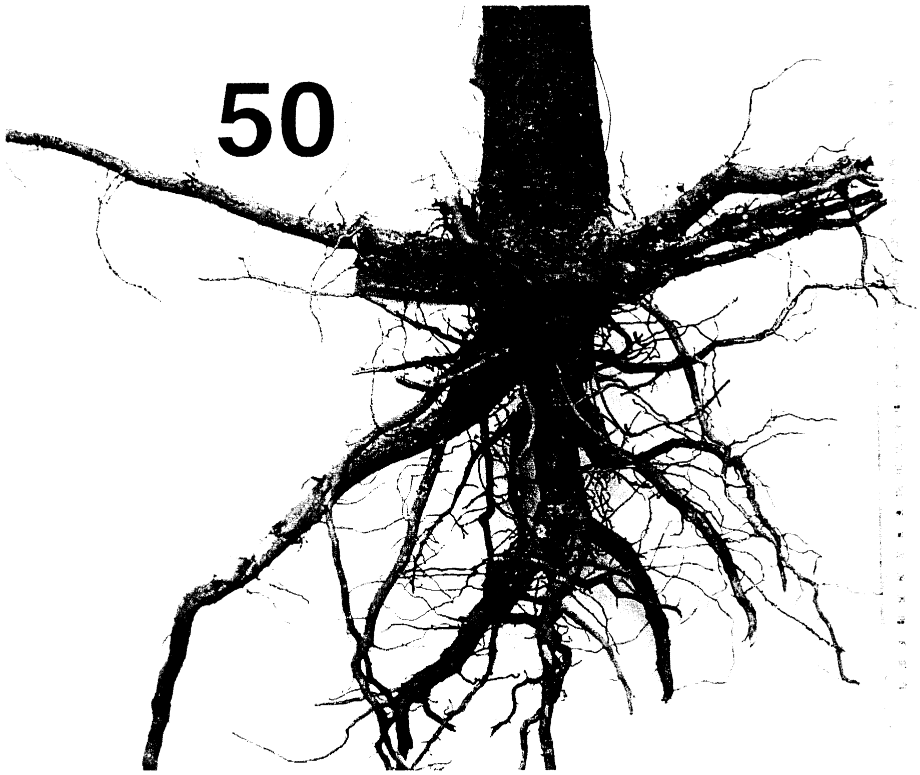
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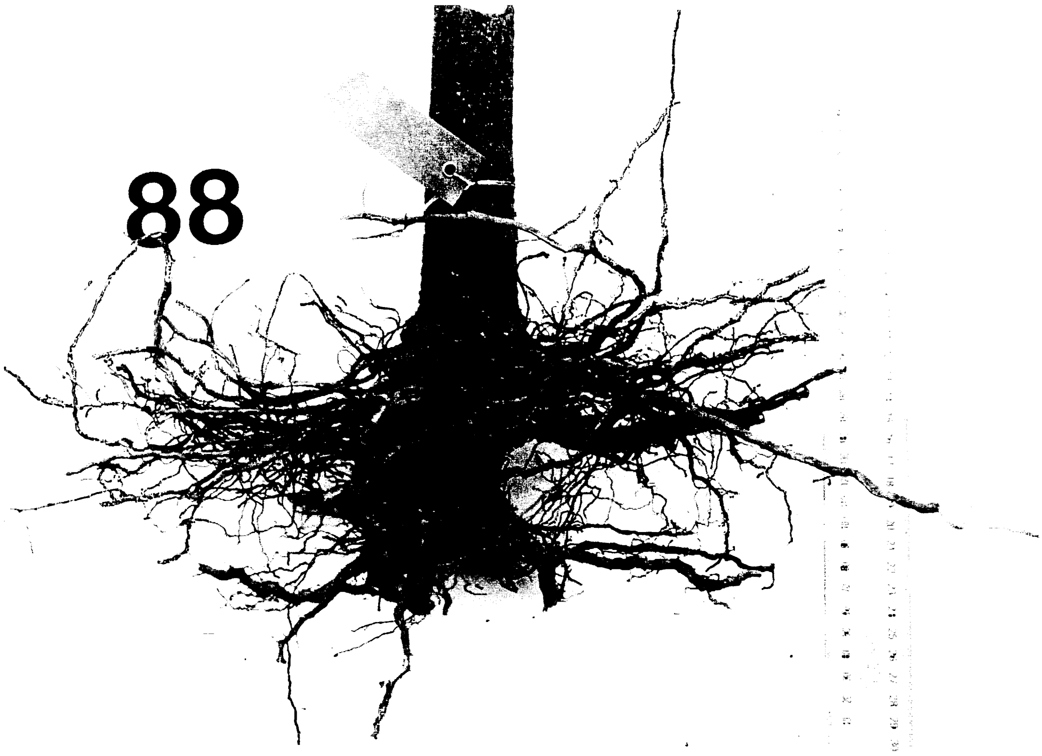
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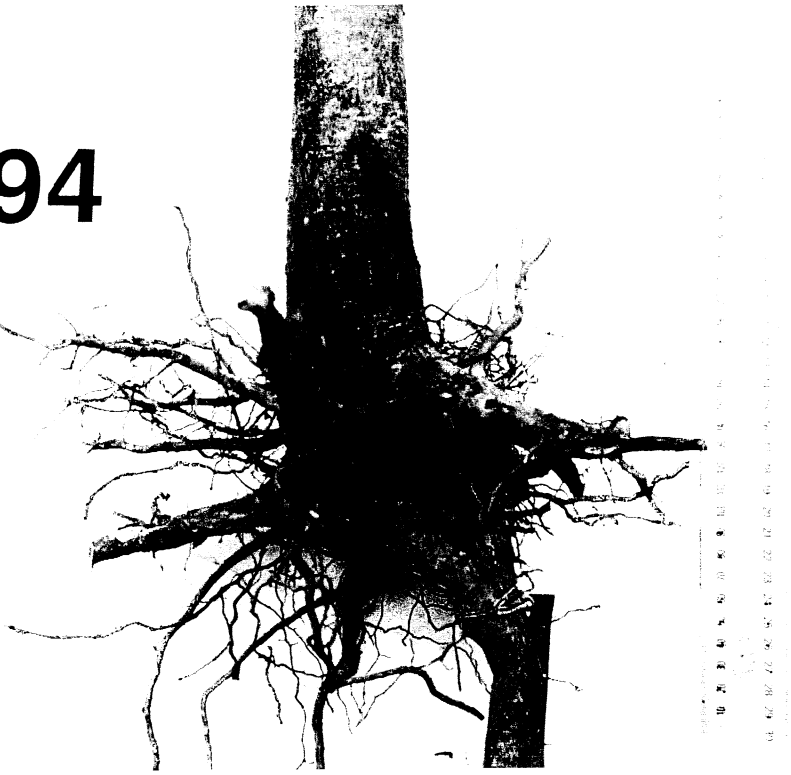

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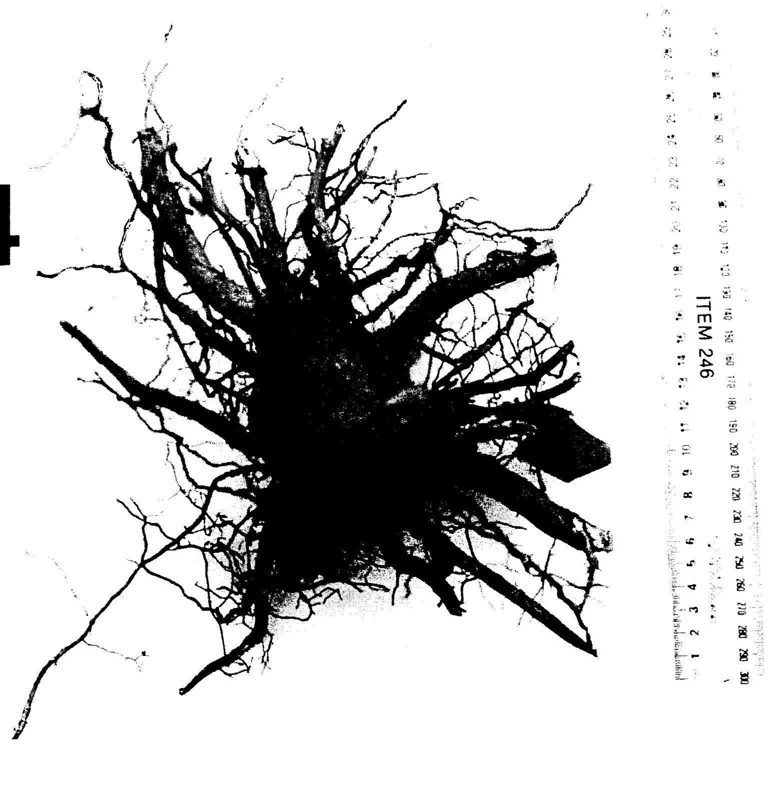

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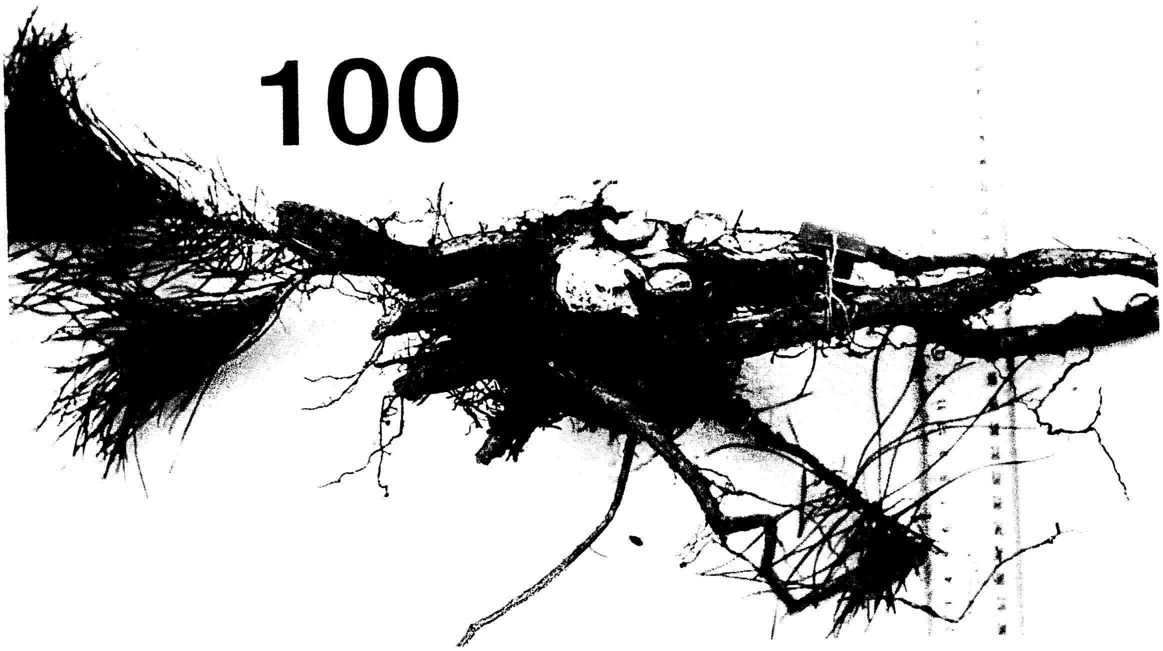
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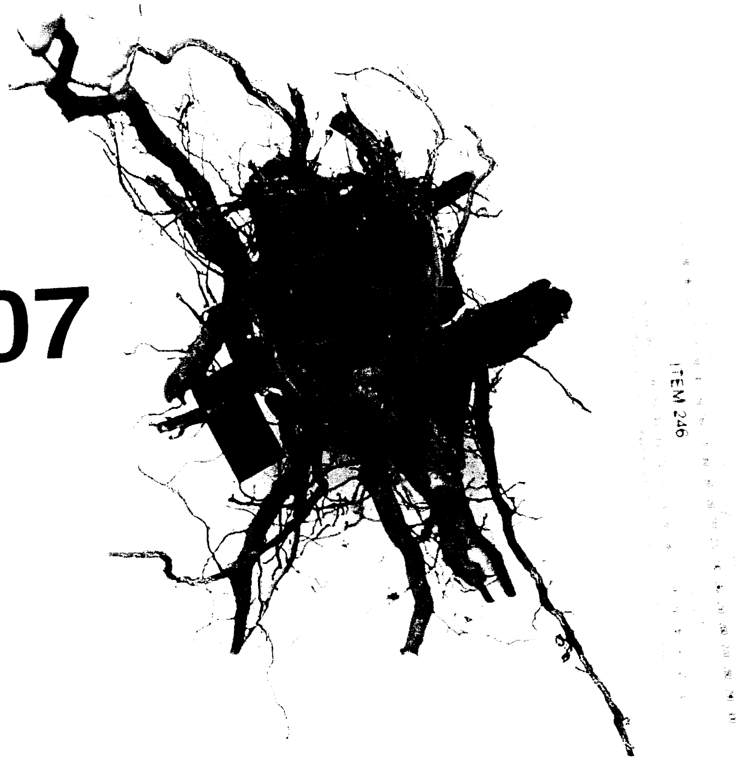

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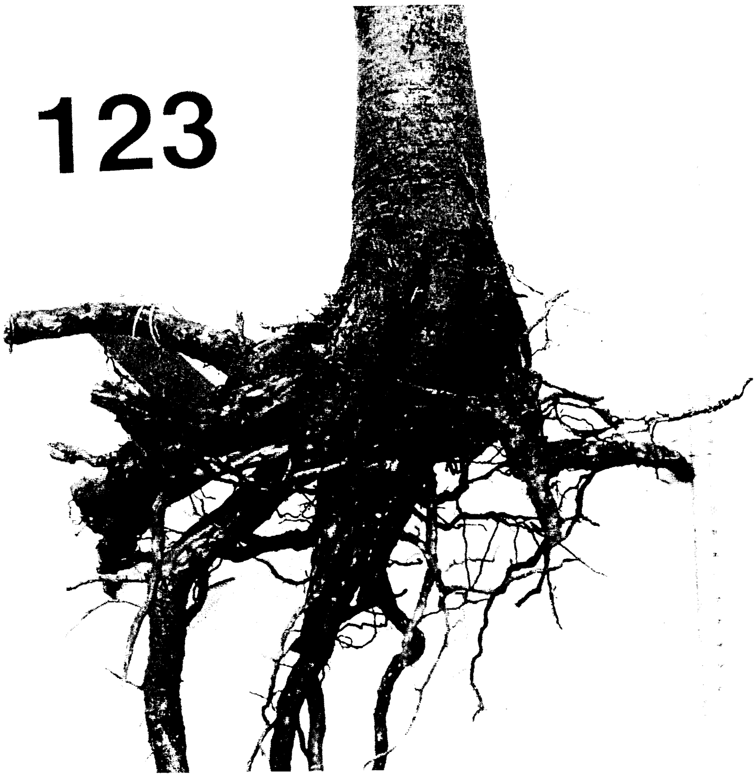

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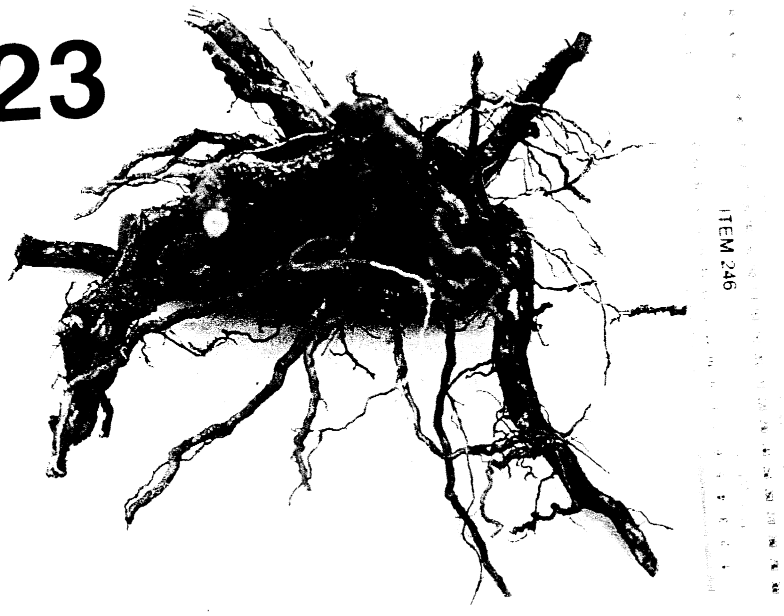

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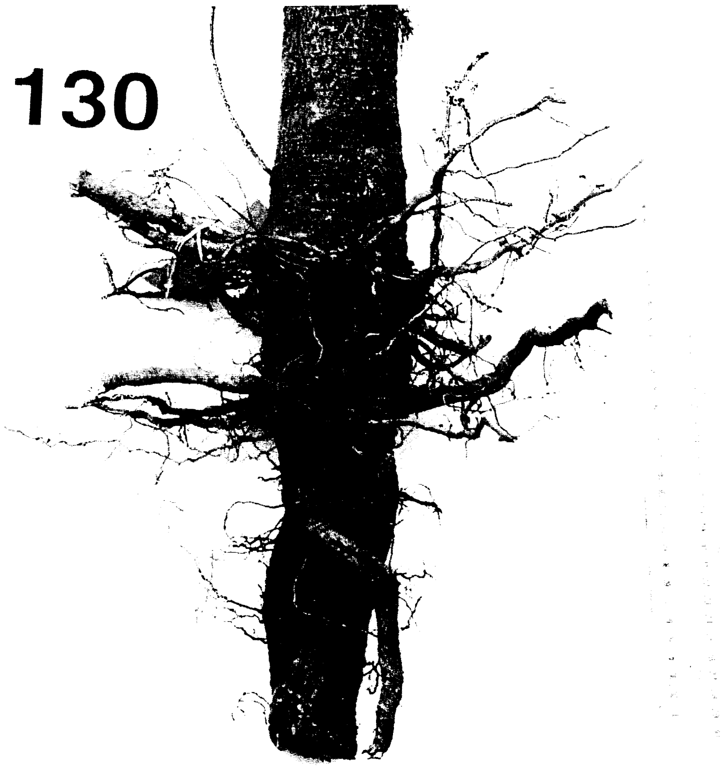

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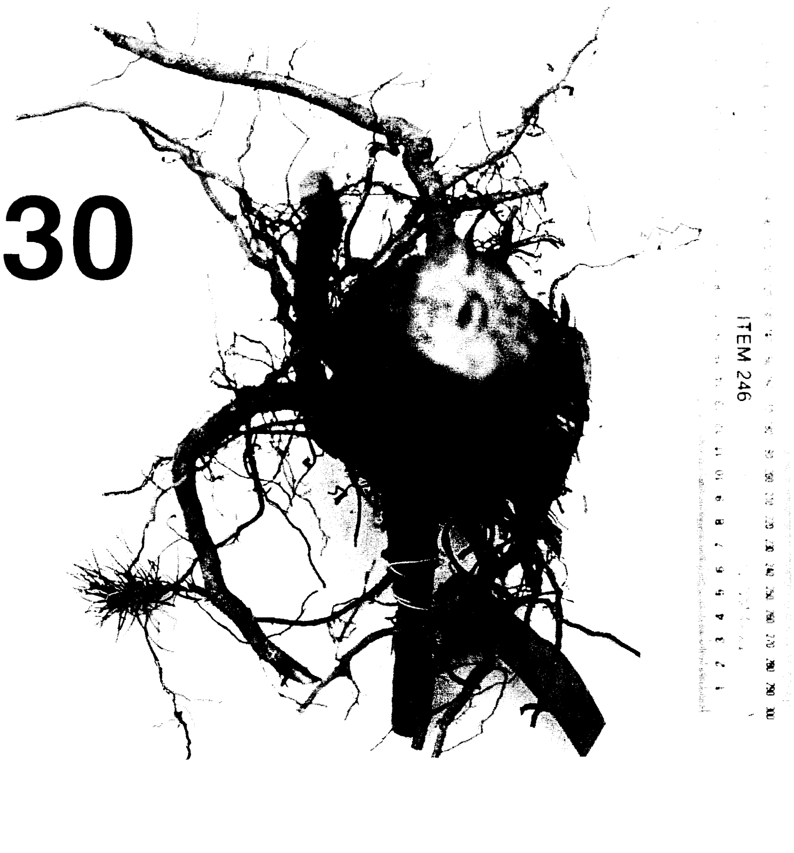

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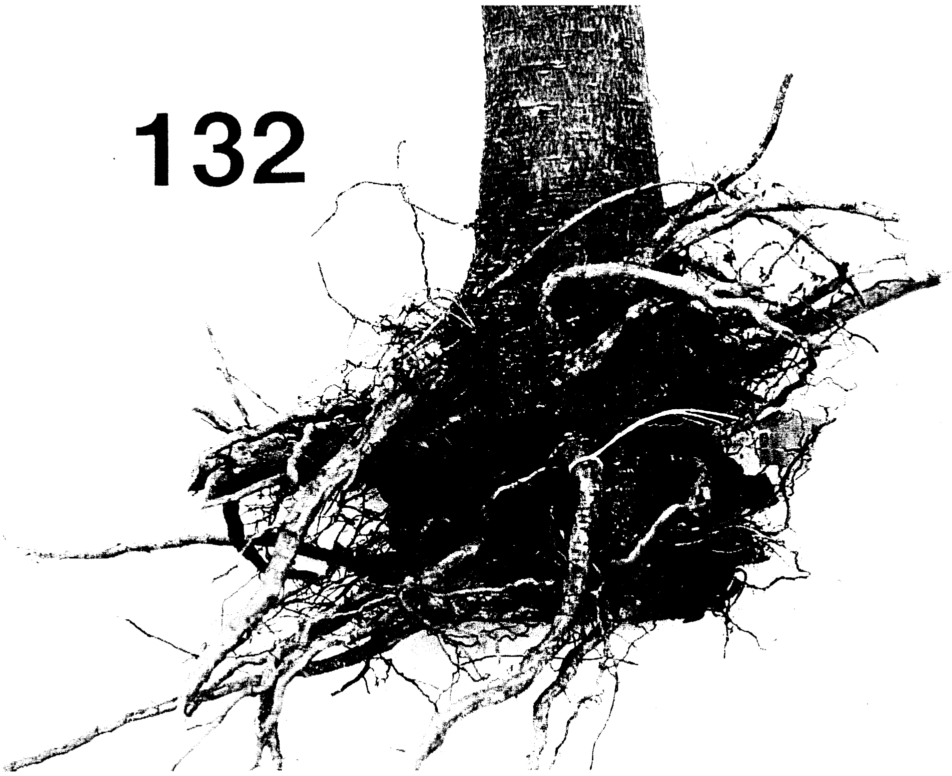

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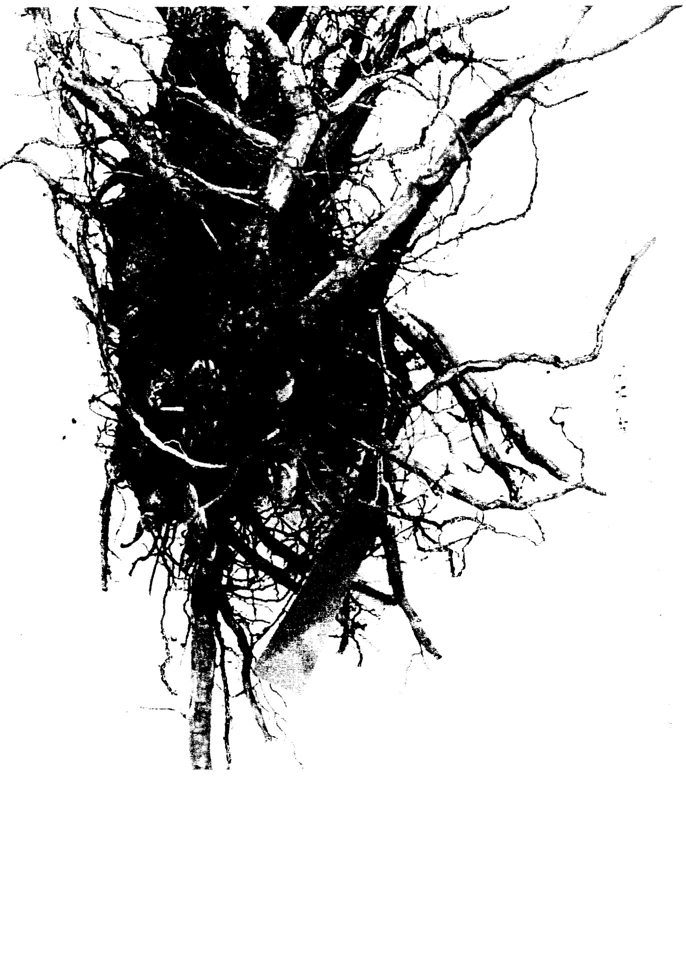

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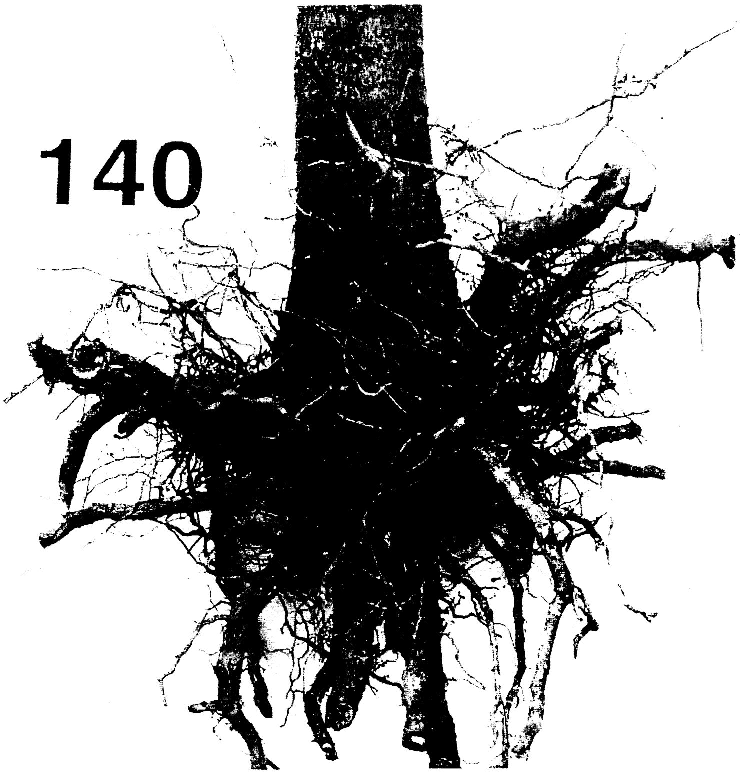

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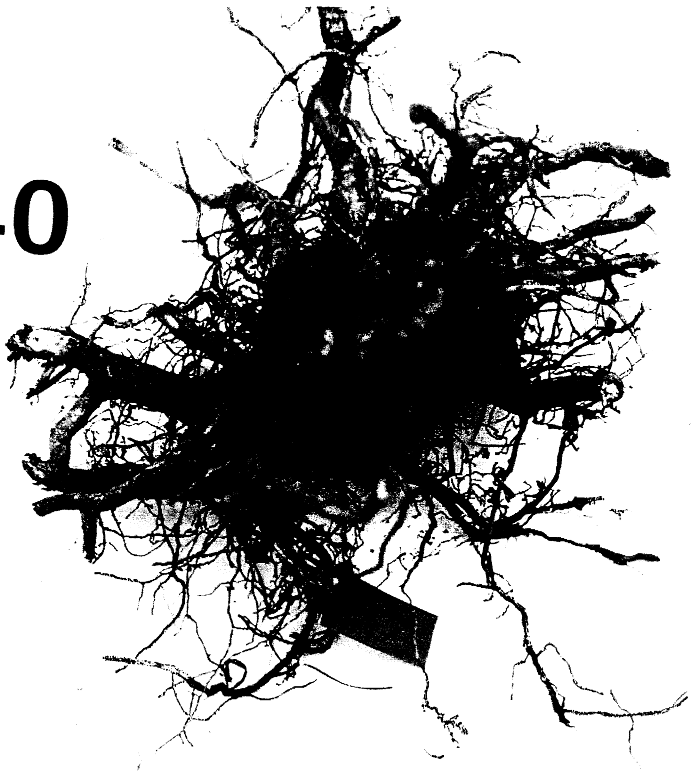

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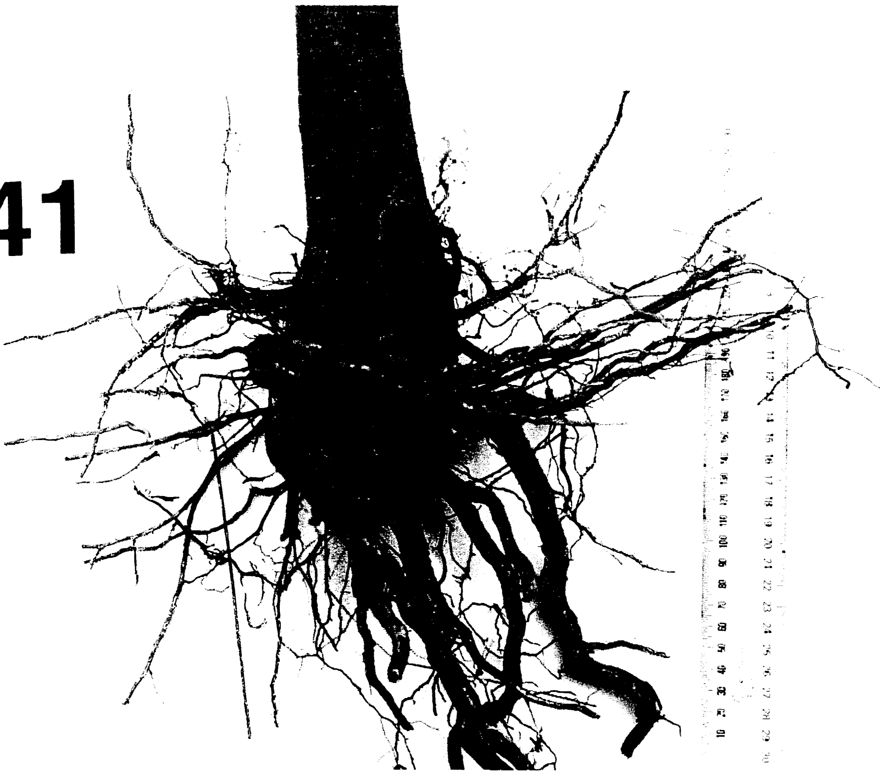

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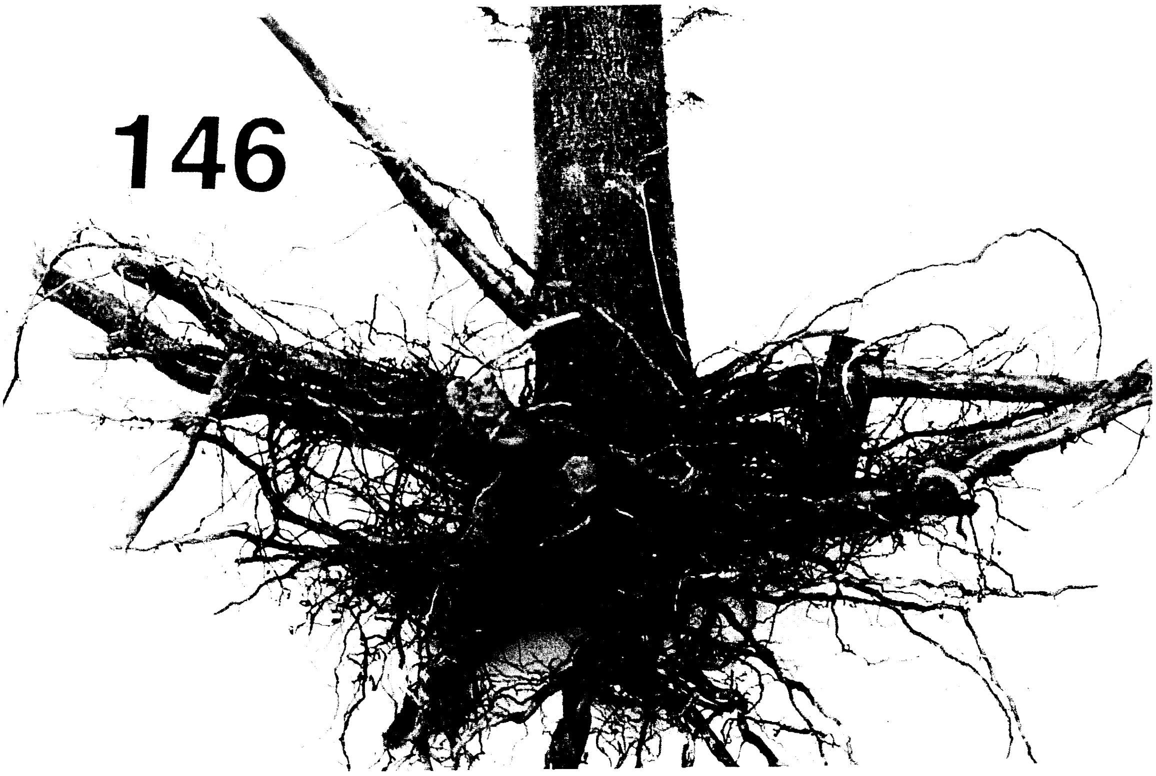

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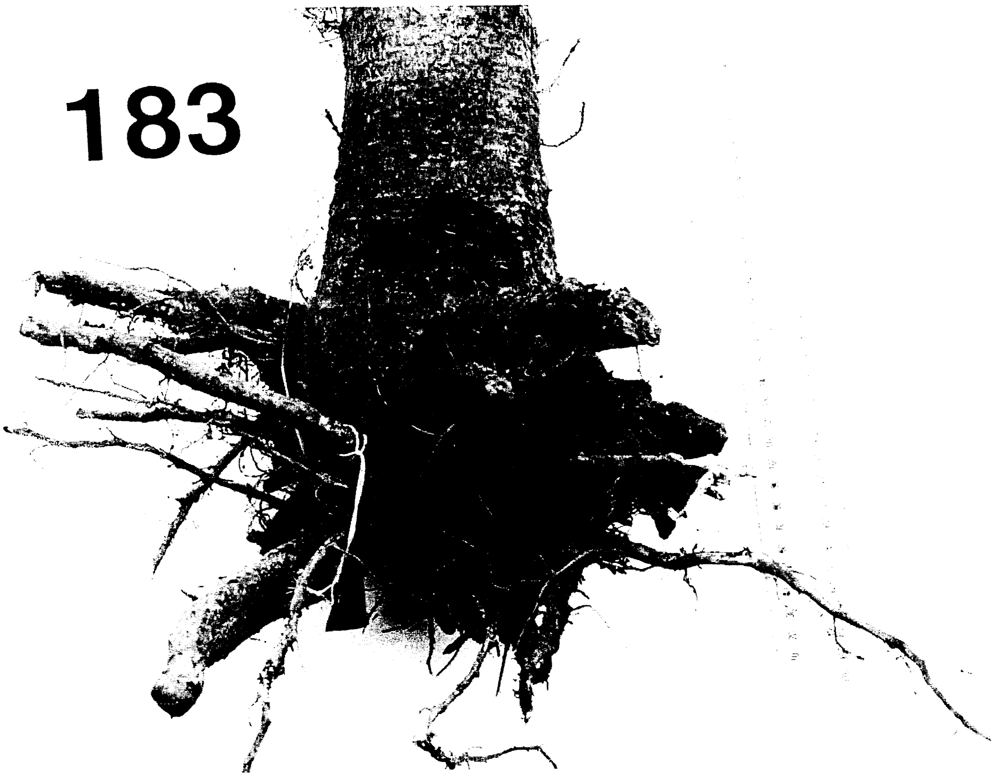

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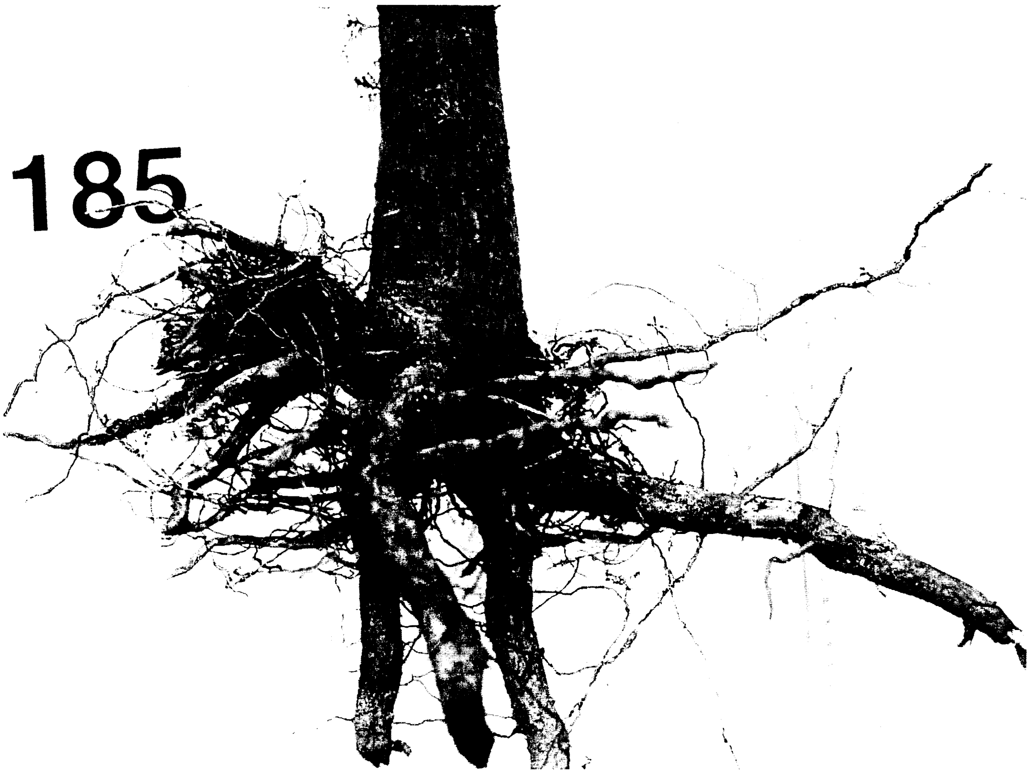

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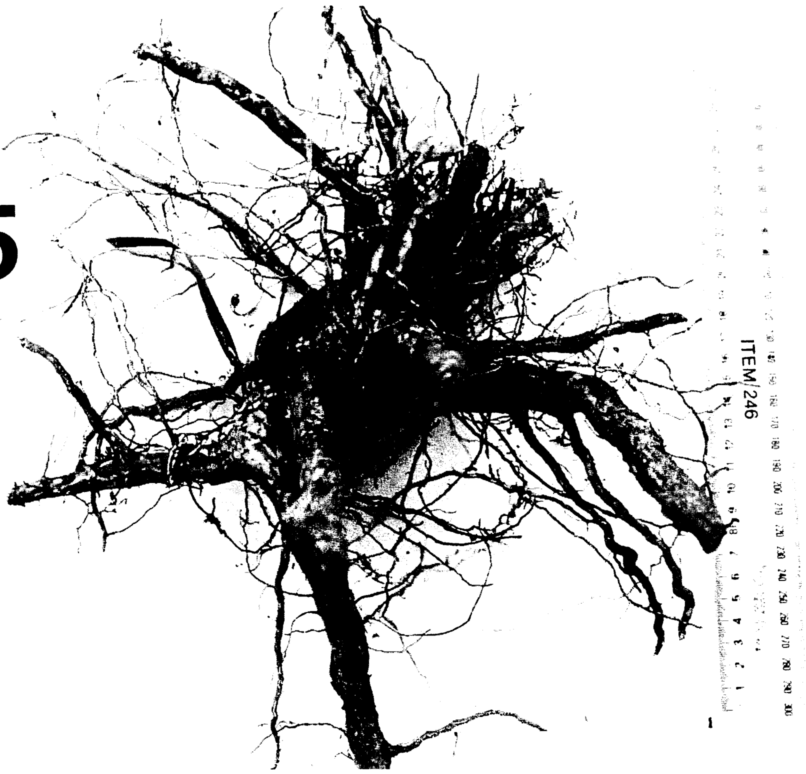
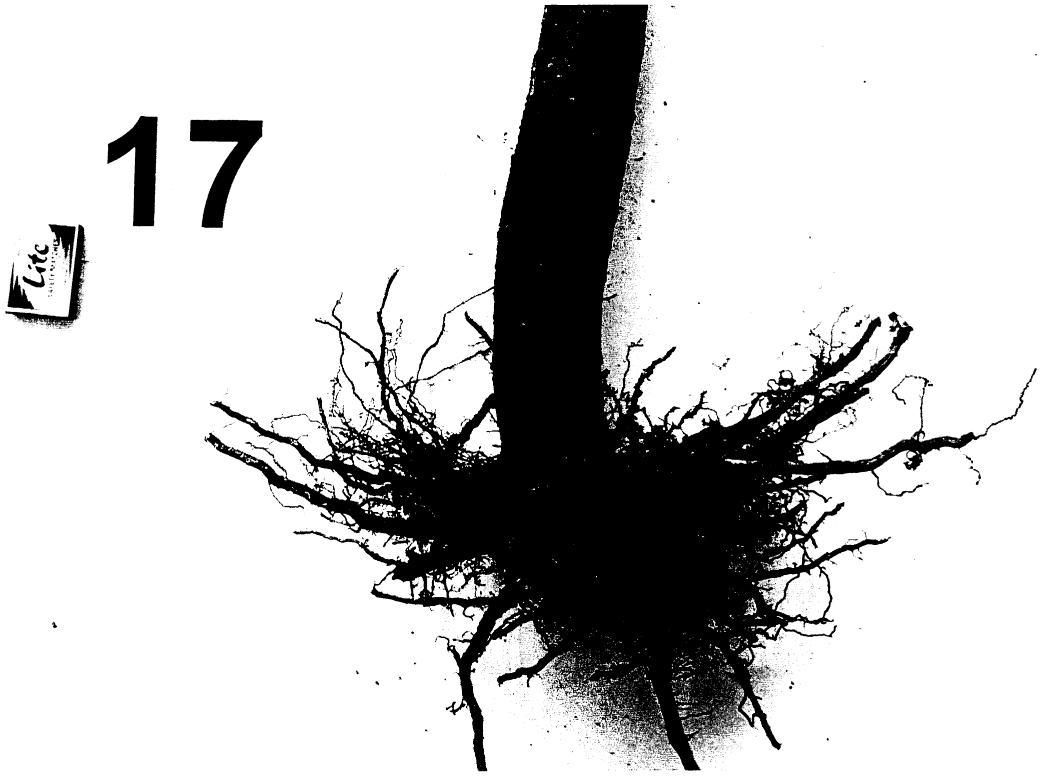


APPENDIX 2:

Photographs of the Waihi root samples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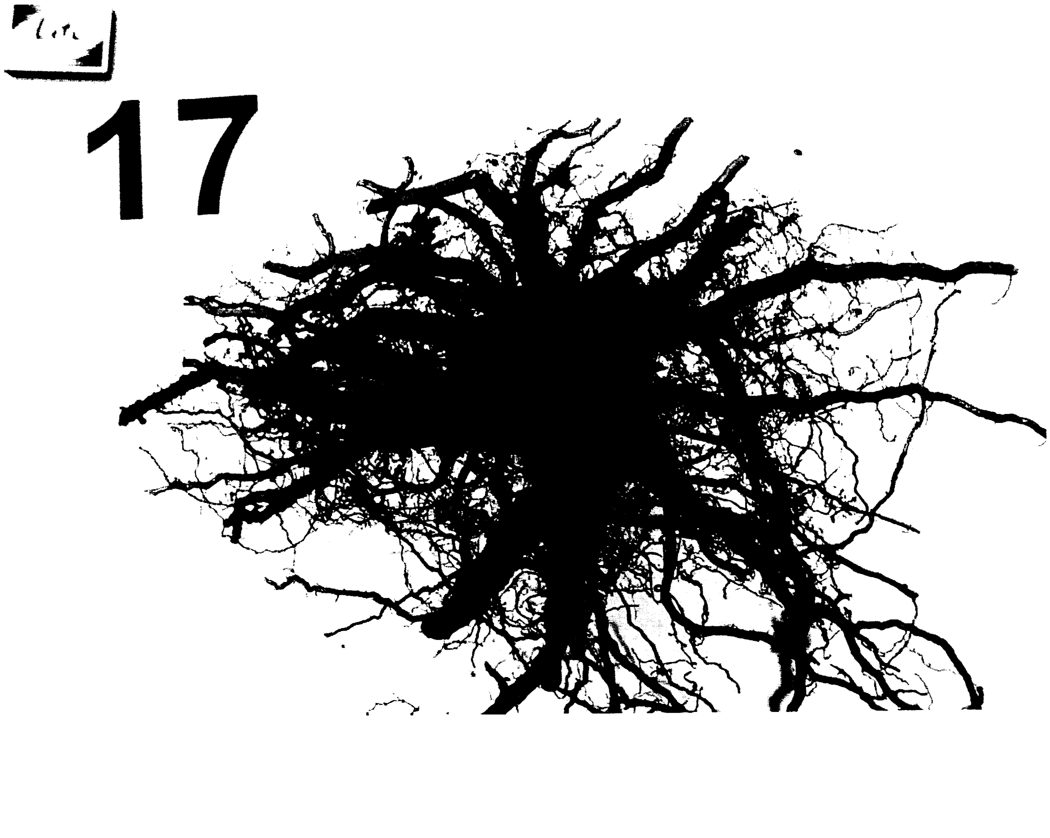
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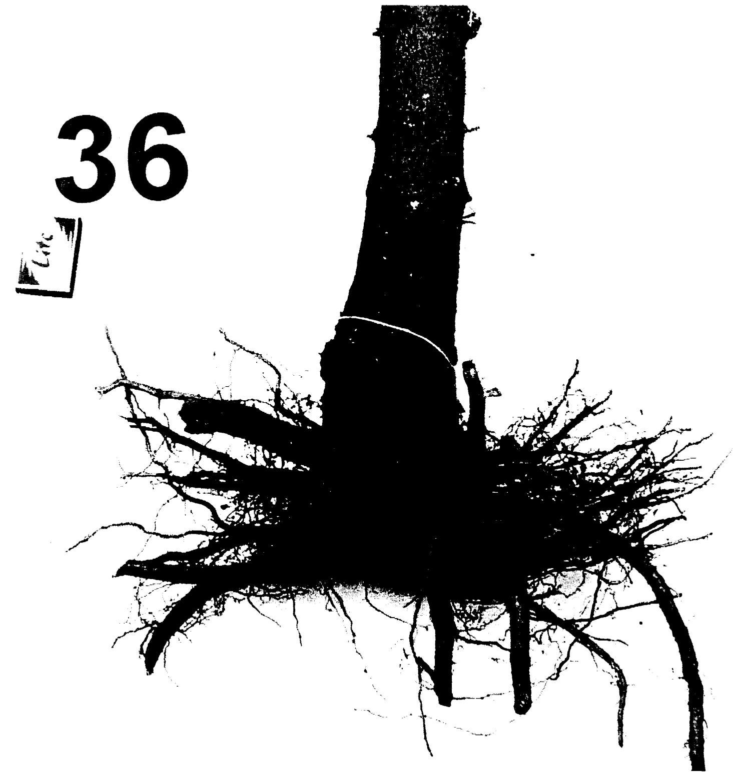
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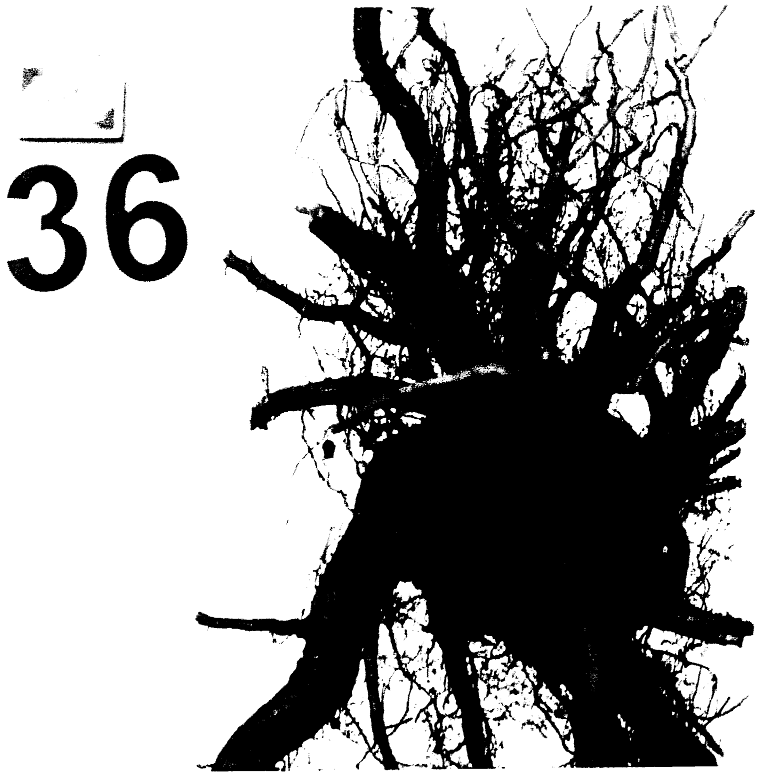
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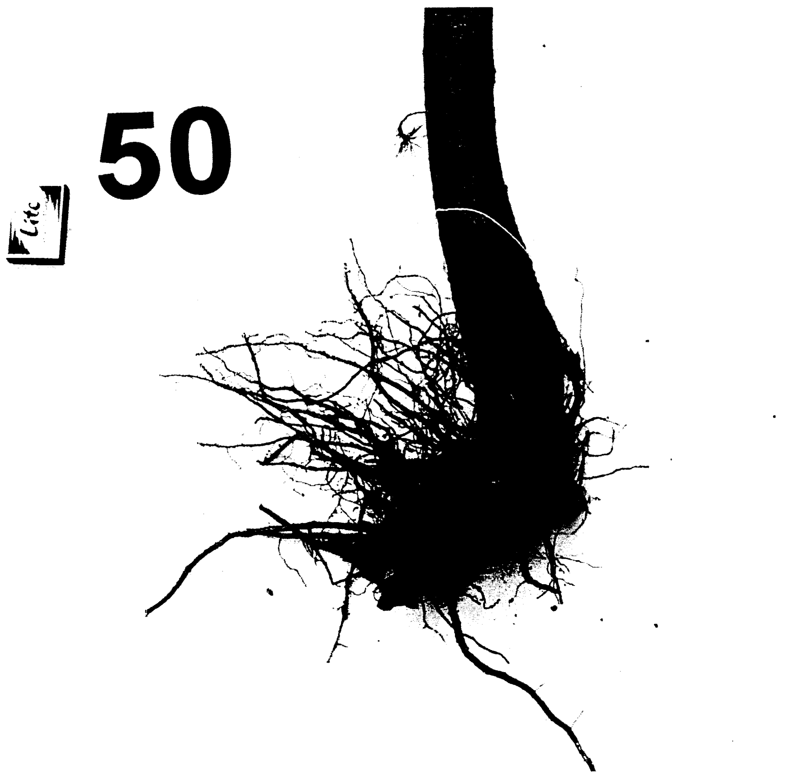
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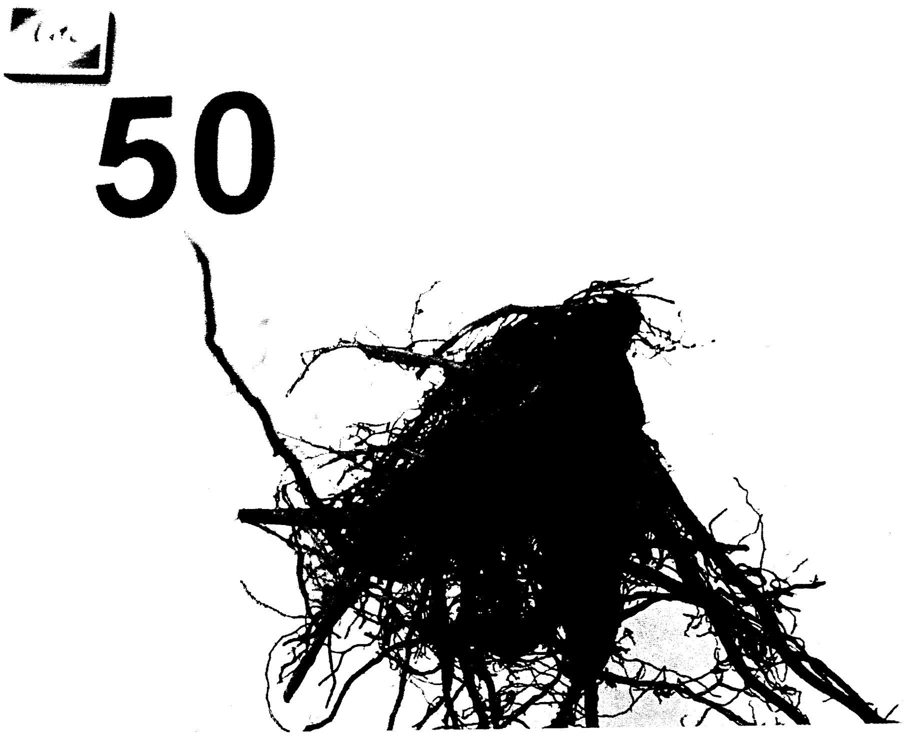
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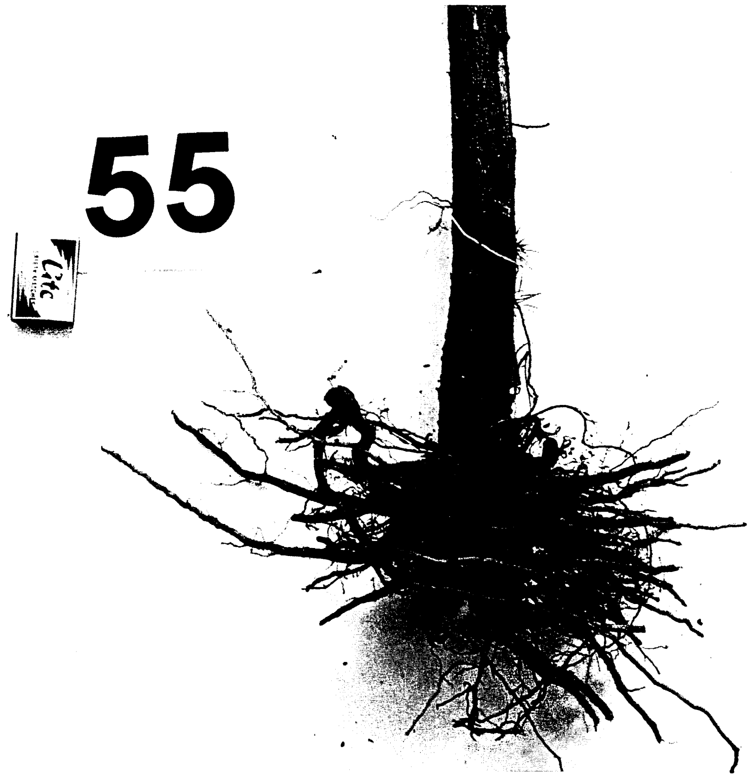
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SAFETY MATCHES
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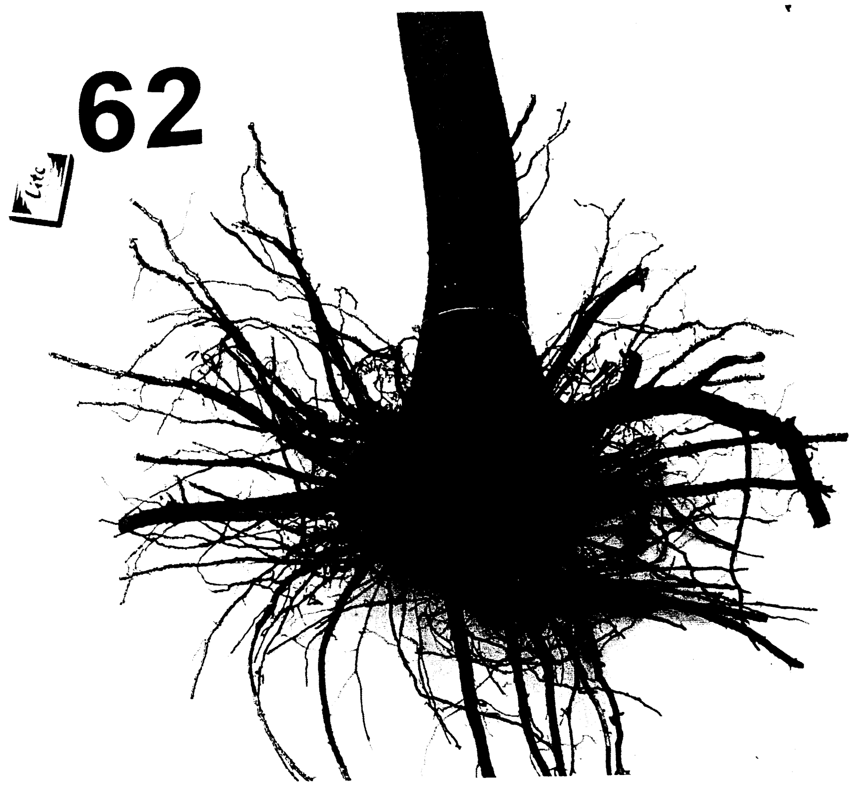
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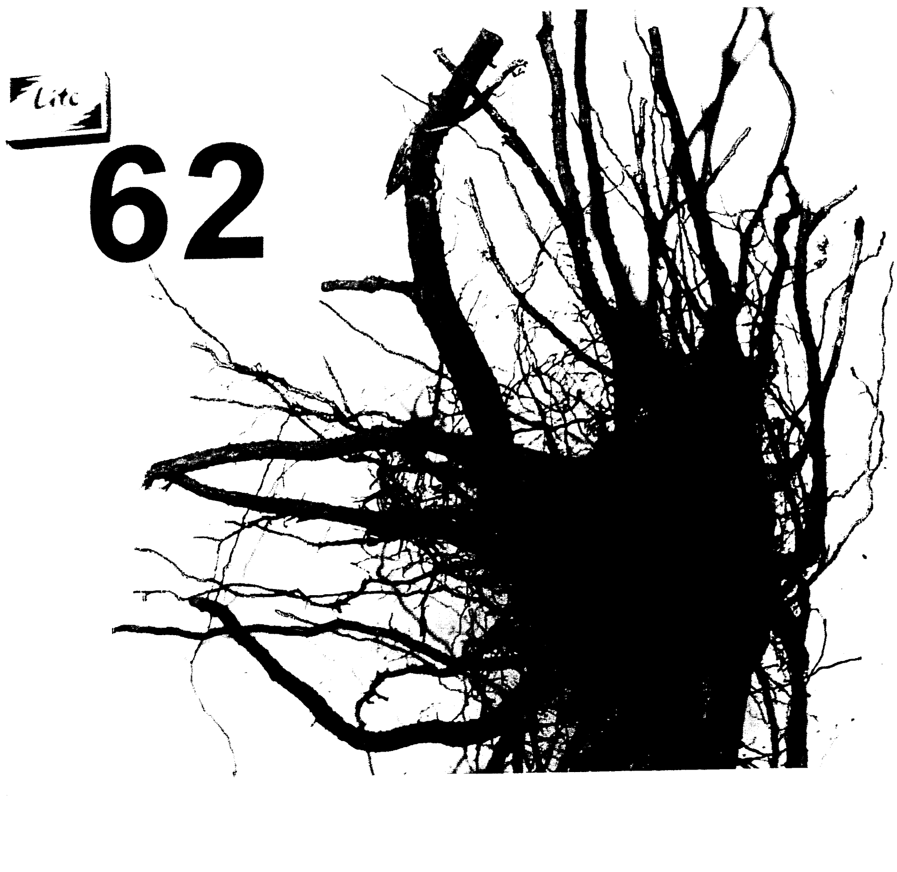
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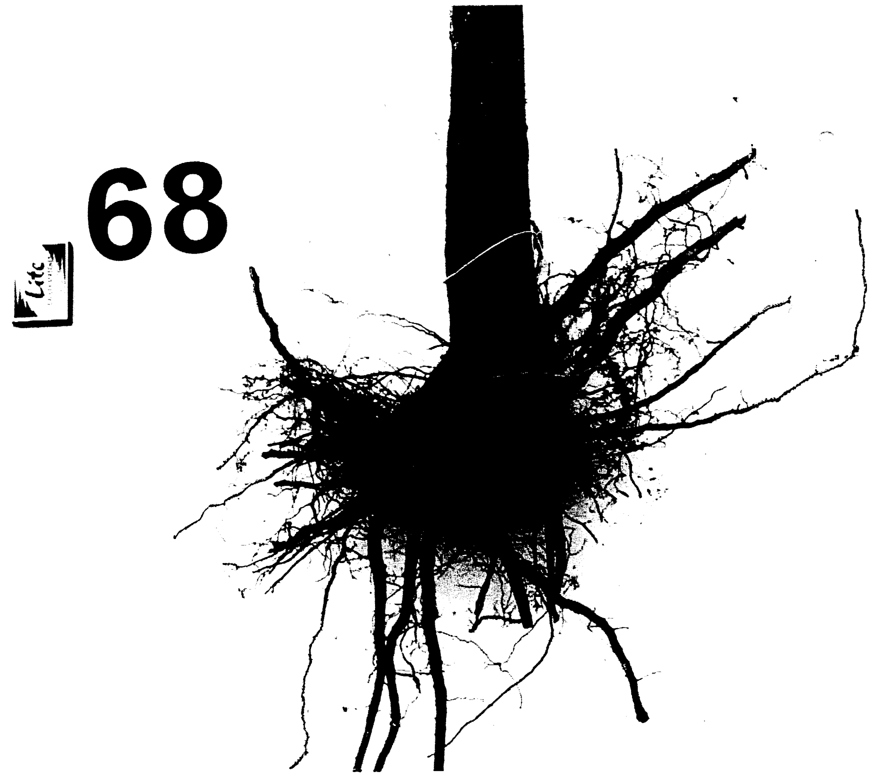
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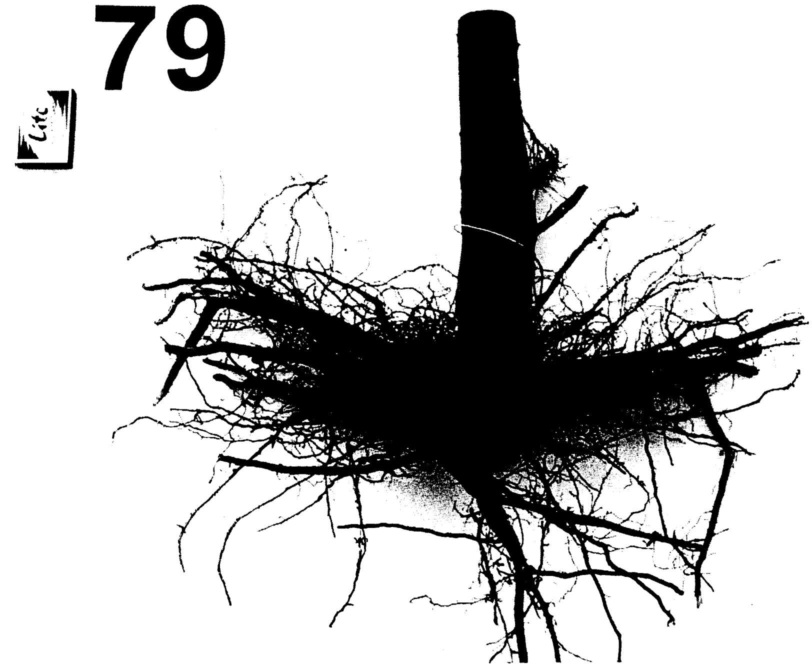
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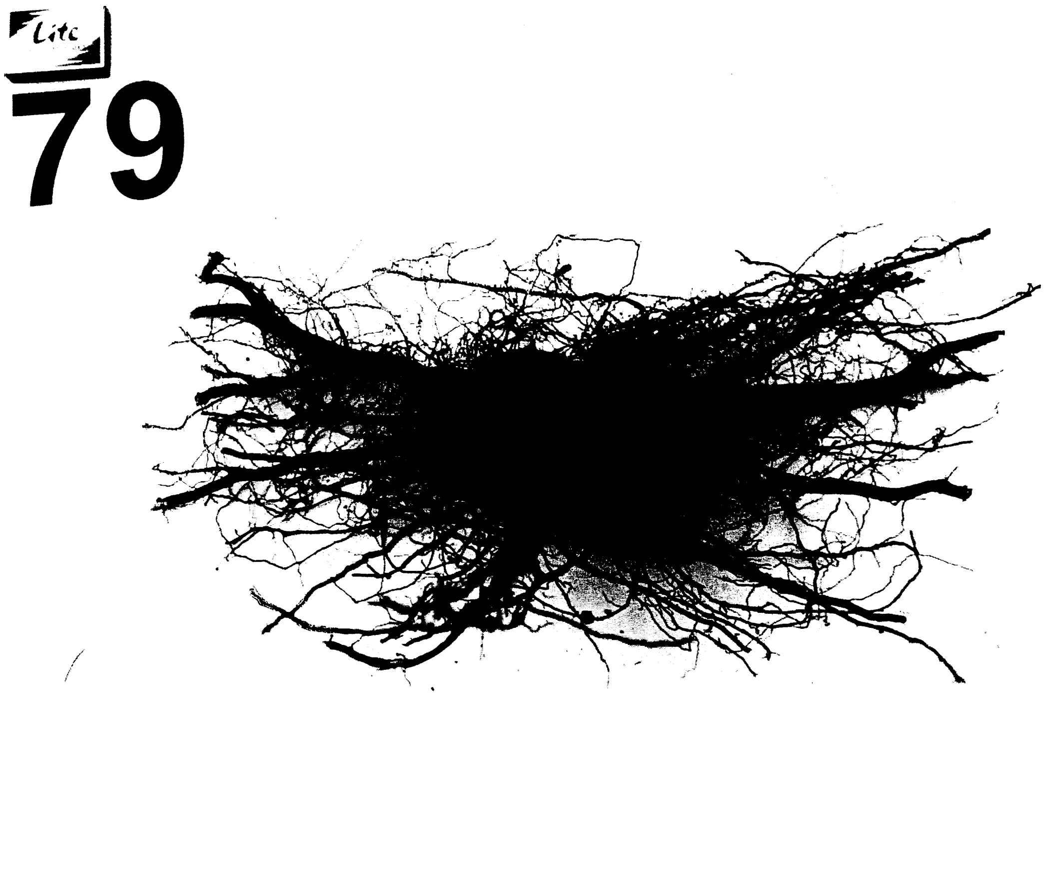
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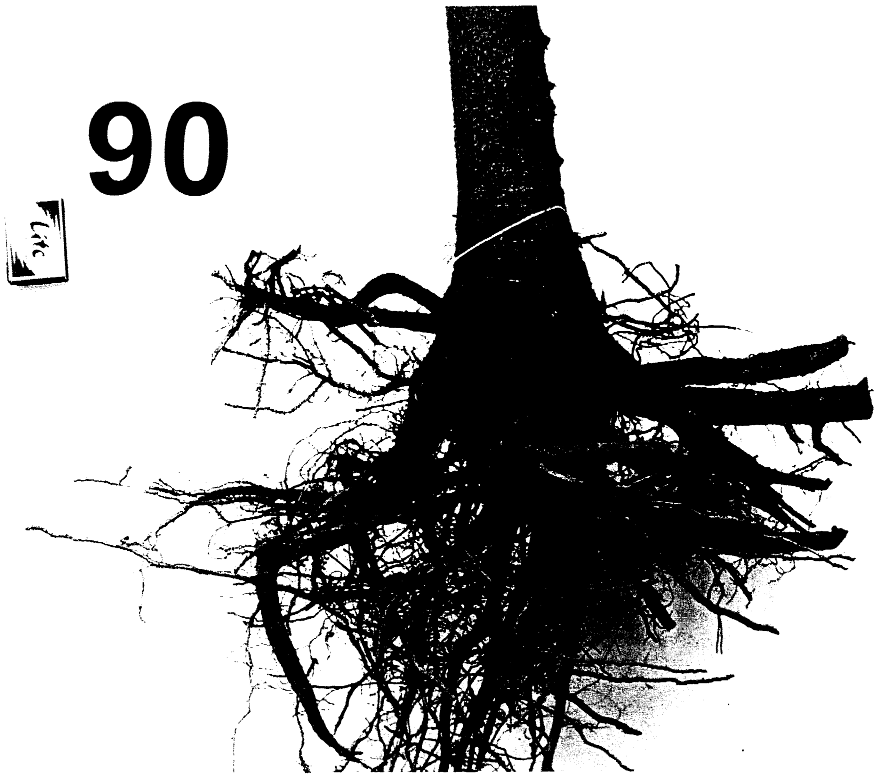
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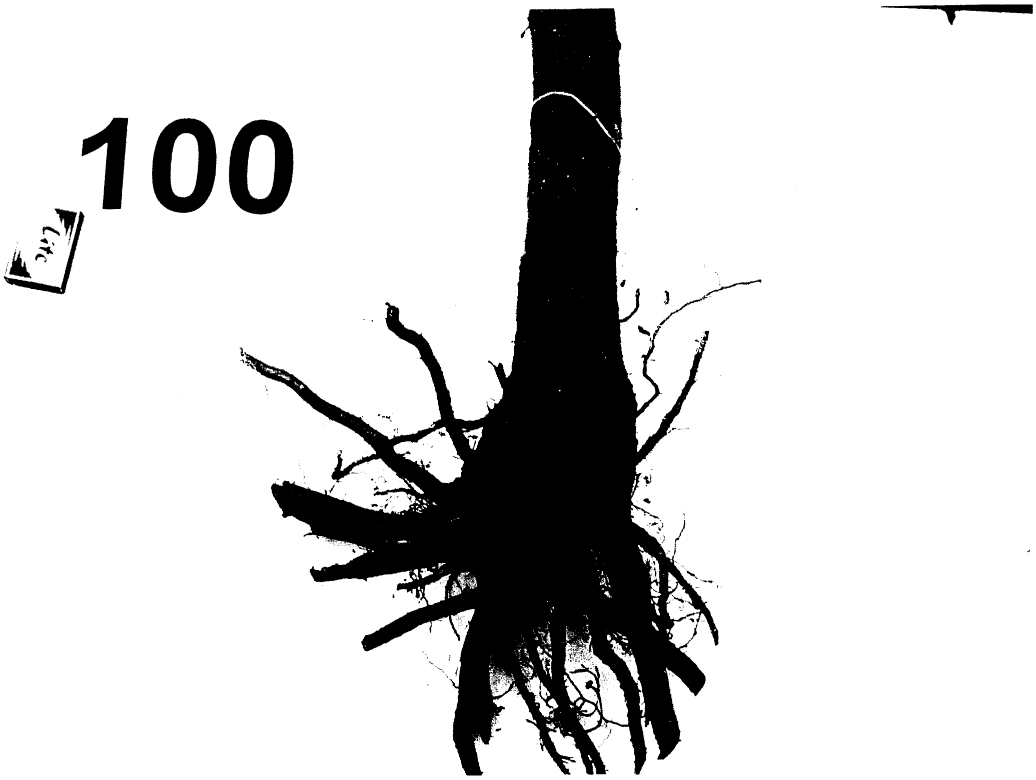
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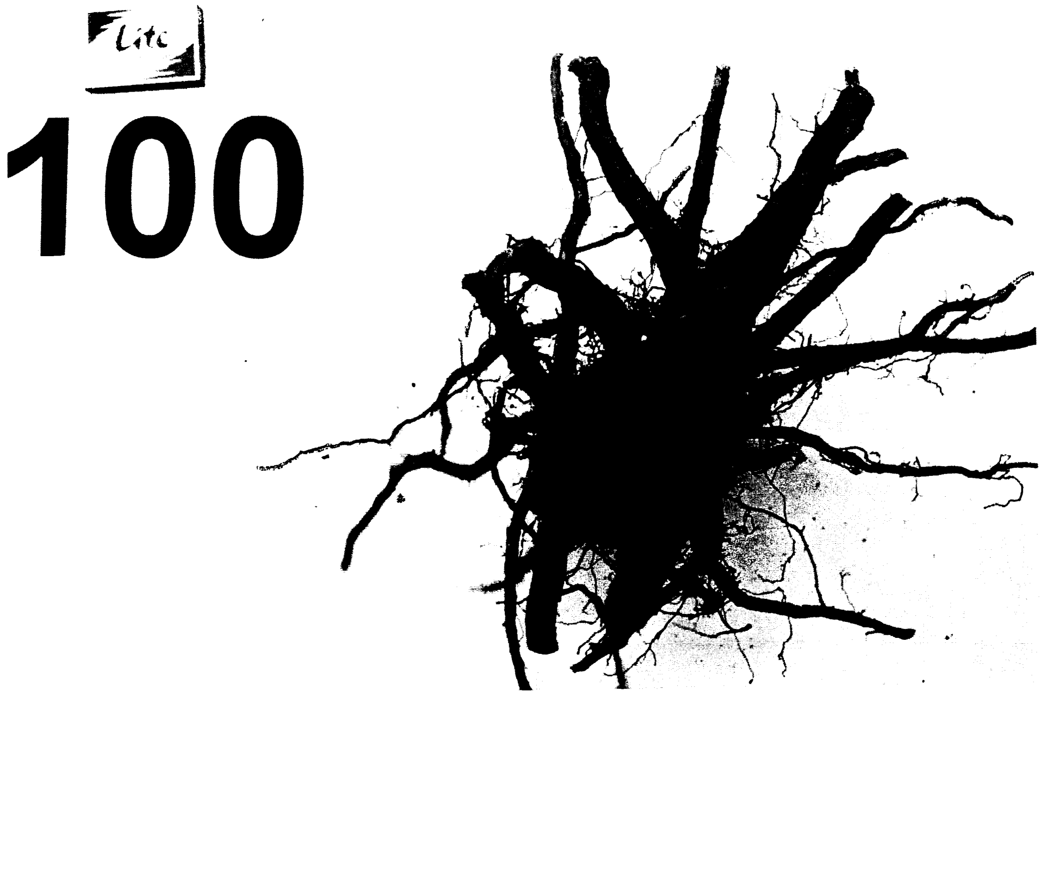
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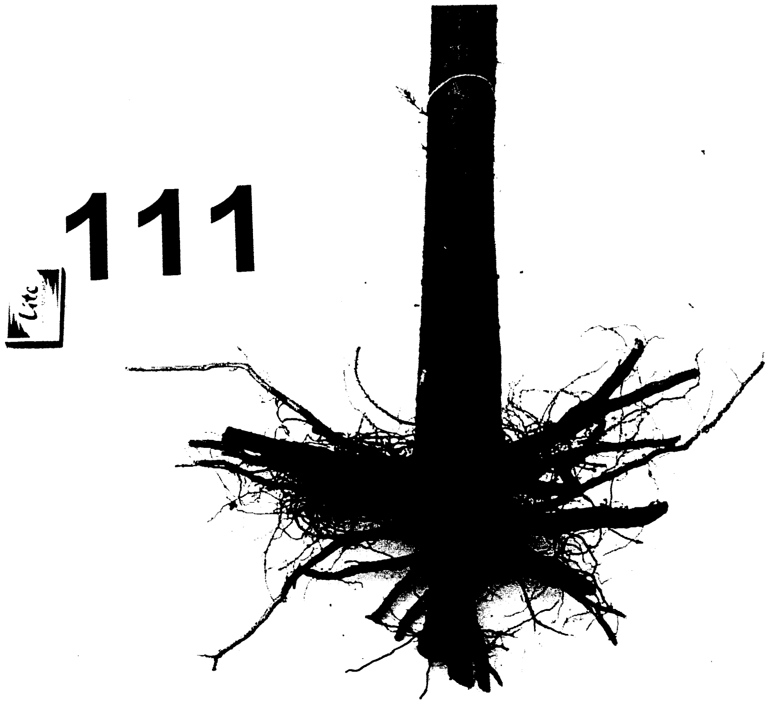
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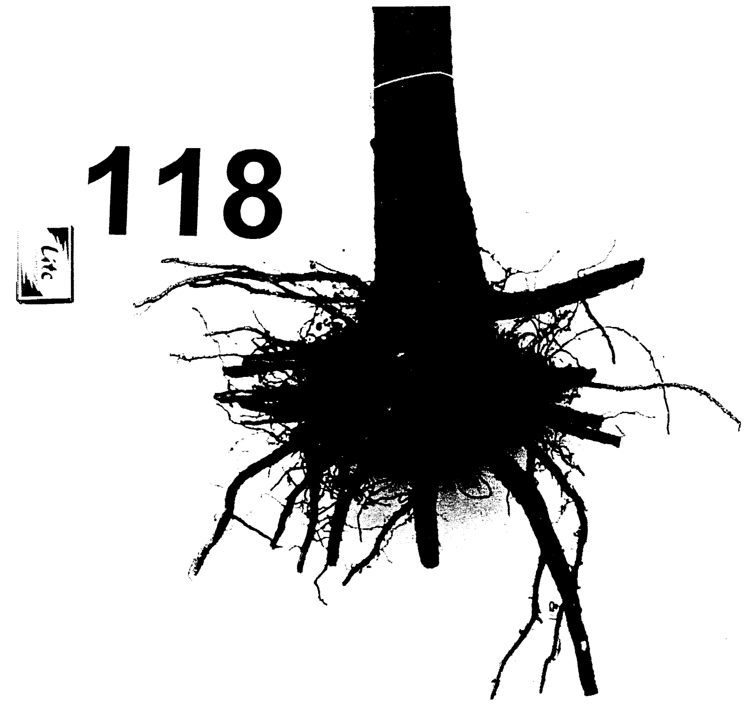
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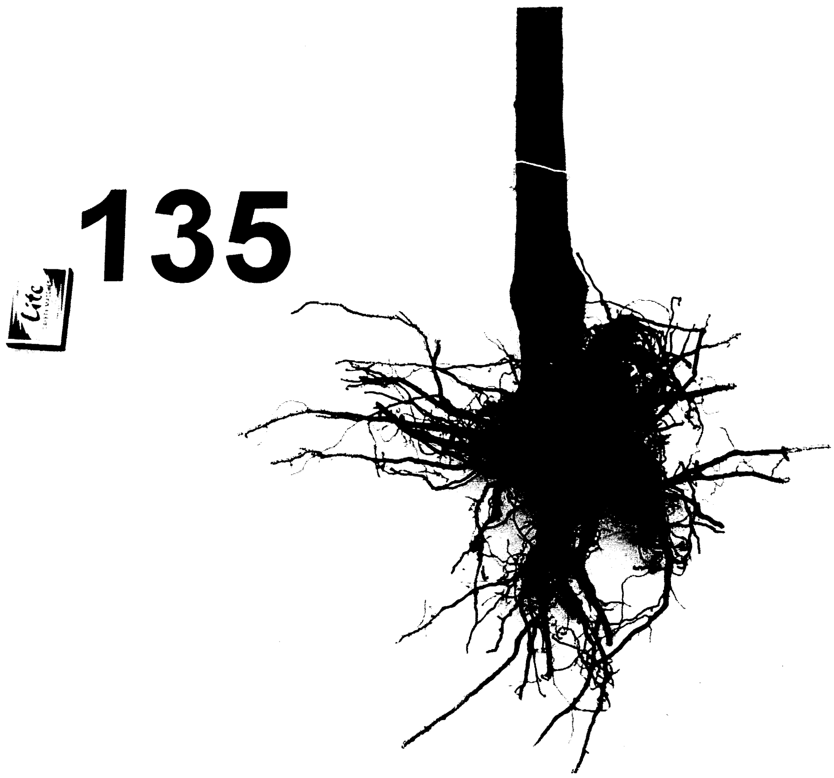
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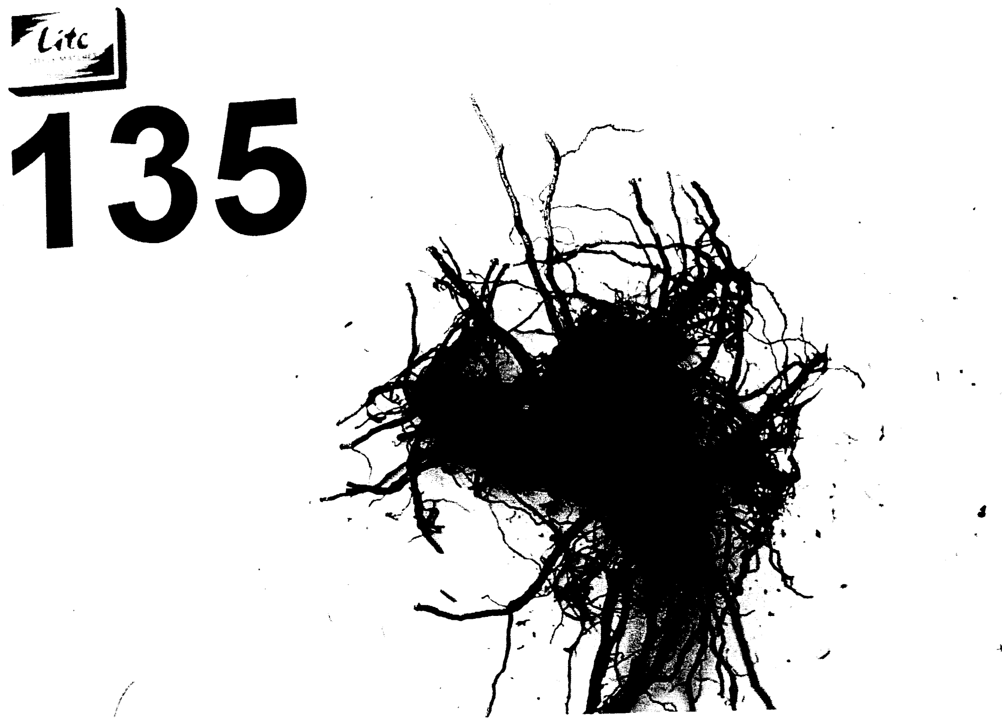
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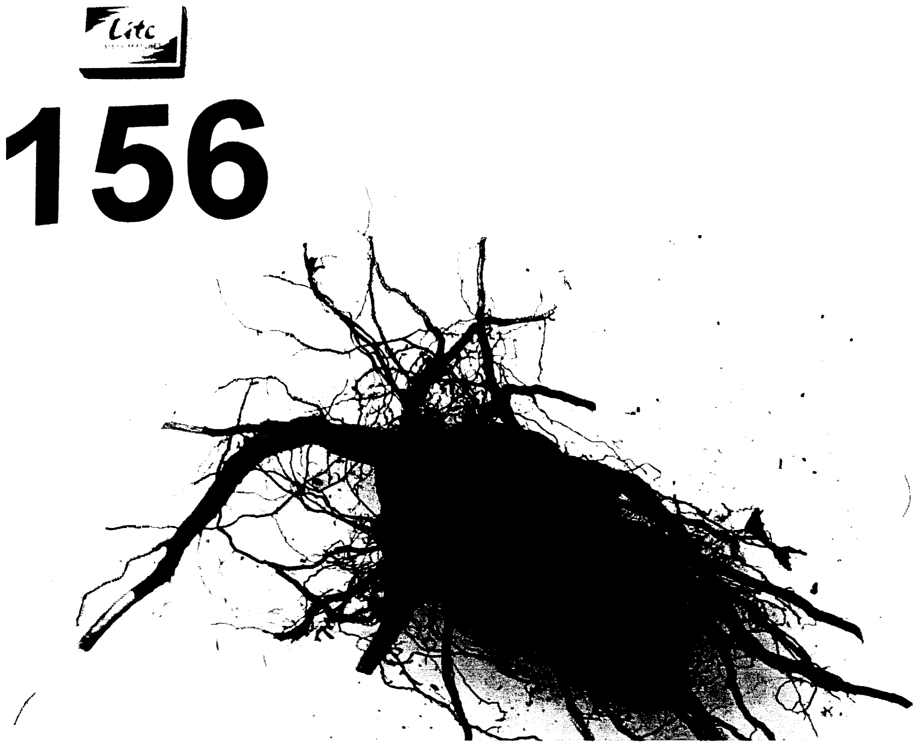
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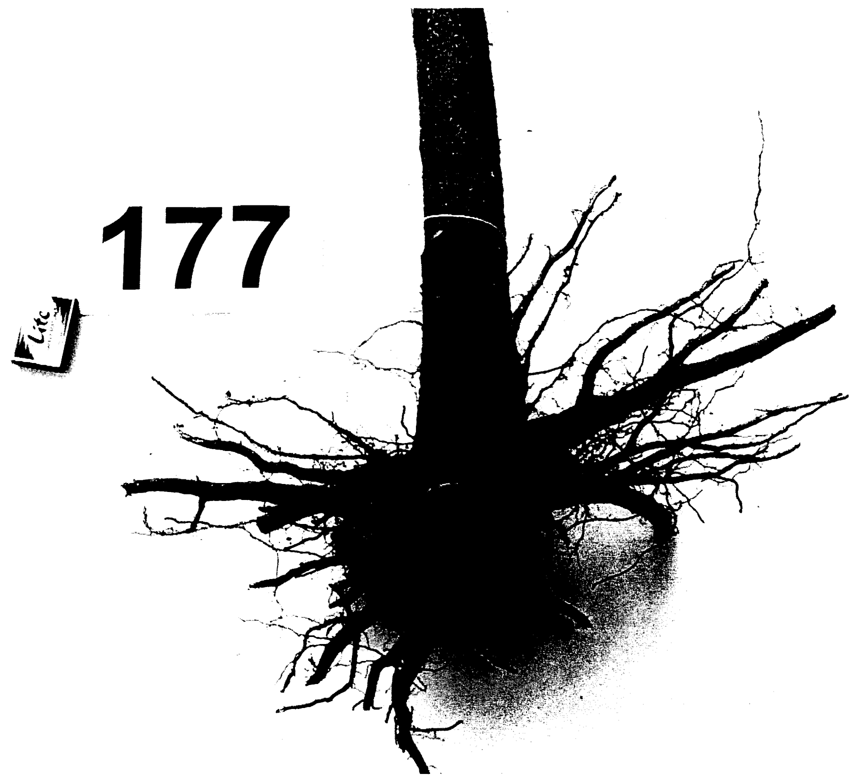
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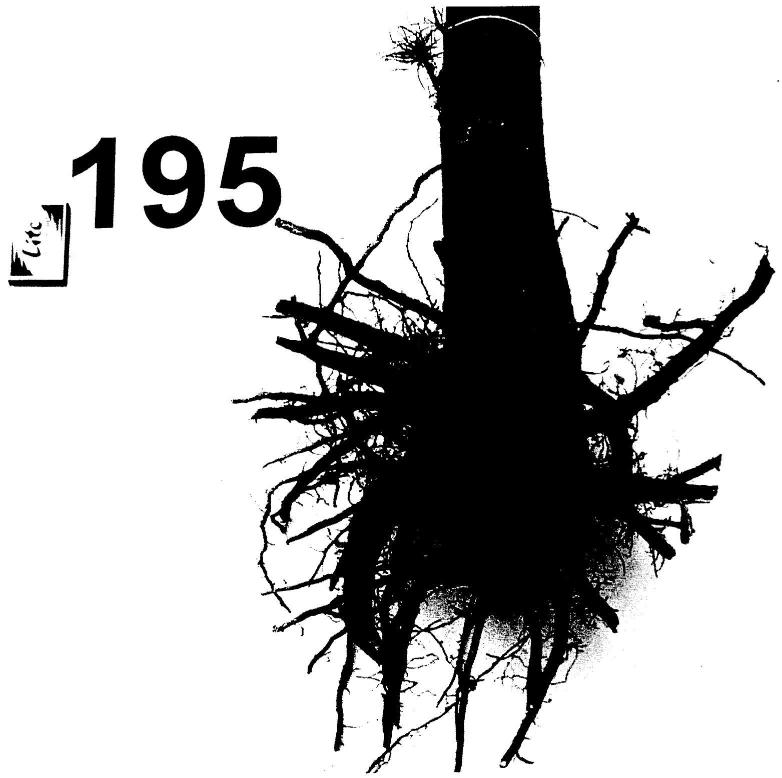
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APPENDIX 3:

Photographs of the Feilding root samples

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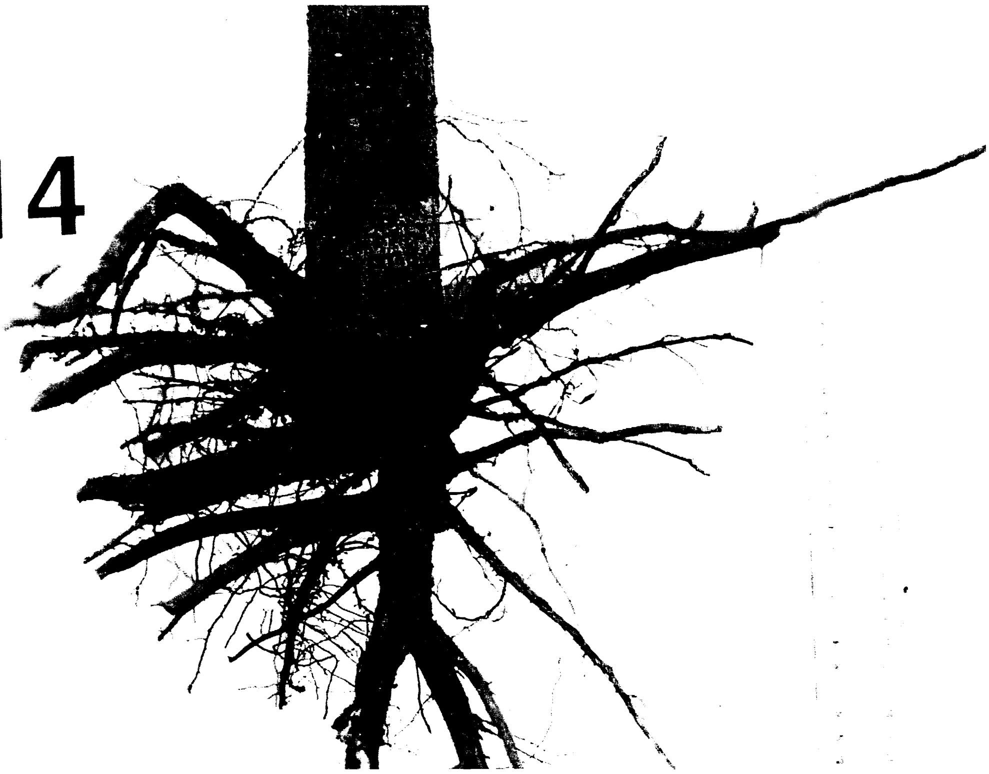

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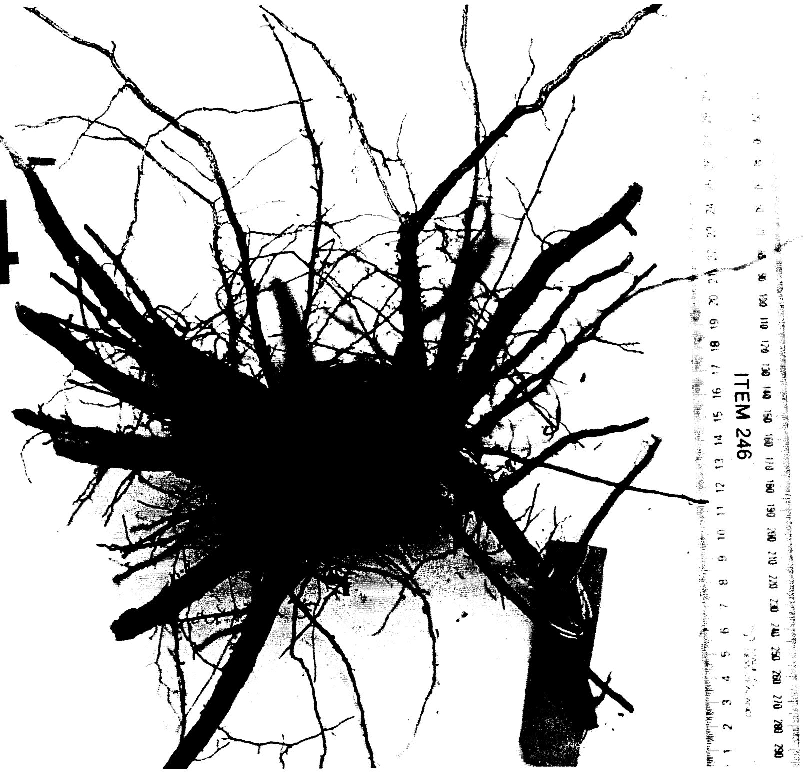

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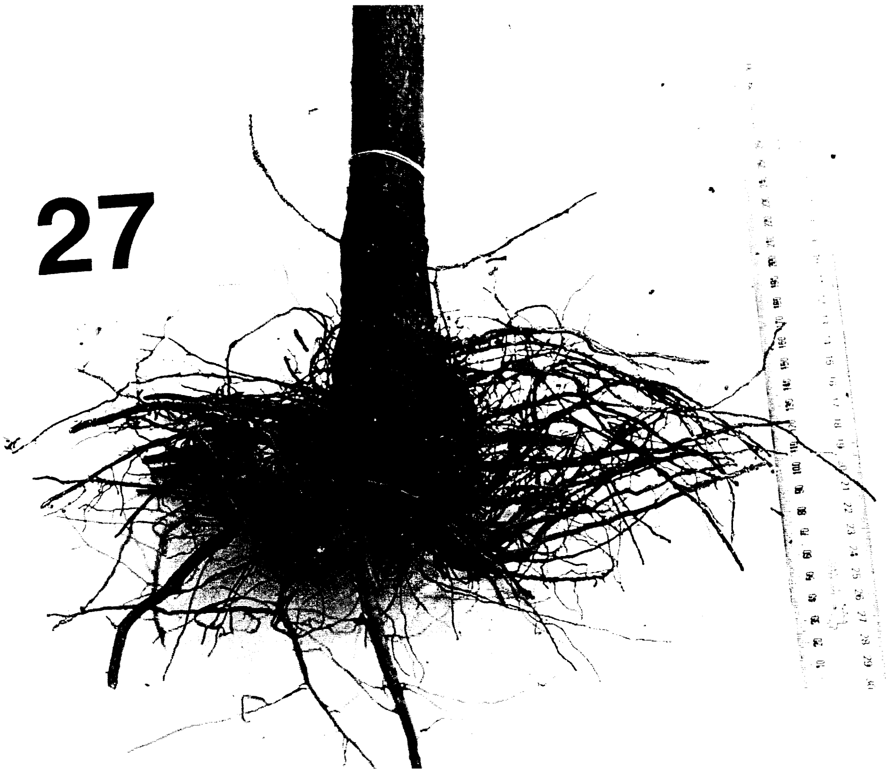

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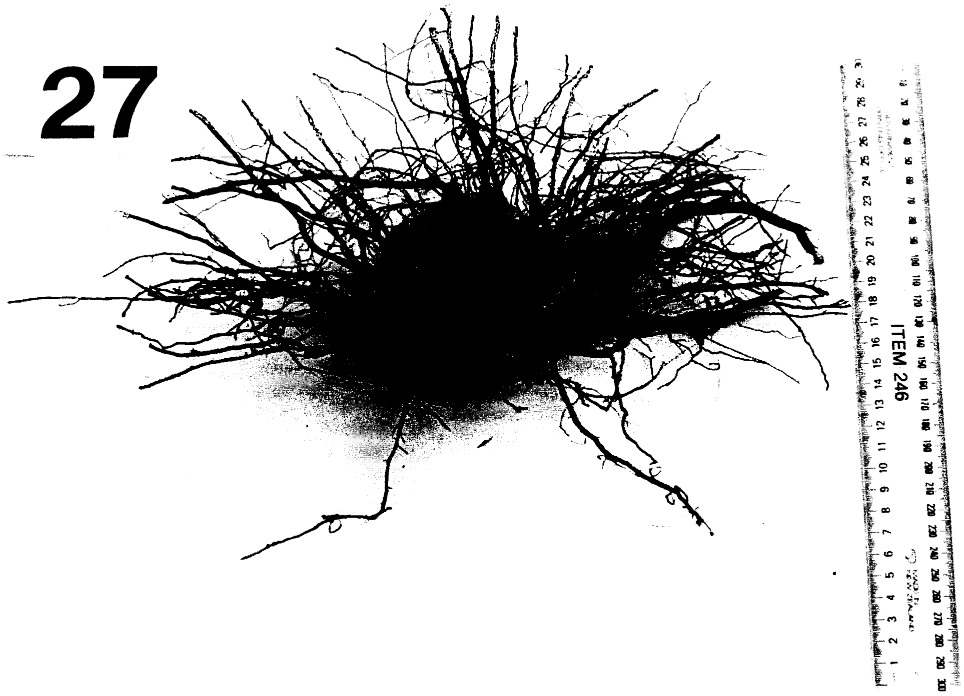

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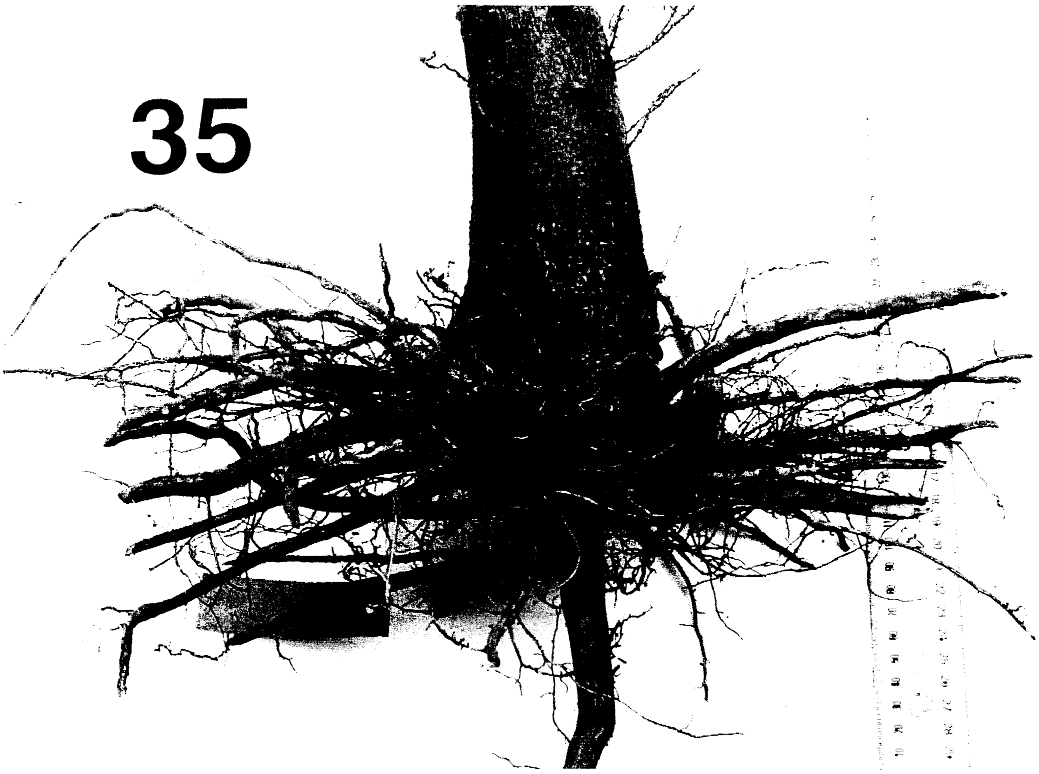

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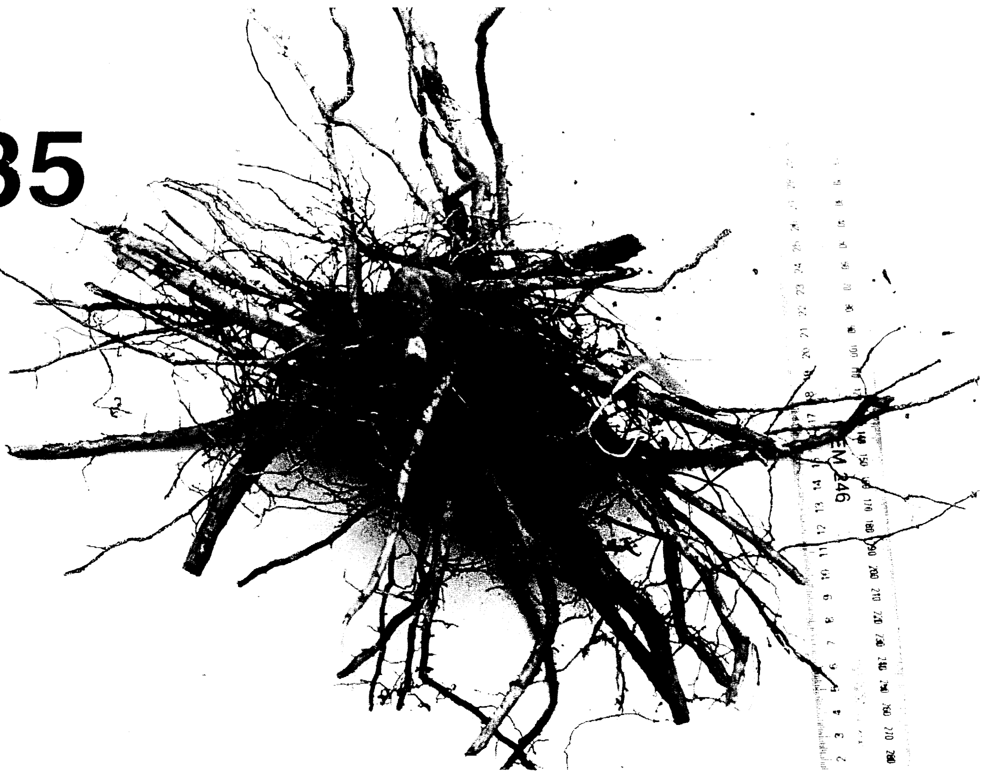

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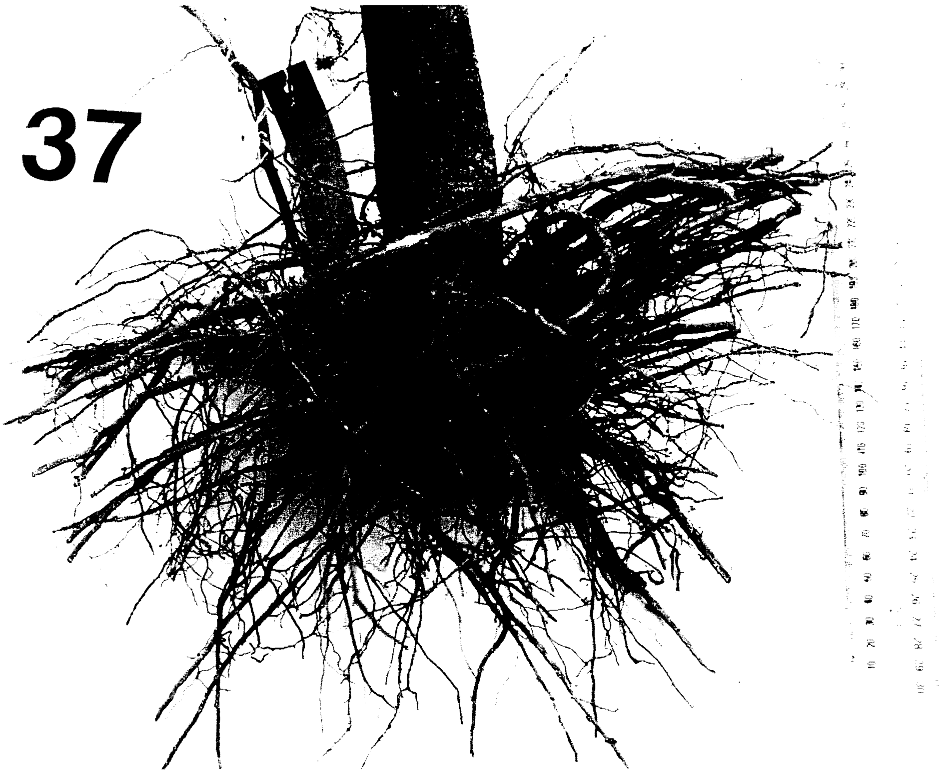

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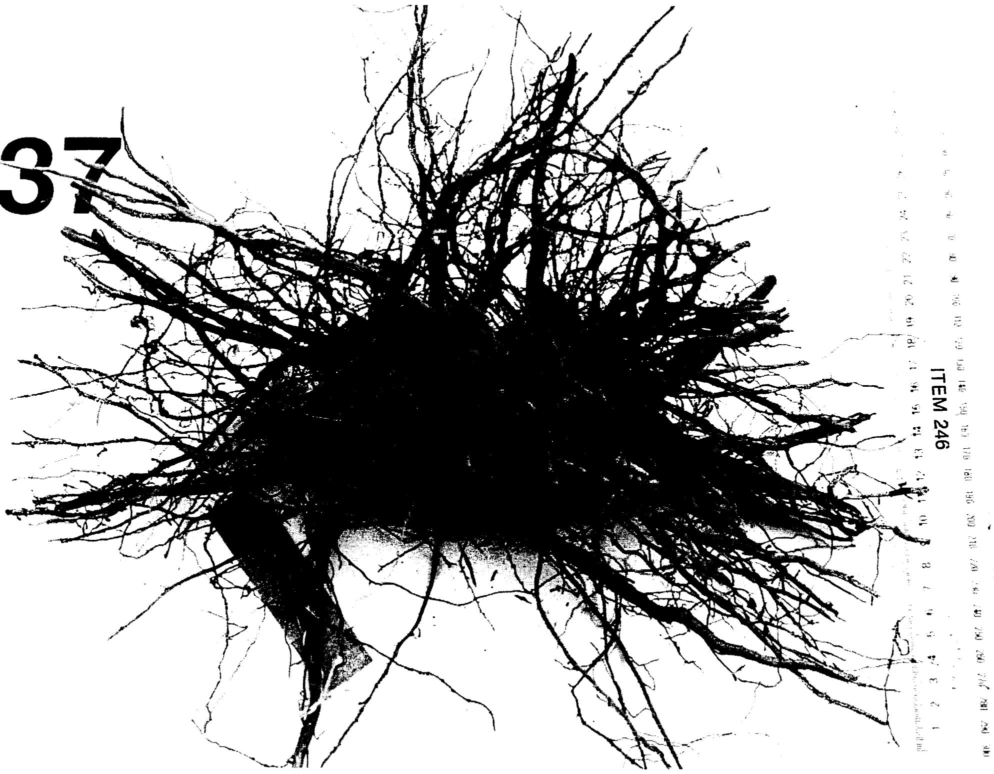

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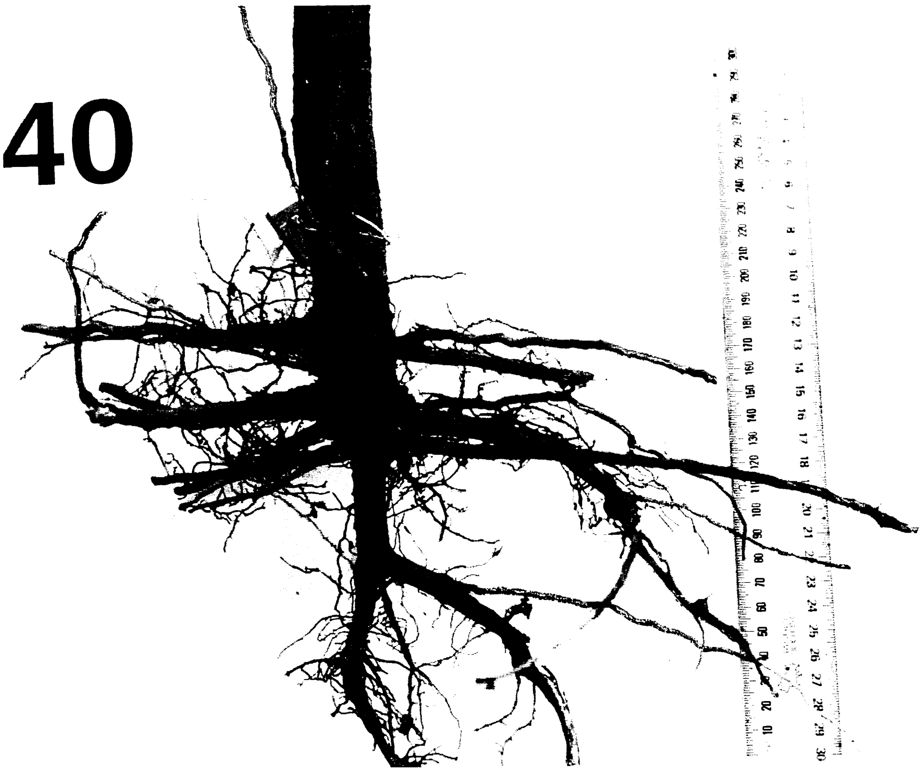

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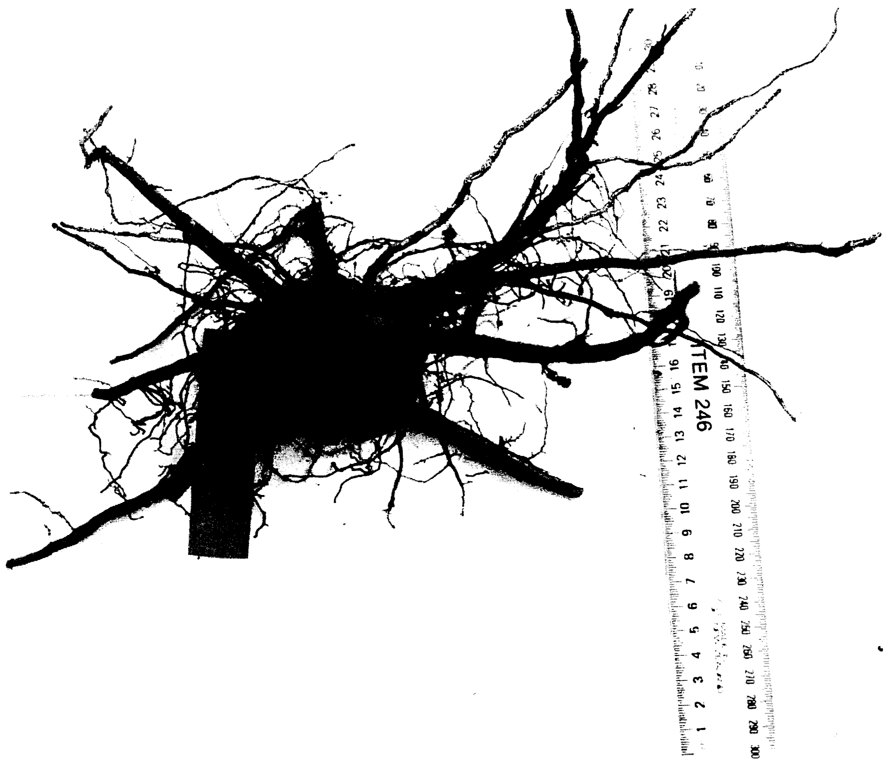

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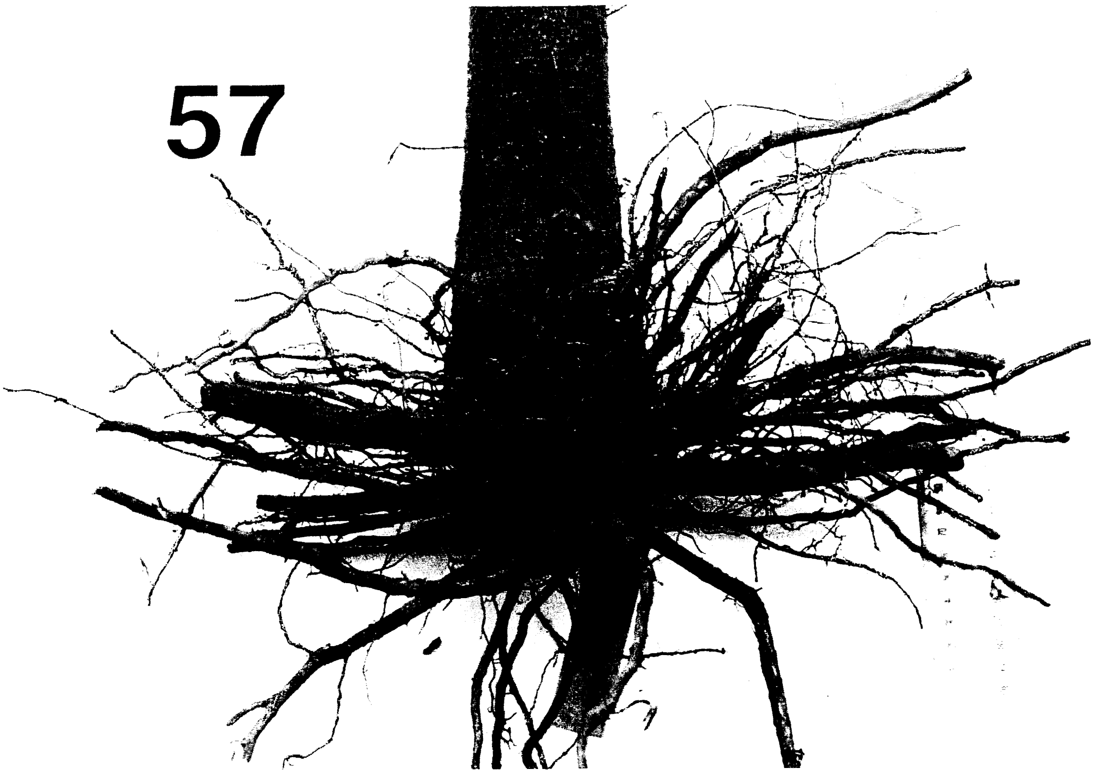

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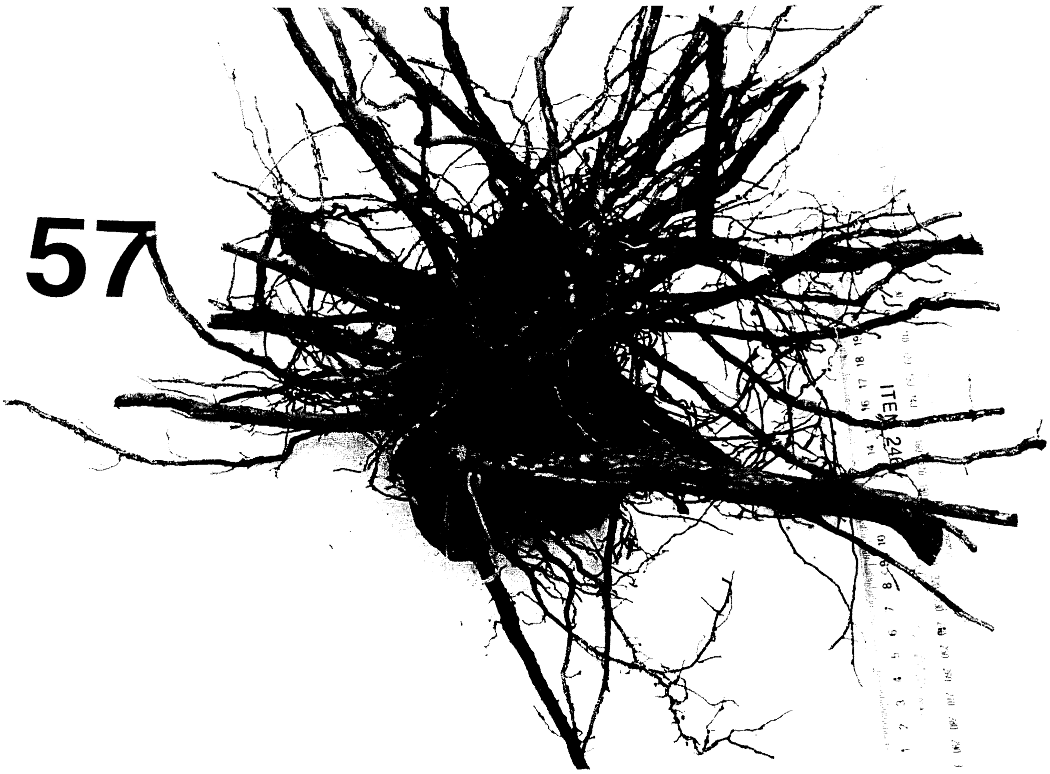

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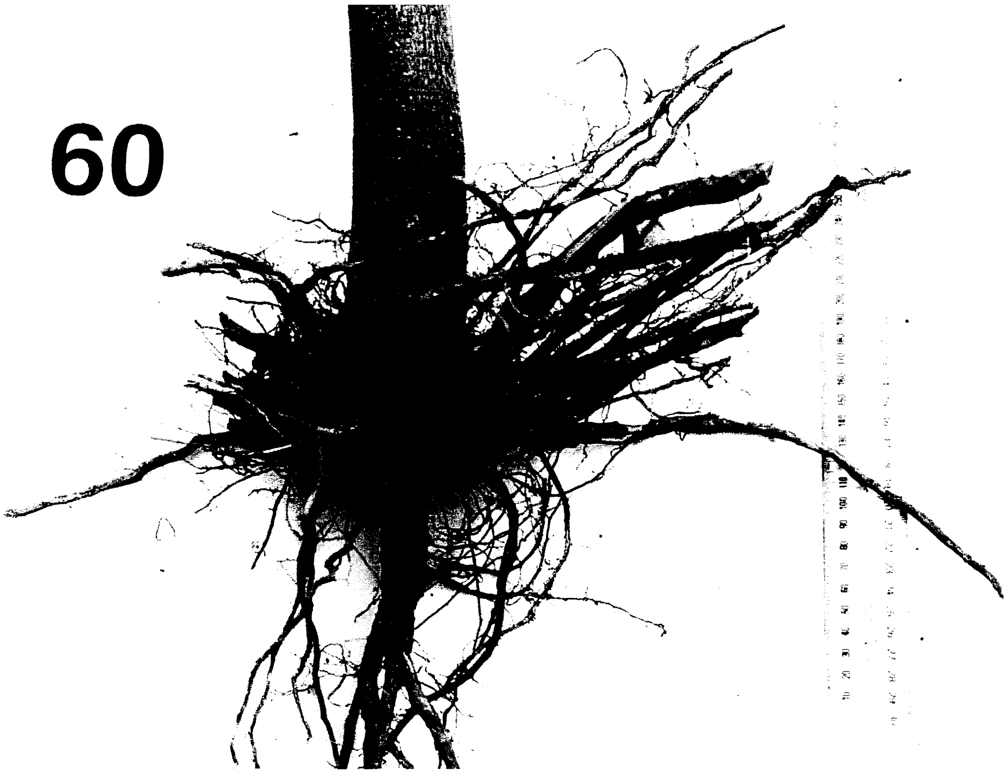

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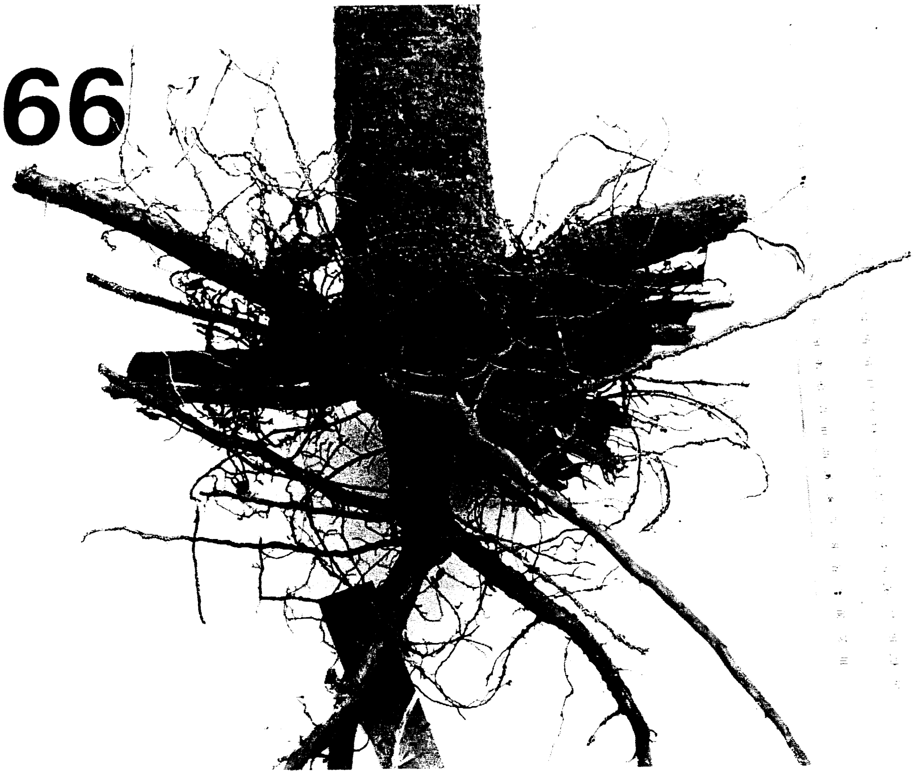

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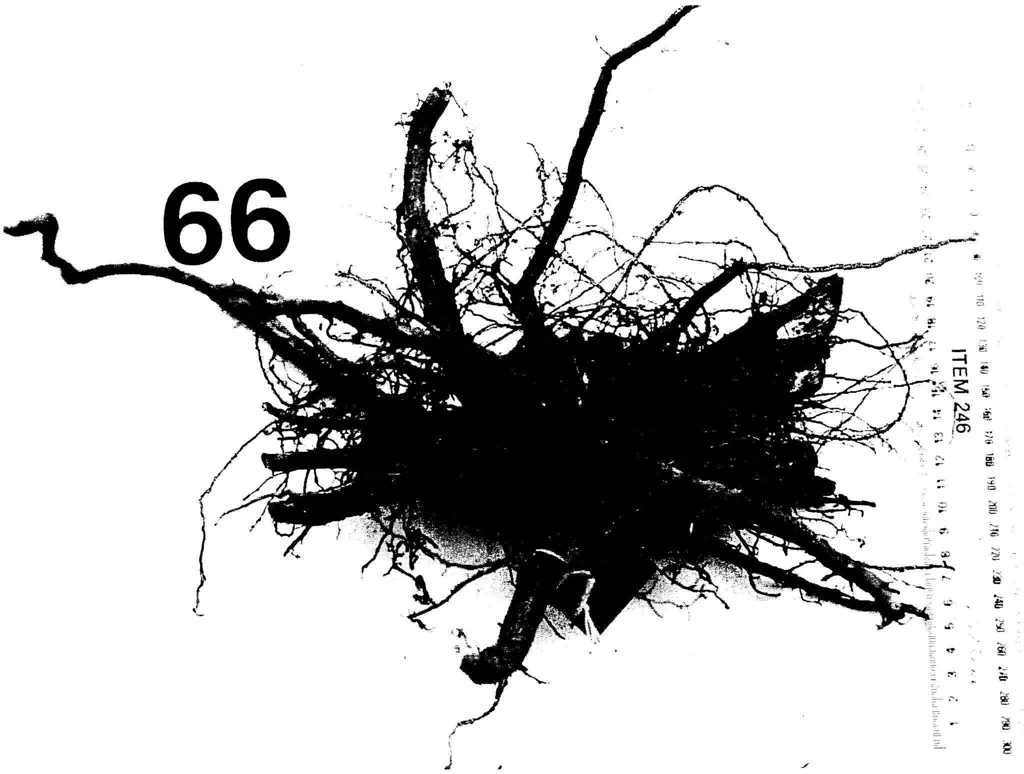


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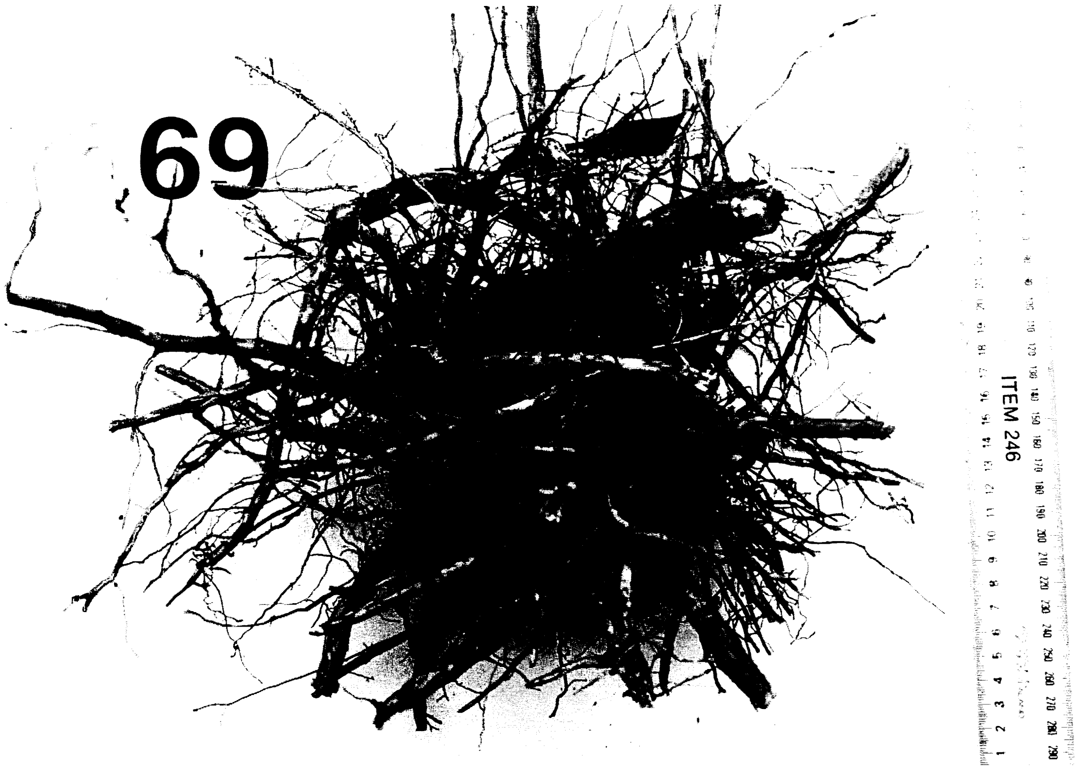
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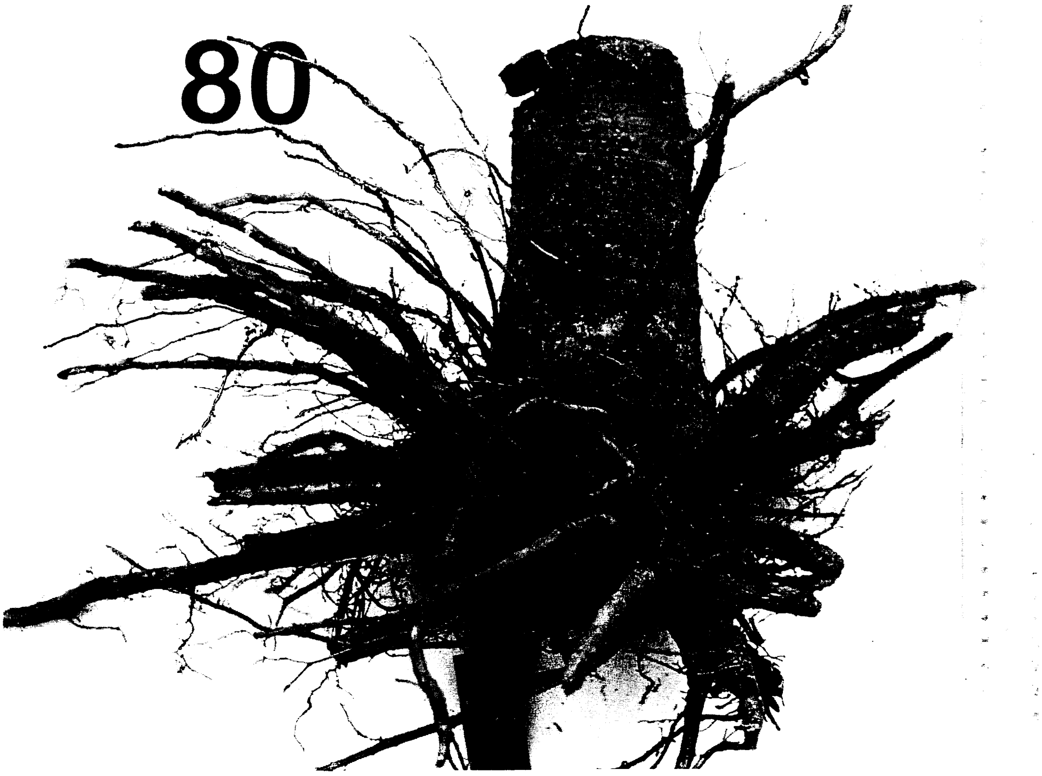
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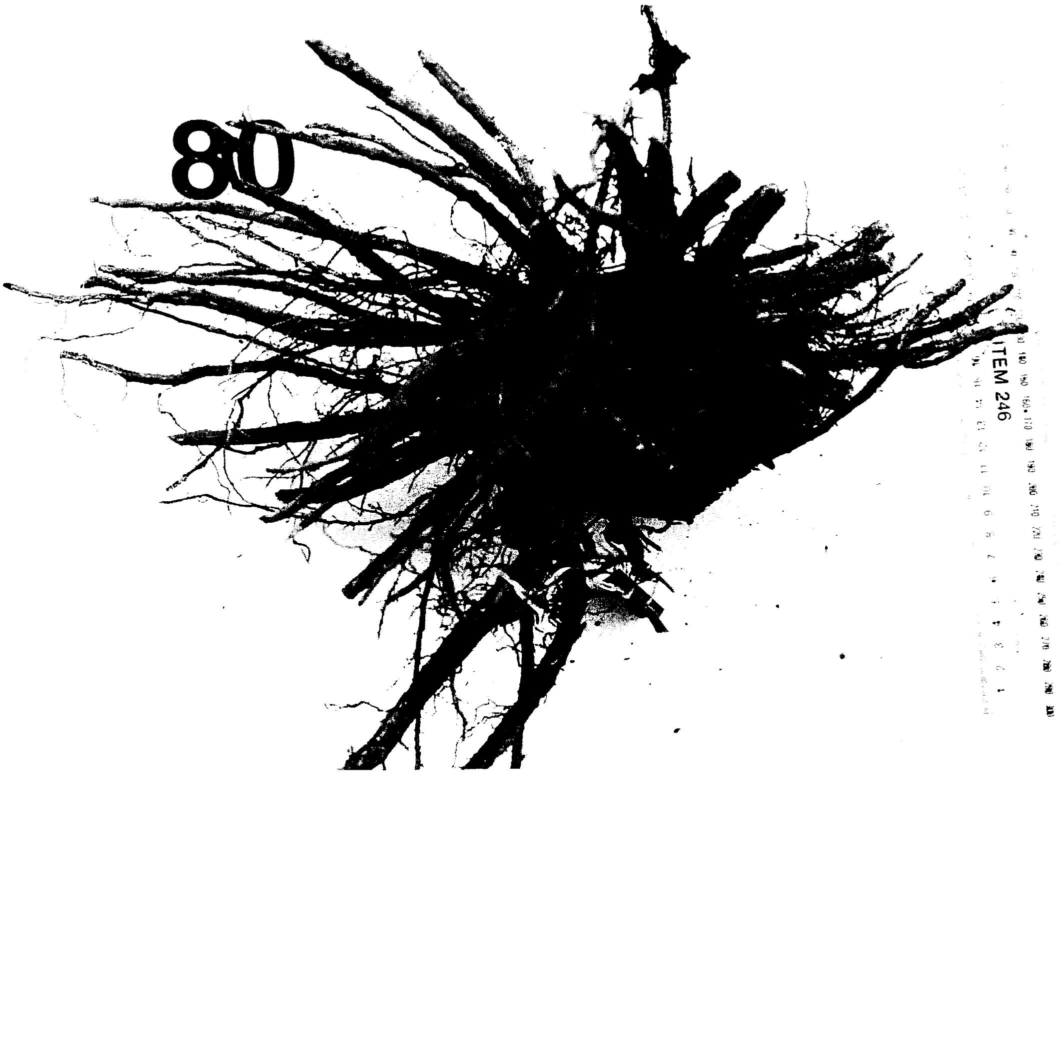
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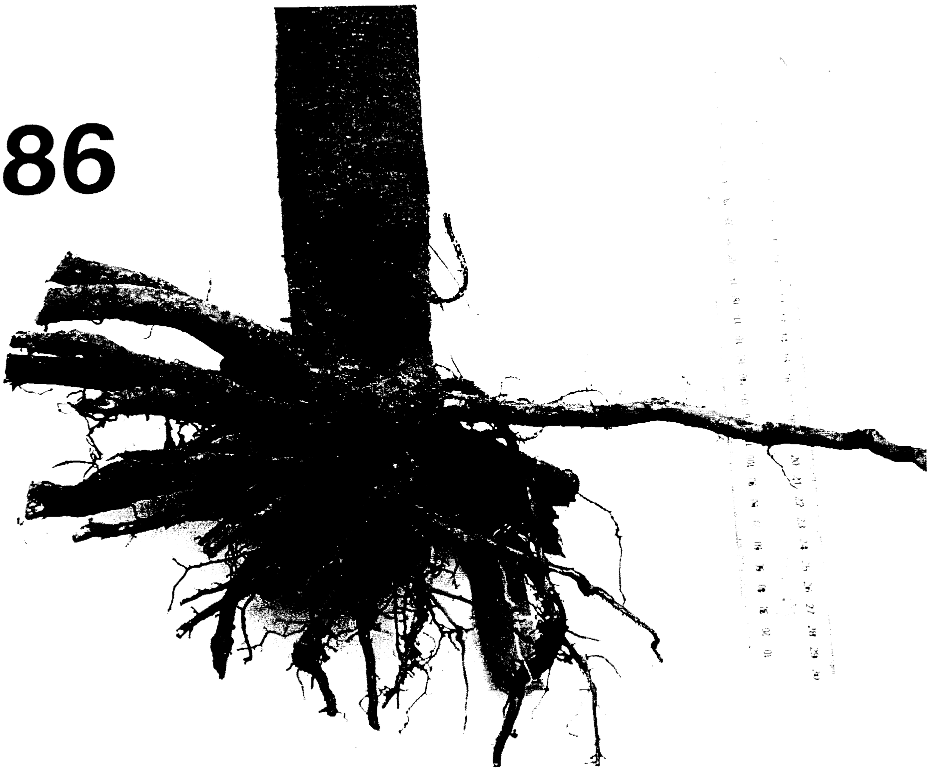

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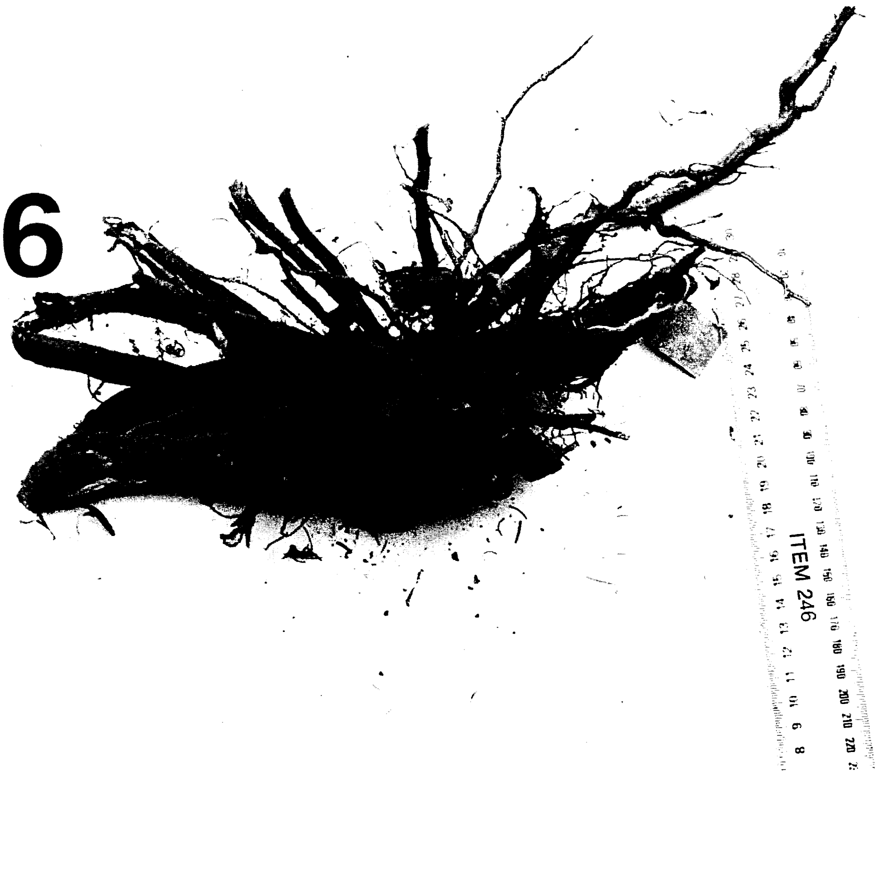

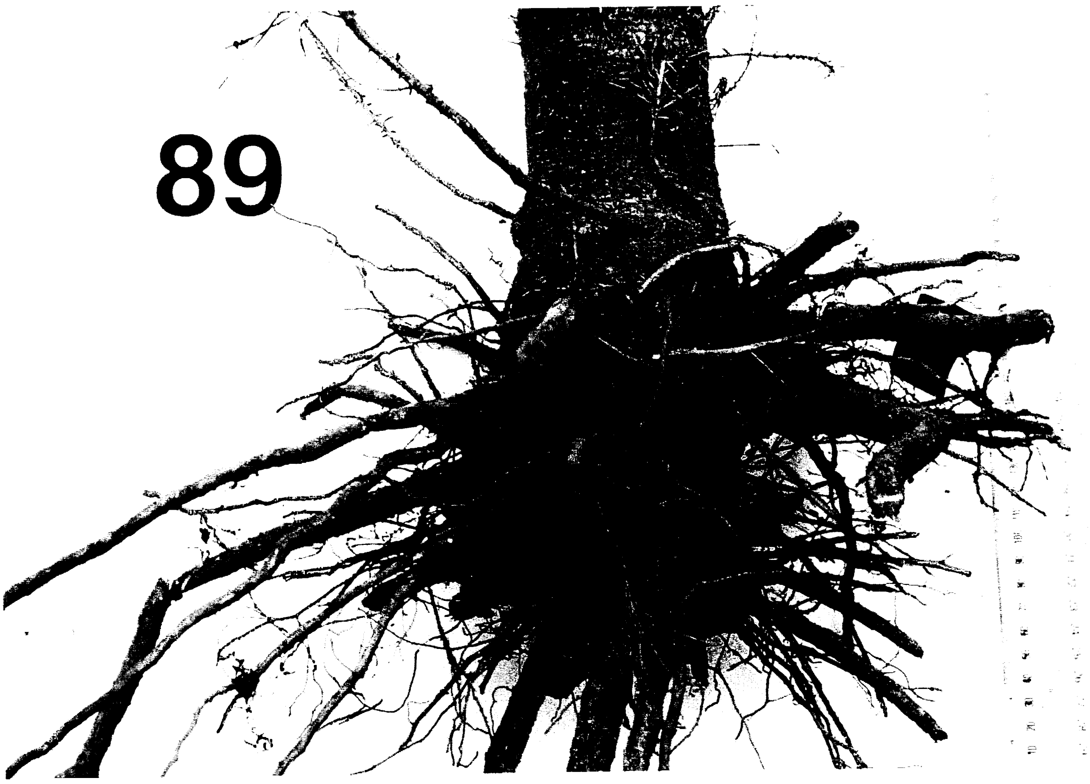
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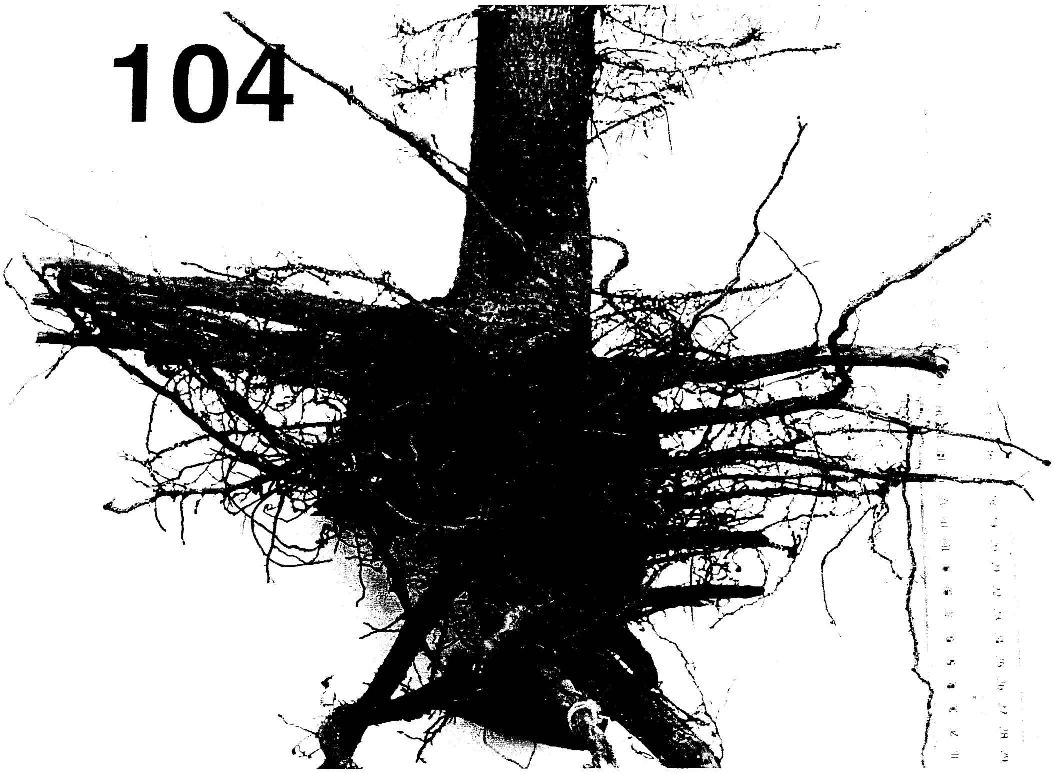
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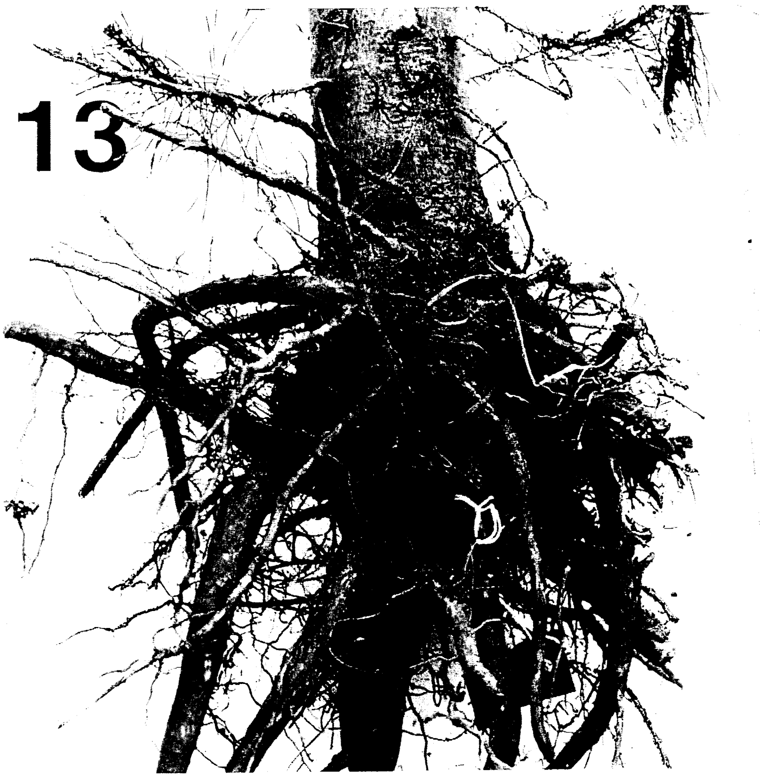

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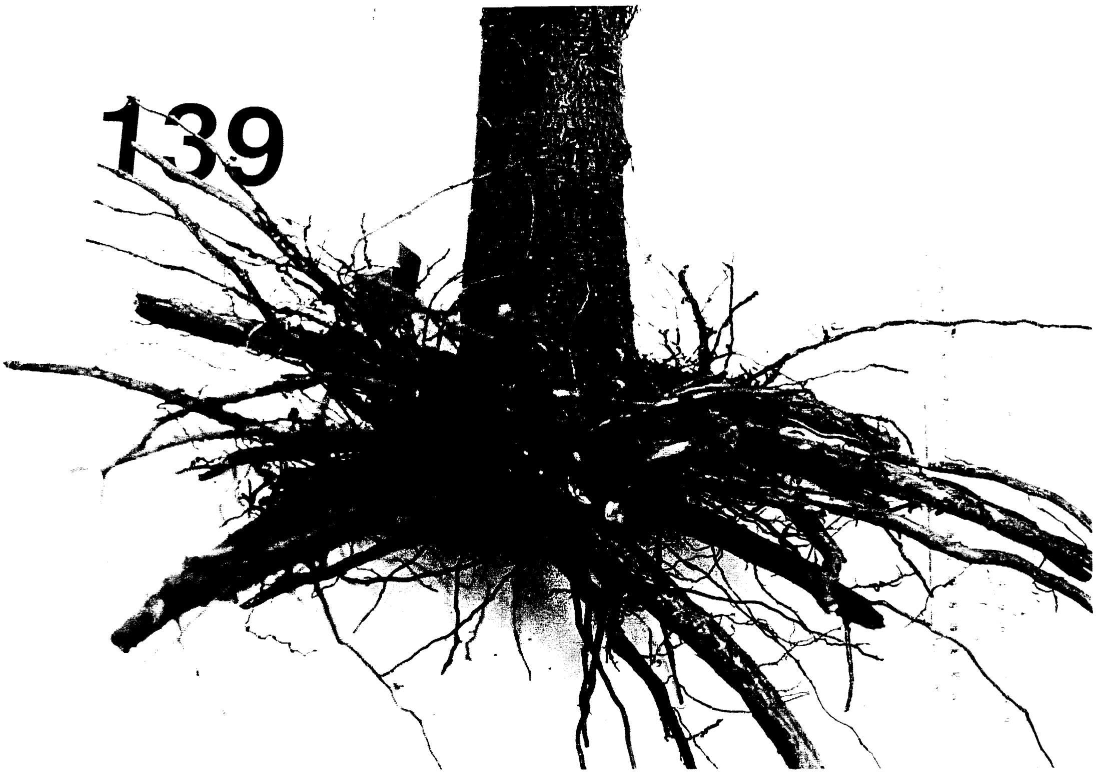

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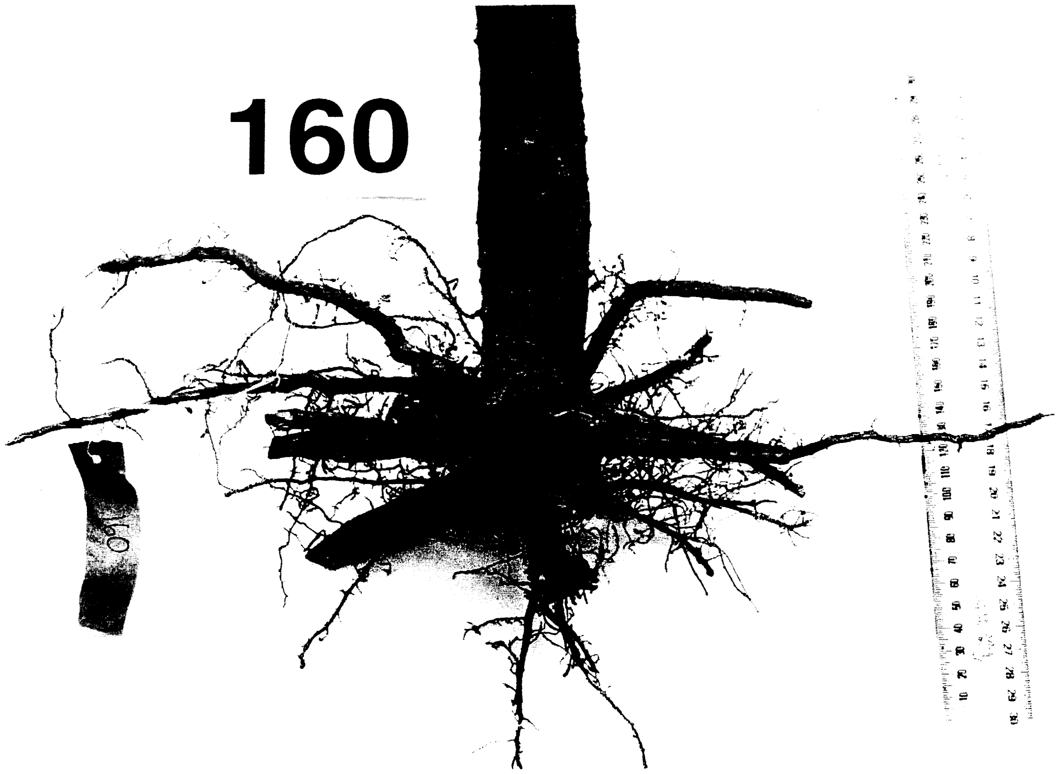
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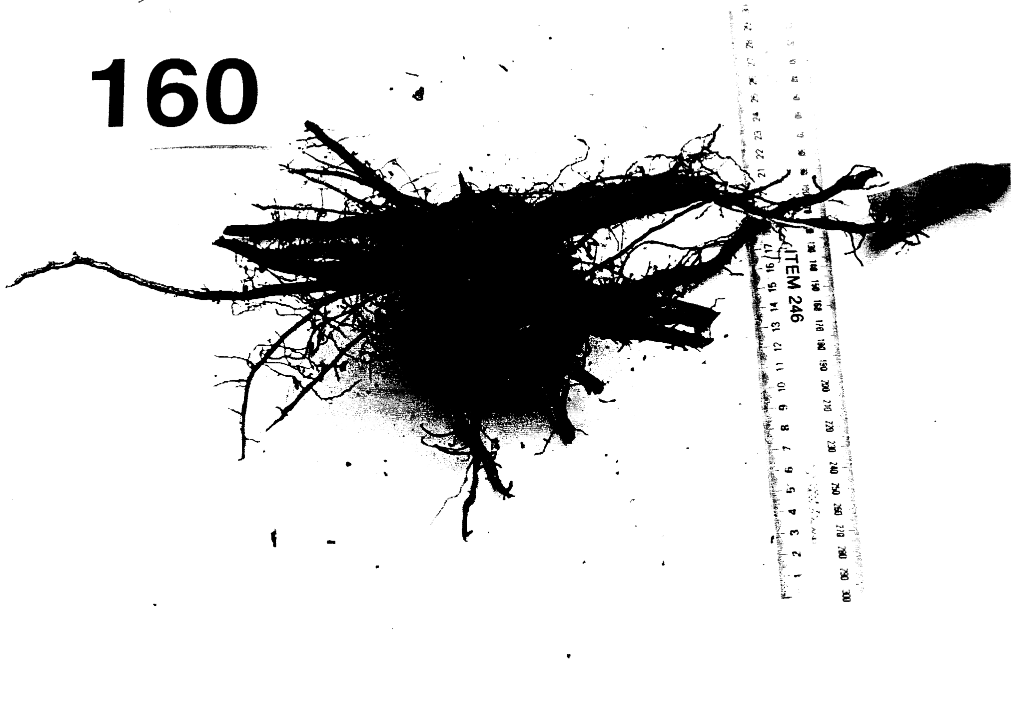
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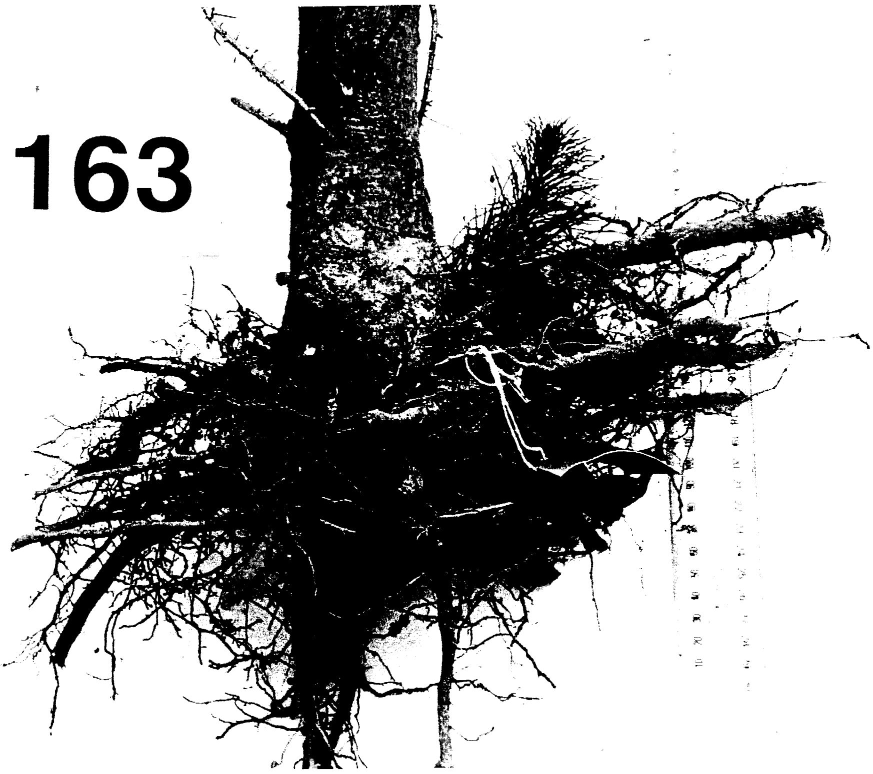

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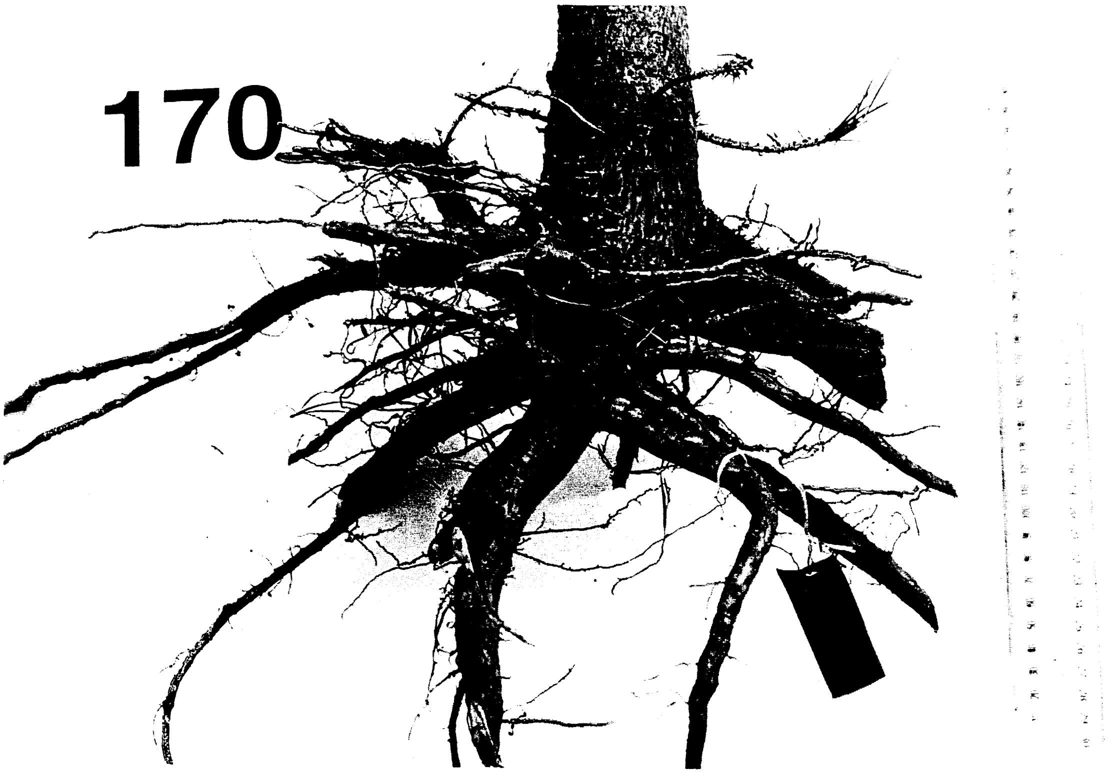

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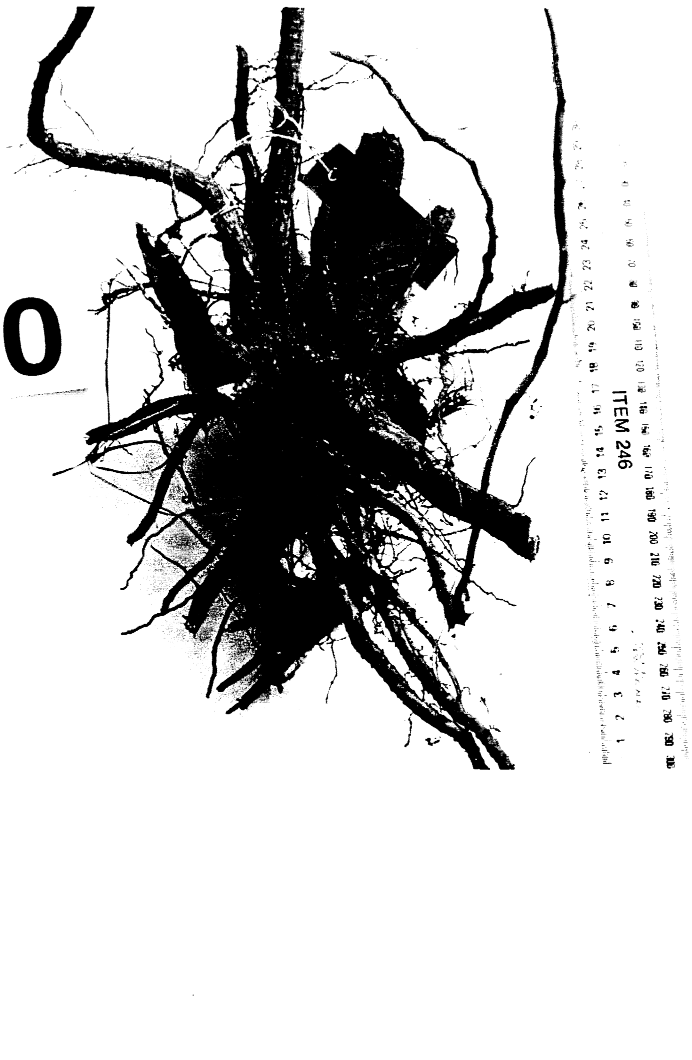

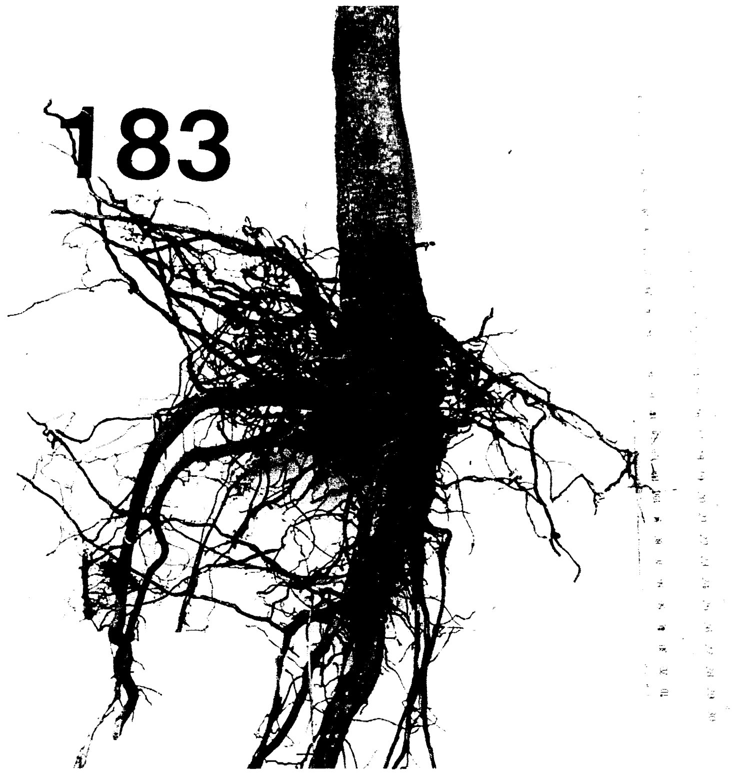
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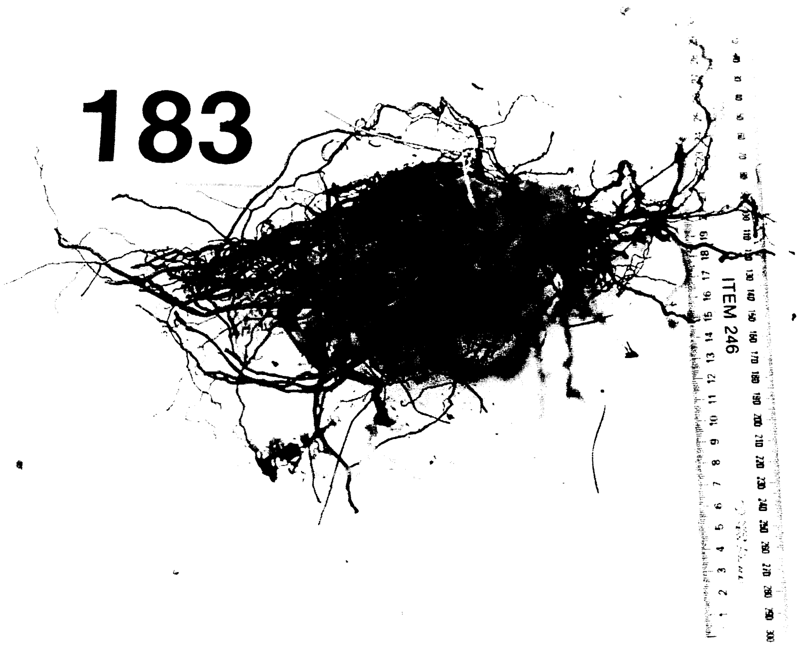
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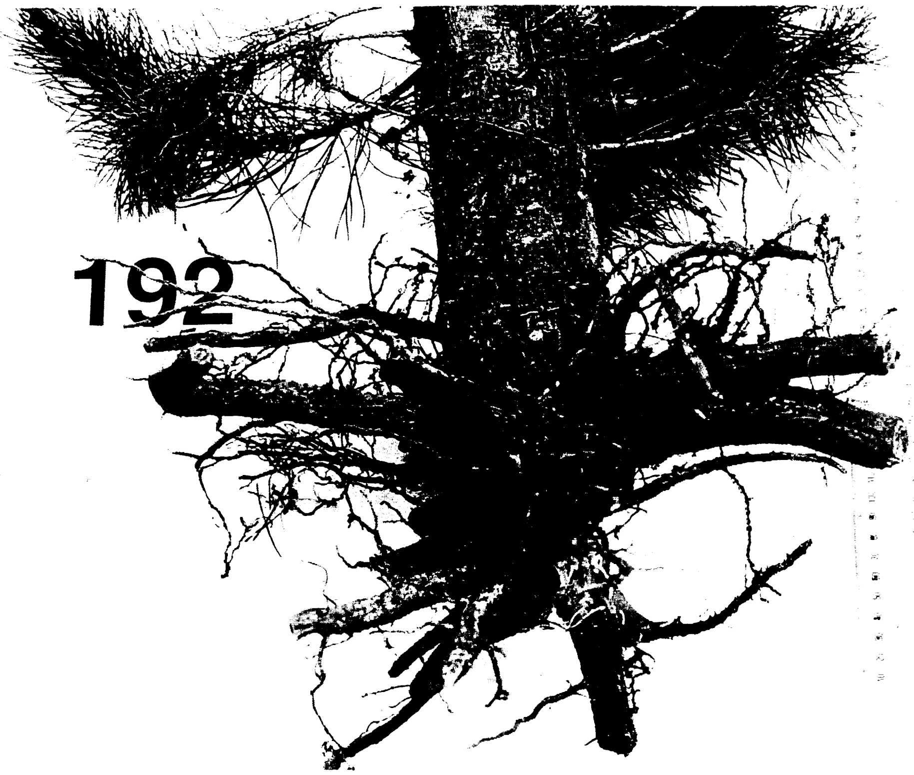

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