EVALUATION OF SOIL AERATION EQUIPMENT[1]

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Abstract. Soil compaction is a widespread problem limiting tree growth in urban areas. The Grow Gun and Terralift were developed to reduce soil compaction. Operationally both machines had advantages and disadvantages. In the soil, both machines created saucer shaped fractures. The area of Terralift fractures were two to four times larger than that of Grow Gun. Oxygen diffusion was improved only at the fracture line. Neither machine reduced soil bulk density.

Résumé. La compaction du sol est un problème répandu qui limite la croissance de l'arbre dans les zones urbaines. Le Grow Gun et Terralift ont été développés pour réduire la compaction du sol. Opérationnellement, les deux machines ont des avantages et des désavantages. Dans le sol, les deux machines ont créés des fractures en forme de soucoupe. La zone que Terralift a fracturée était 2 à 4 fois plus large que celle du Grow Gun. La diffusion d'oxygène était améliorée seulement dans la ligne de fracture. Ni l'une ni l'autre des machines n'a réduit la densité du sol.

Soil compaction is a widespread problem in urban areas, particularly on recent construction sites, near roads and in areas receiving heavy vehicular and foot traffic. A recent survey of arborists found that an average of 40% of commercial and residential properties were believed to have an area of seriously compacted soil around trees (unpublished data). Soil compaction is known to reduce the growth and vigor of many trees (1). Compacted soils are considered those which have bulk densities over 1.3 g/cc. Root growth may be restricted in soils with bulk densities greater than 1.5 g/cc by high physical resistance to penetration and lack of air movement (2).

There are several traditional methods for reducing compaction. They generally consist of the incorporation of organic matter or coarse materials into the soil. This may be done by roto-tilling or cutting vertical slits into the top four to six inches of soil. Subsoil plowing is recommended for deep compaction or when hardpan layers exist below the surface.

The major disadvantages of these methods are the severe damage to existing tree roots and the unsightly appearance if done in a turf area. Dynamite was one of the first treatments for existing trees in compacted soil. Charges were placed around a tree and exploded, lifting a mature tree up to several feet (R.A. Bartlett, Personal Communication). Damage to structures can occur from such treatments and thus have rarely been used since the 1940's.

To avoid these problems and to take advantage of the existing technology, the fracturing of soil using compressed air was pioneered in the late 1920's and early 30's (R.J. Campana & Ed Irish, personal communication).

While the F.A. Bartlett Tree Expert Company and several large tree maintenance companies developed and used their own equipment, the Charles F. Irish Company of Cleveland, Ohio patented their 'Aero-Fertil Gun' for sale to other tree maintenance companies. The idea of this equipment was to inject pressurized air into the soil to fracture compacted layers. Fertilizer, fill materials and/or water were added to the soil after it was fractured. The use of this type of equipment was mostly discontinued in the 1940's with the introduction of liquid fertilization.

During the mid 1980's there was a resurgence in interest in soil fracturing and aeration. Two types of equipment were developed which use compressed air to fracture the soil. A three phase study was undertaken to evaluate the operation of this equipment, the effects in the soil, and tree response. The first two phases are presented here.

Materials and Methods

Operation aspects. Two pieces of aeration machinery were tested, the Grow Gun and the Terralift. The Grow Gun (Grow Gun Corp., 5322 Howell St., Arvada, CO 80002) is very similar in design and operation to the Irish 'Aero-Fertil Gun'. It has a hopper for loading dry materials on top of a metal cylinder which air and liquids are added. Beneath this cylinder is a ground plate for the operator to stand on while the machine

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discharges. Stems from 30 cm (12") to 75 cm (30") long attach to the bottom of the cylinder.

The Grow Gun is attached to a trailored air compressor capable of providing air at least 6.9 bars (100 pounds per square inch {psi}) and 475 liters per second (100 cubic feet per minute {cfm}). It may also be connected to a water source such as a truck mounted sprayer or water faucet. A 5 cm (two inch) diameter hole 15 cm (six inches) deeper than the stem length must be drilled prior to insertion of the stem. The operator opens the air valve to fracture the soil then adds dry materials blowing it into the soil with additional air discharges. Water may be added and blown into the soil as desired.

The Terralift (R.E. Jarvis Co., Rt. 9, Fayville, MA 01745) is a self-propelled, self-contained piece of machinery. The mobile unit carries a gasoline engine which operates the compressor. The compressor is linked to air motors to propel the unit, air storage cylinders, and to an air-powered hammer which drives the probe into the soil. Dry materials are added to a hopper. Once the probe is driven to the operating depth, the control valve is switched to discharge the compressed air from one storage cylinder then instantaneously the other cylinder is discharged through the hopper, transporting the dry material into the open fracture in the soil. The Terralift operates at variable pressures from 6 to 20 bars (87 to 290 psi).

Both machines were operated for at least fifteen hours over a two month period. Machine operation was by factory representative or by an operator trained by a manufacturer representative. The speed of operation was timed, problems were noted, and various fill materials and techniques were tested.

Soil effects. Two sites were selected at the Bartlett Tree Research Laboratories (BTRL) in Charlotte, North Carolina to measure the soil effects of the aeration equipment. The hill site had a sandy clay loam topsoil (A horizon) 15 - 20 cm (6 to 8 inches) thick. The field site had a clay loam A horizon 15 - 23 cm (6 to 9 inches) thick. Both sites have a clay subsoil.

The machines were operated at both locations using various fill materials and water with blue Signal™ dye. The fractures were excavated and examined.

Tests for changes in oxygen diffusion rate (ODR) were conducted using Grow Gun fractured clay loam test plot soil. Fractures were made on December 8, 1988, using styrofoam insulation as a fill material. ODR measurements were taken 25 days later at one meter intervals starting a half meter from the fracture site in two 180° different directions from the site. The final measurement was at least one meter beyond the furthest extent of surface movement. The platinum electrodes were inserted at eight cm (3 inches) deep. Ten measurements were made at each distance.

Two test plots were selected to analyze changes in bulk density, tree stem growth and terminal growth. The first plot was a street tree planting of willow oaks *(Quercus phellos)* at the Charlotte Douglas Airport. The second was a highway median planting of Bradford pears *(Pyrus calleryana* cv. 'Bradford') in Charlotte, NC. Treatments were applied in January and February 1989. Treatments are detailed in Table 1.

Bulk density is a direct measurement of soil compaction. Cores of soil were collected at all airport test area trees and selected replicates of the highway median test area. Bulk density samples were collected one and a half meters from the tree trunk outside of the mulch layer. Five cm (2 inches) by 6 cm (2 3/8 inches) diameter samples were from 5 to 10 cm (2-4 inches) beneath the soil surface.

Analysis of variance and T-Tests were used to determine statistical significance of all data.

Results and Discussion

Operational aspects. A comparison of operational aspects are presented in Table 2. The Grow Gun is a relatively inexpensive, dependable machine. Due to the low number of moving parts, it can be expected to operate for years without need for major repairs. However, its operation is best suited for two people. The process of drilling holes then discharging air, water and materials into them is relatively slow, requiring about 10 person-minutes to discharge 2 liters of fill materials.

No mechanical problems were encountered with the Grow Gun when used at the Bartlett Tree Research Laboratories. One serious problem resulting in personal injury was encountered with an early version at the Bartlett Sohner Division in San Rafael, California (Dave Anderson, personal communication), this manufacturing flaw has been corrected.

Operation of the Terralift was found to be less time consuming than the Grow Gun. When injecting two liters of fill material only three person-minutes were required per injection hole. Therefore the Terralift operates at about three times the speed of the Grow Gun. The Terralift is adapted to a one person crew. Another major advantage of the Terralift is its ability to discharge air and fill material at more than one level at an injection hole.

Frequent maintenance is required with the Terralift. Eight mechanical problems were encountered during 15 hours of operation. Three problems stopped operations for 15-30 minutes during testing. The control valve design has been improved on later versions so that two of these three problems will not occur. No safety problems were encountered. The Terralift is best suited for a single operator since problems need to be diagnosed and corrected on a regular basis.

Soil effects. Both the Terralift and Grow Gun produced similar effects in the soil. This typically consisted of a single saucer shaped fracture, that is, a horizontal flat circle which curved upward away from the center (Figure 1 - 4).

Although the general fracture pattern was similar for the two machines, there were definite differences in the size of the fracture, and the ability to produce more than one discharge per injection hole.

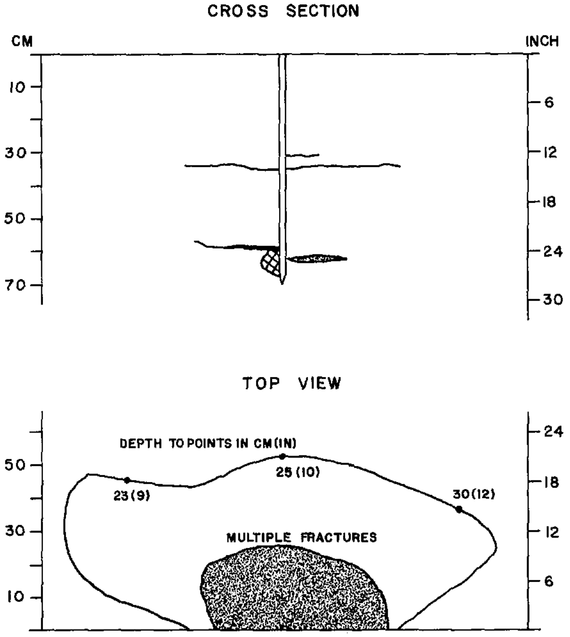

Figure 1. Fracture pattern of the Terralift in clay loam field soil. Discharges at 14 and 24 inches filled with perlite and Supersorb.

Table 1. Soil Aeration Treatments Used in Growth Studies at Two Charlotte, NC sites.

Treatment code	*Number of trees*	*Machine*	*Probe depth (cm)*	*Fill material*	*Fill volume (liters)*	*Fractures per tree*
Site: Douglas Airport - Willow Oaks *(Quercus phellos)*						
GG Sty	5	Grow gun	30	Styrofoam insulation	2	4
TL Comb	5	Terralift	45/70	Styrofoam 'C' Supersorb 'F'	2 X 2 2 X 0.025	4
Core Ar	5	Core aerator	8	—	—	—
Water	5	Fert. needle	20	Water	2	6
Control	5	—	—	—	—	—
Site: Airport Freeway - Bradford Pear *(Pyrus calleryana* cv. 'Bradford')						
GG Sty	11	Grow gun	30	Styrofoam insulation	2	4
GG Sup	11	Grow gun	30	Supersorb 'F'	0.2	4
TL Sty	11	Terralift	45/70	Styrofoam 'C' Beads	2 X 2	3
TL Sup	11	Terralift	45/70	Supersorb 'F'	2 X .075	3
Core Ar	11	Core aerator	8	—	—	—
Water	11	Fert. needle	20	Water	2	6
Control	11	—	—	—	—	—

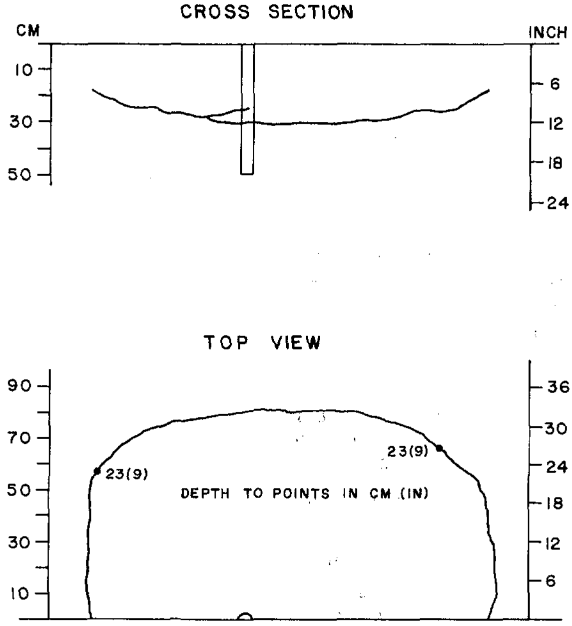

Figure 2. Fracture pattern of the Grow Gun in clay loam field soil. Eight quarts of perlite fill applied through 14 inch stem.

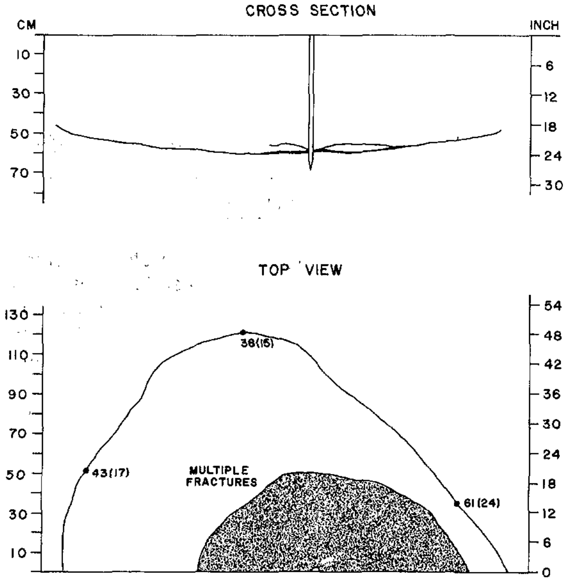

Figure 3. Fracture pattern of the Terralift in sandy clay loam hill site. Single discharge at 25 inches filled with six quarts of vermiculite.

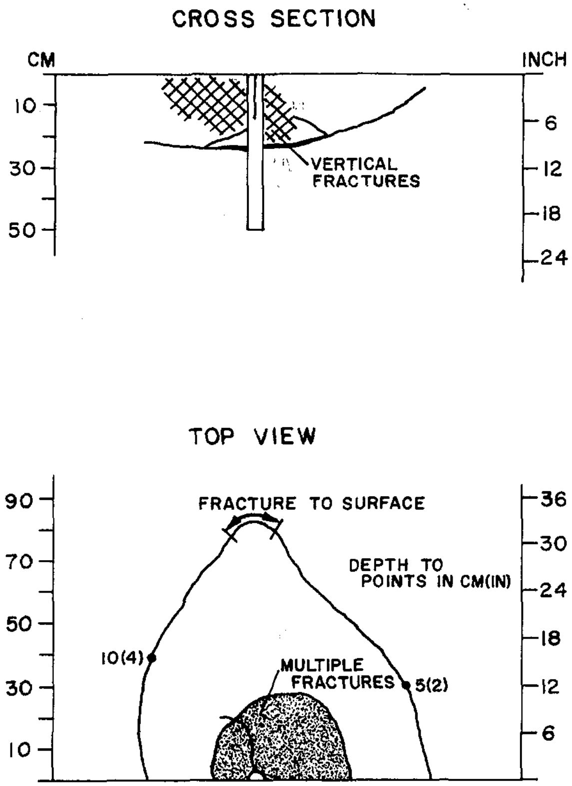

Figure 4. Fracture pattern of the Grow Gun in sandy clay loam hill site. Six quarts of styrofoam insulation fill applied through 14 inch stem.

Only the Terralift could produce more than one fracture at a single injection hole. This is due to the Terralift probe being mechanically driven into the soil. A tight seal is formed which allows for discharge at a controlled and multiple levels. The Grow Gun will only produce one fracture because its probe fits into a drilled hole. Air injected with the Grow Gun may move in the drilled hole producing fractures at a weak layer of unpredictable depth.

Fifty eight fractures were excavated at two sites at the BTRL (Grow Gun 25, Terralift 33).In both locations the average fracture size produced by the Terralift had a larger radius than did the Grow Gun (Table 3). Estimates of the fracture area were made from average radius data. These estimates of area reveal greater differences between the two machines. The average fracture area for a single discharge of the Terralift was 4.3 square meters (46 square feet) per discharge versus 1.8 square meters (19 square feet) for the Grow Gun. The Terralift can produce two or more discharges per injection hole.

At the airport and highway median test sites

Table 2. Comparison of soil aeration equipment: operational aspects

Factor	*Terralift*	*Grow Gun*
Safety	High pressure system appears safe. Storage bottles will need to be inspected/tested regularly, hydraulic hoses need regular inspection (similar to stump grinder). Operator is 12+ inches from high pressure system, safety shield can be erected if needed.	One potentially serious accident in California; problem has been corrected. Operator's chest is 6 inches or less above top of machine.
Safety equipment required	Hardhat, face shield, hearing protection required.	Hardhat, face shield required. Hearing protection for drill/generator and compressor recommended.
Crew training time	4 hours +	2 hours or less
Speed	Average 3 minutes/hole; discharges at two levels per site, 2 liters of fill discharge.	10-12 person minutes/hole using 1 discharge per hole, and 2 liters of fill.
Crew size	1 or 2 people	2 people - operator must be able to lift heavy loads (40-60 lbs.) repeatedly.
Frequency of repair	8 problems in 15 hours of operation. 3 did or could stop operation for 15-30 minutes; 2 of these serious problems have been designed out in new version.	0 mechanical problems in 20 + hours at Bartlett Tree Research Lab. Parts readily available.
Suitable for multiple operators	No - requires well trained operator.	Yes
Fill material	Will accept styrofoam 'C' beads, perlite or vermiculite; will not accept fine water absorbing polyacrylimide in moist environment, will not accept peat with large particles; may accept course water absorbing polyacrylimides and fine peat (not tested).	Will not accept peat with large particles. Will accept all other tested materials. May accept fine peat (not tested).
Transportation	Requires trailer or full size pick-up truck with ramps.	Full size pick-up truck is suitable (must tow heavy compressor).
Property access	Climbs 20+% slope; jumps curbs with difficulty.	Must be within air hose distance of compressor (50 or 100 feet increments). Hand carried over any terrain.
Operation under low limbed trees	Requires 6+' of overhead clearance.	Drill and operator more limiting than machine.
Terrain	Climbs 20+% slope, outrigger requires close to level soil.	Requires "20" diameter circle of flat surface, Tufts of grass may interfere with operation.
Recommended options	Heavy duty engine (Kohler), US manufactured air powered wheel motors. O-ring free main control valve.	Slightly less than 2" diam. drill bit. Lighter weight (aluminum) model 'Grow Gun Lite'.
Approximate cost	$18,500 - 26,000	$3,000 - Grow Gun - Steel $4,000 - Grow Gun Lite $50 - Auger $250 - Gas Drill or Generator rental $12,000 - Compressor or $50-75/day rental
Major advantages	Speed, able to fracture soil at multiple depths.	Low initial cost without compressor purchase. Low repair cost.

there were no significant decreases in bulk density following any of the treatments (Table 4).

The oxygen diffusion rate was higher only at the fracture layer. No increase in ODR was found within or outside of the fracture (Table 5).

Both machines create basically one fracture line and lift the overlaying soil as a unit. This is why they do not reduce compaction of the soil. There is no force which pulverizes the soil above the fracture line in the clay soil studied. In areas with hardpan layers the probe hole and fracture layer should improve drainage. This effect has not been studied. The impact which these machines have on tree growth are currently under study.

Table 3. Fracture radii produced by the Terralift and Grow Gun in two soil types.

	Average max. radius in inches	
Site	*Terralift*	*Grow gun*
Hill (Sandy Clay Loam over Clay)	45	34
Field (Clay Loam over Clay)	47	25

Table 4. Mean bulk densities five months after treatment with the Grow Gun, Terralift, core aerator and water injection.

Treatment	*Bulk density (g/cc)*	*Number of trees*
Airport test area		
Grow Gun	1.53	5
Terralift	1.50	5
Core Aeration	1.54	5
Water Injection	1.50	5
Control	1.53	5
Freeway median		
Grow Gun	1.64	21
Terralift	1.66	23
Core Aeration	1.70	11
Water Injection	1.58	10
Control	1.75	11

No bulk density values are significantly different.

Table 5. Oxygen Diffusion Rate (ODR) Measurements Twenty Five Days After Treatment with Grow Gun.

Direction and distance from tree (meters)	*Distance from gun hole (meters)*	*ODR reading*	*SD*
West 1 Inside	.5	.163	.026
East 1 Inside	.5	.172	.026
West 2 Fracture Line	1.5	.192	.054
East 2 Fracture Line	1.5	.197	.034
West 3 Outside	2.5	.161	.057
East 3 Outside	2.5	.170	.055
West 4 Outside	3.5	.181	.021
East 4 Outside	3.5	.181	.059

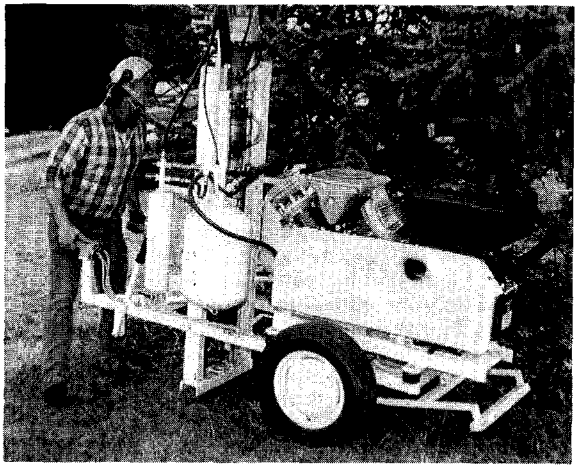

Figure 5. Soil aeration machines have received a great deal of interest within the tree care industry. George Clairmont, R.E. Jarvis Co., is shown operating the Terralift for experiments at the Bartlett Tree Research Laboratories.

Summary

The Terralift and Grow Gun can be used to inject fertilizer and other materials into the soil. The Terralift produced larger fractures and more than one level of fractures in an injection hole. Fractures from either machine did not reduce the soil bulk density (compaction) near the soil surface. Soil aeration was improved only near the fracture line. The impact of treatment on tree growth is still under study.

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Literature Cited

1. Patterson, J.C. and D.L. Mader, 1982. Soil compaction: causes and control. **In** P.J. Craul, Urban Forest Soils: a reference workbook. SUNY College of Environmental Science and Forestry, Syracuse, NY.
2. Russell, E.W. 1973. Soil Conditions and Plant Growth. Longman, London 849 p.

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