Interaction of soil salinity, sodicity and texture on apparent freeze damage of 3rd to 7th leaf pistachios: is there a definite threshold?

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Summary

Over the last three years, young 2nd to 7th leaf pistachios have died or had severely restricted spring shoot growth in marginal to severely saline/sodic "hot spots" in some Westside orchards in Kern and Fresno Counties. The symptoms of this decline (dead bark, brown phloem tissue near the bud union on dead trees) appear the same as frost damage and have generally been located in a lower part of the field. However, some adjacent trees at virtually the same elevation appear to have no symptoms at all. Subsequent sampling by Craig Kallsen in 2010 found elevated sodium (Na) the bark near the bud union, but not in leaf tissues. Nearby trees that appeared unaffected had lower Na accumulation in the bark. Elevated sodicity, decreased available calcium and an increase in silt and water holding capacity is very consistent with often small alkali areas in fields across the San Joaquin Valley. These "hotspots" have a very real potential of maintaining greater osmotic stress on trees throughout the season that might not show significant toxicity symptoms in the leaves, but can prevent the trees from sufficiently drying out the soil profile and properly hardening off at the end of the season and leave them more vulnerable to frost damage. This project is an attempt to chart a soil "sodicity/salinity" gradient from the center of one of these hotspots, which had considerable tree death/decline due to apparent frost injury, into a vigorous unaffected area of the orchard to determine if one or more salt/sodium/metals thresholds existed that separated frost susceptible trees from their neighbors showing no damage.

Five sites were selected that exhibited this "hotspot" behavior with four of these sites showing a very clear gradient of frosted trees in the center of the hotspot moving to unaffected trees down the same row and moving into an apparently less saline/alkali usually slightly sandier soil. Orchard age varied from 3rd to 7th leaf with all sites irrigated by single line drip with 4 to 6, 1 qph emitters/tree. The predominant soil types are Garces and Lethent silty clay loams, exhibiting obvious salt rings at the edge of subbing patterns from drip emitters. Some hardpan is present in these areas but there is no perched water.

A rapid non-invasive measurement of bulk soil "apparent" electroconductivity (ECa) was made using a hand-held Geonics EM38DD along a transect of 15 trees starting at the center of the affected apparent frost damage area extending beyond the obvious "hotspot" area up the row into unaffected trees. This device is about 1 meter long and sends an electromagnetic pulse from one end of the instrument to the other – measuring the change in the signal as it is affected by water content and soil salinity to a vertical depth of about 45 inches and horizontal radius about the same distance. The assumption is that the water content will be much more uniform at any given measurement period than the differences in soil salinity. Therefore, the variation in the readings can be related mostly to salinity differences. At two of the sites soil samples were taken in 15 inch increments to a depth of 45 inches at different distances from the hose,

analyzed for ECe and sodium content and correlated by multiple regression to the EM38 readings. This relationship was a reasonably good fit with an R-squared of 0.77. (An R-squared = 1.00 is a perfect fit.) Rootstock and scion wood borings along with leaf tissues were also taken at one site and analyzed for sodium content.

Three of the sites exhibited a very clear threshold where the apparent frost damage susceptibility ceased to be a problem when average rootzone soil salinity was ECe < 6 dS/m, soluble Na < 40 meq/l (920 ppm) and Na/Ca ratios < 15 at a distance of 60 to 90 inches from the drip hose. This roughly corresponds to an EM38 reading of about 80 milli-Seimens/m (mS/m). All EM38 readings and measured soil salinities where below this threshold when measured between 2 emitters right on the hose. But this represents a zone of significant leaching during the establishment of the orchard and is not representative of the native salt/sodium load in the soil that can have some of these adverse uptake issues which is the concern of this research project. Of the two sites that did not show this clear trend – one had affected trees all along the transect and never really "broke into" totally healthy trees. The regressed soil EC numbers at the 60 and 90 inch distance from the hose were all above the 6 dS/m soil EC threshold. Thus, it is not surprising that the problem appeared more random at this site without a section of completely unaffected trees. At the second site, all EM38 readings and regressed ECa values were considerably below this threshold, but there was still a small section of about 6 trees by a couple rows wide that had the appearance of a typical "hotspot" and where frost damage was significant.

These "hotspot" areas can also be associated with naturally elevated levels of heavy metals not usually tested for that can also cause varying specific ion toxicities, particularly arsenic and chromium. At one site exhibiting this clear salinity/sodicity threshold and gradient we also tested the soil samples for these and other metals. Only total arsenic showed somewhat elevated concentrations in the samples at 12 to 16 ppm, with the highest concentration actually occurring just outside of the "hotspot" area where the trees showed no susceptibility to this salt-frost syndrome. This suggests that these more exotic elements are probably not associated with frost susceptibility in pistachio.

Procedures

Sites: Five distinct areas in different fields along the I-5 corridor from Buttonwillow to Highway 46 have been identified. The predominant soil types are Garces and Lethent silty clay loams. Poor soil structure and slow infiltration predominate with significant salt rings obvious at the edge of subbing patterns from drip emitters. All irrigation systems are single-line drip with 4 to 6, 1 gph emitters. There are no known hardpans or clay "perching" layers that restrict drainage and create perched water. "Hotspot" acreage varies from 0.4 to 2.28 acres in these fields, for a total of 6.17 acres as mapped with a hand-held GPS. Individual tree locations sampled and rated by Kallsen in Spring 2010 have also been mapped. These locations were used as sampling sites with expanded tree ratings and salinity sampling as outlined below.

Data Collection and Analysis

Soil salinity

EM38 (all sites): A very rapid, non-invasive estimate of bulk soil apparent electroconductivity (ECa) to a depth of about 3 feet can be made using a hand-held electromagnetic impulse device called an EM-38. Four measurements with this device around a single affected tree in the center of the "bad" area will be used to characterize salinity variability with respect to the tree trunk and adjacent drip emitter. Taking this center tree as #0, an identical pattern of measurements will be made for tree #2, 4, 8 and 16 in a transect line extending from the center of the "bad" area into the "good" area either down, across or diagonally to rows as most appropriate for that site. Measurements were made during July to August. This device will also be used to take a single measurement at each tree within the "hot-spot" GPS boundaries as noted in 2010 to develop contours of ECa and compare/regress with contours of visual tree ratings as described below.

Soil moisture (two sites): Gravimetric determination of soil moisture for the 0-15, 15-30 and 30-45 inch depth soil samples was made coinciding with measurement of EM38 readings to improve calibration of estimated ECa.

Laboratory analyses (1 site only): Soil samples for 3 depths, 0-15, 15-30 and 30-45 inches were taken on 7/22/11 from these same locations (60 total), dried, ground and split. One set of samples was sent to the UC Davis Agriculture and Natural Resources Lab to be analyzed for saturation percentage (SP) as a means to identify soil texture and water-logging potential and soluble salts: EC, pH, Ca, Mg, Na, Cl, HCO3, B, NO3-N. The second set of samples was sent to the UC Davis California Animal Health & Food Safety Laboratory System, which was better equipped for heavy metals analyses consisting of arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, thallium, vanadium and zinc.

Bulk Rootzone ECa (all sites): Bulk rootzone apparent electroconductivity (ECa) over a distance of 4 to 6 feet (depending on emitter spacing) across the rootzone will be assessed in the spring and fall using a conductivity meter attached to pair of simple stainless steel 3/8” rods driven to a depth of 45 inches underneath the drip emitters adjacent to opposite sides of the tree. This type of measurement is directly affected by soil water content/texture and bulk salinity and may be a good indicator of whole rootzone water-logged conditions. This is a similar reading that would be generated by a VERIS (electrified disc coulters run down the row) except the technique proposed here would send the current under the tree instead of down the adjacent row.

Plant measurements

Tree vigor ratings (all sites): Trees will be rated with Craig Kallsen using a 0 (dead) to 4 (no problem) scale after shoot push in April/May and again in August to be correlated with other data.

Tree bulk ECa (all sites): Bulk electroconductivity (ECa) of the tree above and below the graft union will be as assessed in the spring and fall using two ¼ inch diameter stainless steel probes inserted to a depth of 1.5 inches and 1.5 inches apart attached to a conductivity meter for all transect trees and those sampled by Kallsen for bark analysis. These readings will be correlated with …

Tree wood samples for lab analysis (all sites): The drilled wood borings for the above probe insertions from the tree trunk above and below the graft union will be analyzed for Ca, Mg, Na, K, and Cl for a total of 40 samples from the transect trees, 200 analyses total.

Results and Discussion

(The following discussion refers to sampling sites by number to maintain the privacy of respective growers.)

Rhodes, et al. (1999) provides some excellent discussion on the theory and operation of the EM38 probe. EM38 readings consist of a magnetic pulse in the horizontal (EMh) and vertical (EMv) planes basically integrating a “bulk apparent EC” for a soil volume representing a quarter sphere in volume with a diameter of 1 to 1.2 meters depending on soil texture and water content. If salinity is more concentrated in the upper part of the soil then EMh readings will be the more sensitive measure of changing salinity. This situation is common in fine-textured soils under drip irrigation. As you move away from the dripper the salinity in the top foot increases due to water and salts wicking out from the emitter and being drawn upward by drier soil and subsequent evaporation. This is the case for our study sites in this project and is perfectly illustrated in Figure 1 where the EMh readings show a much steeper slope as a function of changing salinity than do the EMv readings. Figure 2 shows the excellent repeatability of EM38 readings in the same location at two different dates roughly two weeks apart. Corwin and Rhodes (1989) provide generic calibration curves for log transformed ECa numbers from extensive sampling in the San Joaquin

Valley as well as a discussion of the operation and calibration of the EM38 readings. One of these calibration curves was examined for goodness of fit for the data obtained in this study, but was rejected in favor of a simple multiple regression of the EMvertical and EMhorizontal readings with the laboratory measured soil ECe. This calibration curve was applied to all sites (Figure 3).

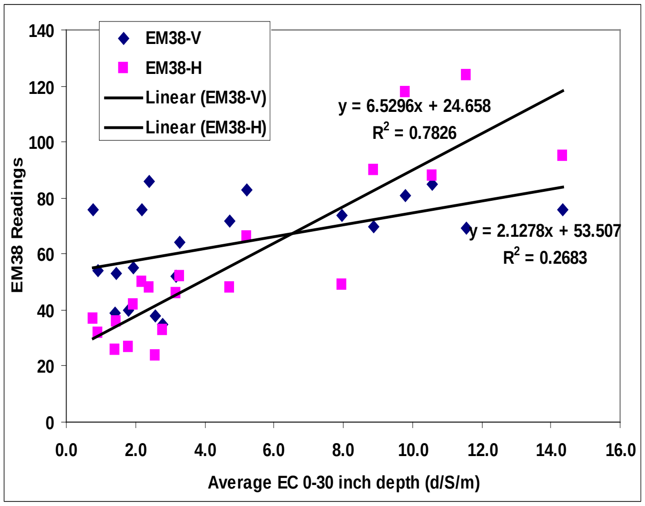


Fig.1. Vertical and horizontal EM38 readings regressed against average soil saturation extract ECe for the 0-30 inch depth.

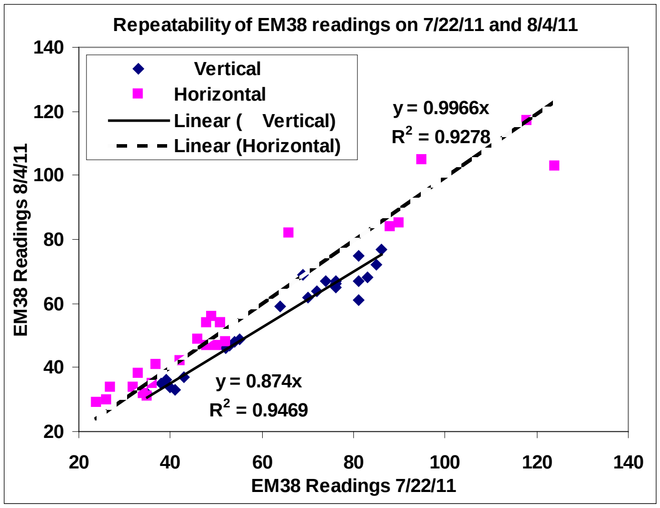


Fig.2. Repeatability of EM38 readings

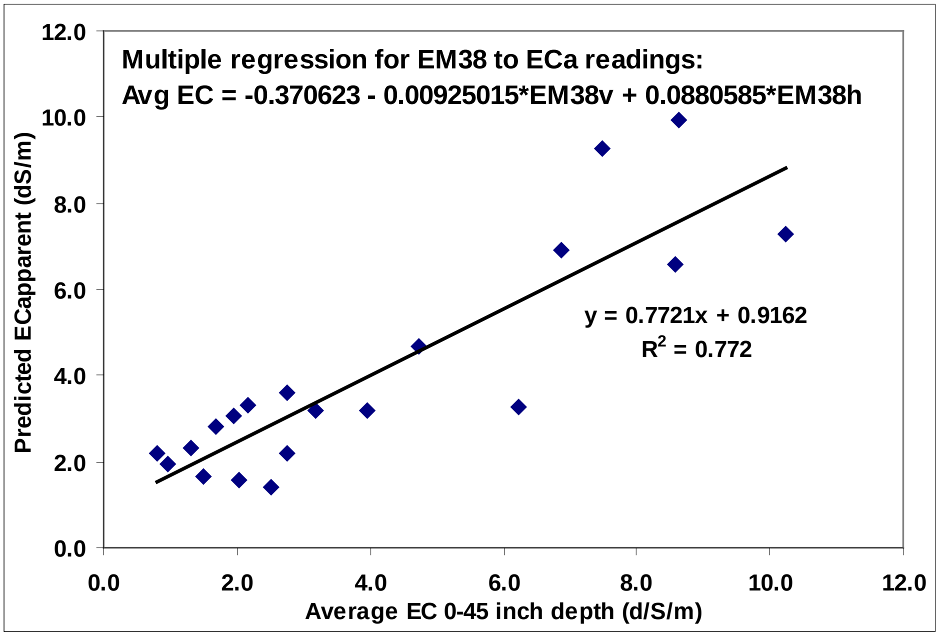


Fig.3. Mutiple regression calibration relating EM38 estimates of bulk soil ECa to average lab determined ECe.

The following figures and discussion are for Site 1.a. – the most intensively sampled location. Charts are all in the same layout with different y-axes of different characteristics as noted. The depth of the sample (or average) is written in bold. The 4 lines represent samples taken on the drip hose near the tree, then 30, 60 and 90 inches into the drive. The "0" on the x-axis is the center of the apparent frost damaged area.

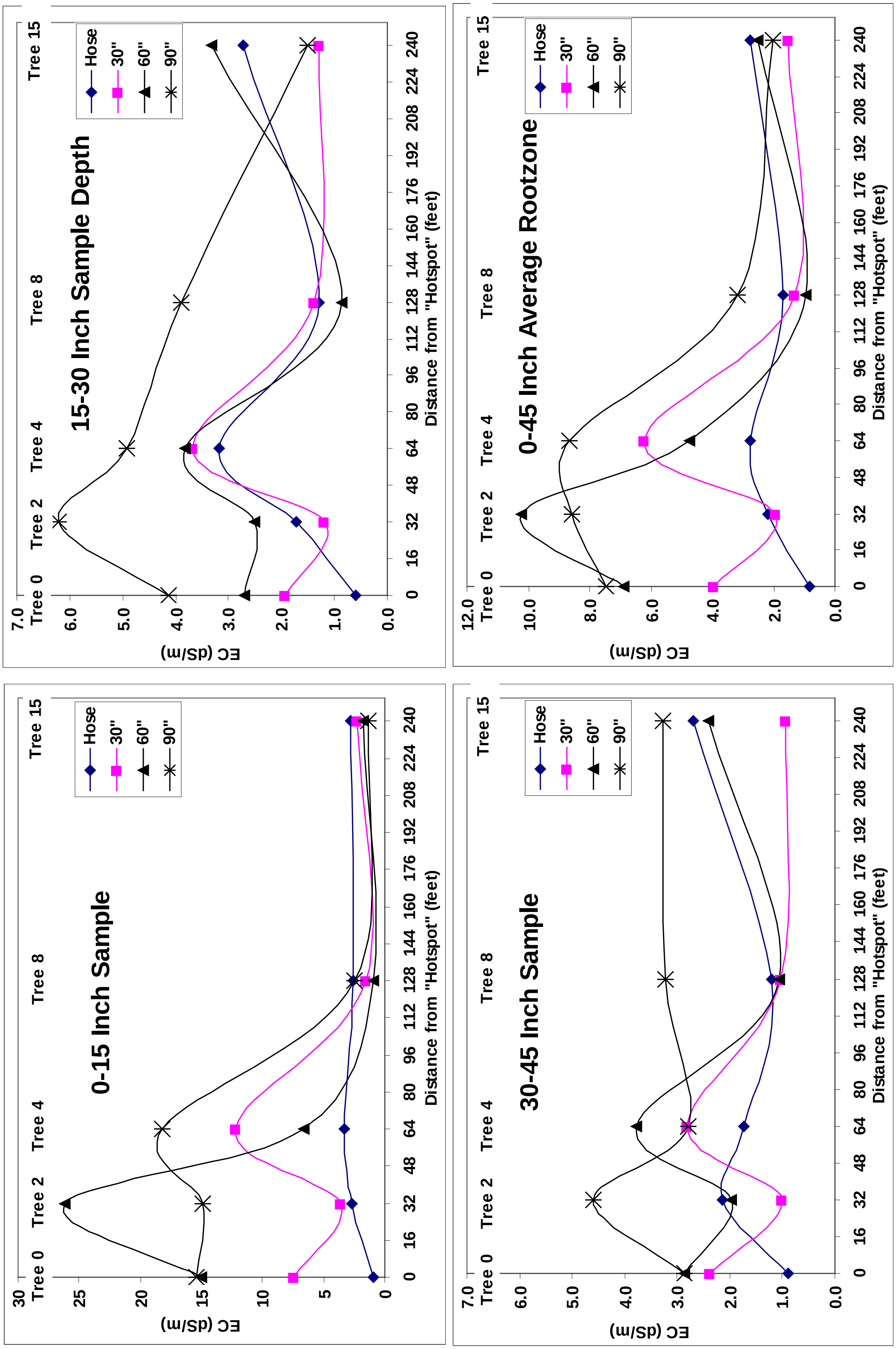


Fig.4. Laboratory determined saturation extract ECe for all depths along transect. Site 1a.

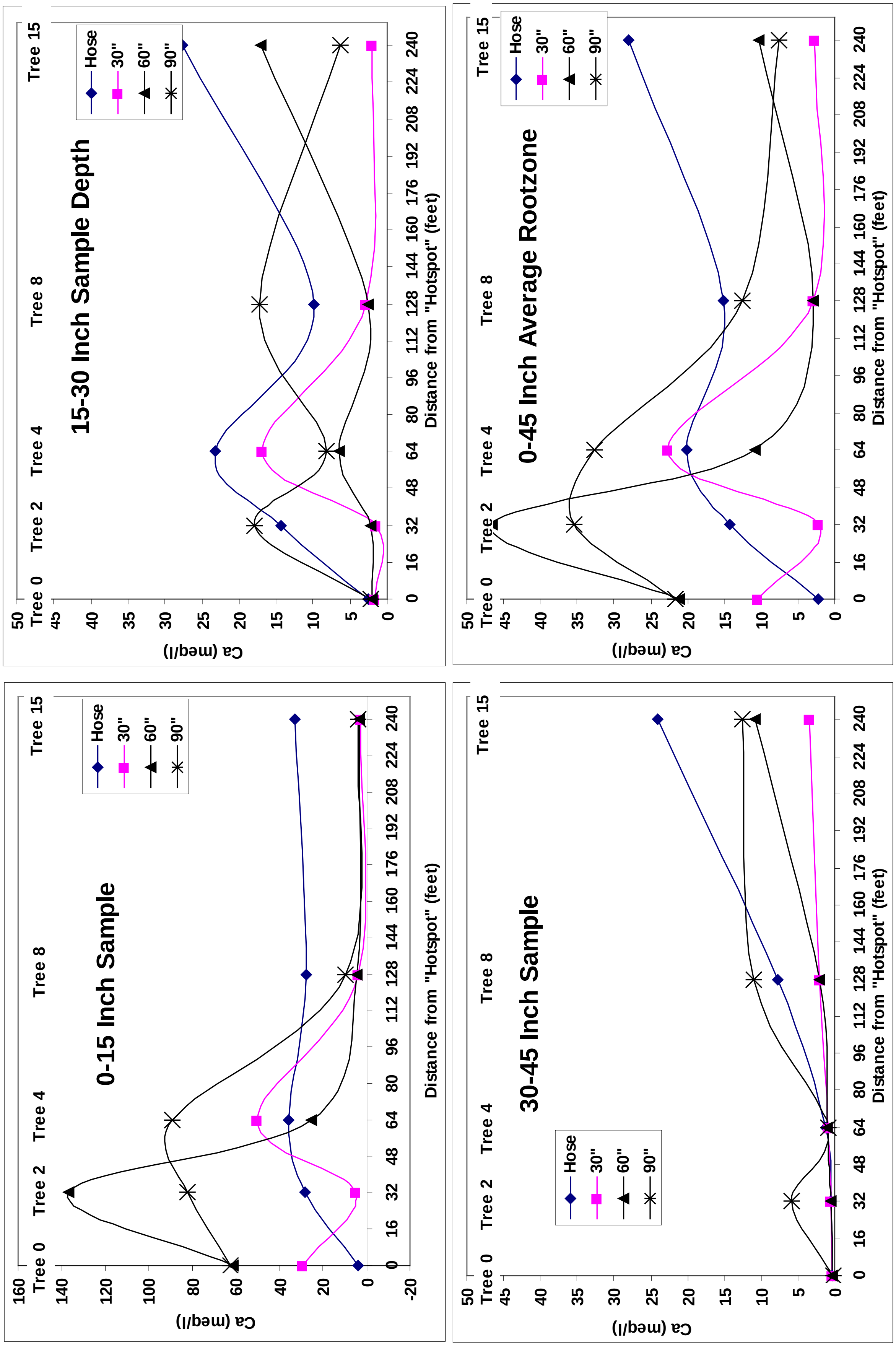


Fig.5. Laboratory determined saturation extract soluble calcium for all depths along transect. Site 1a.

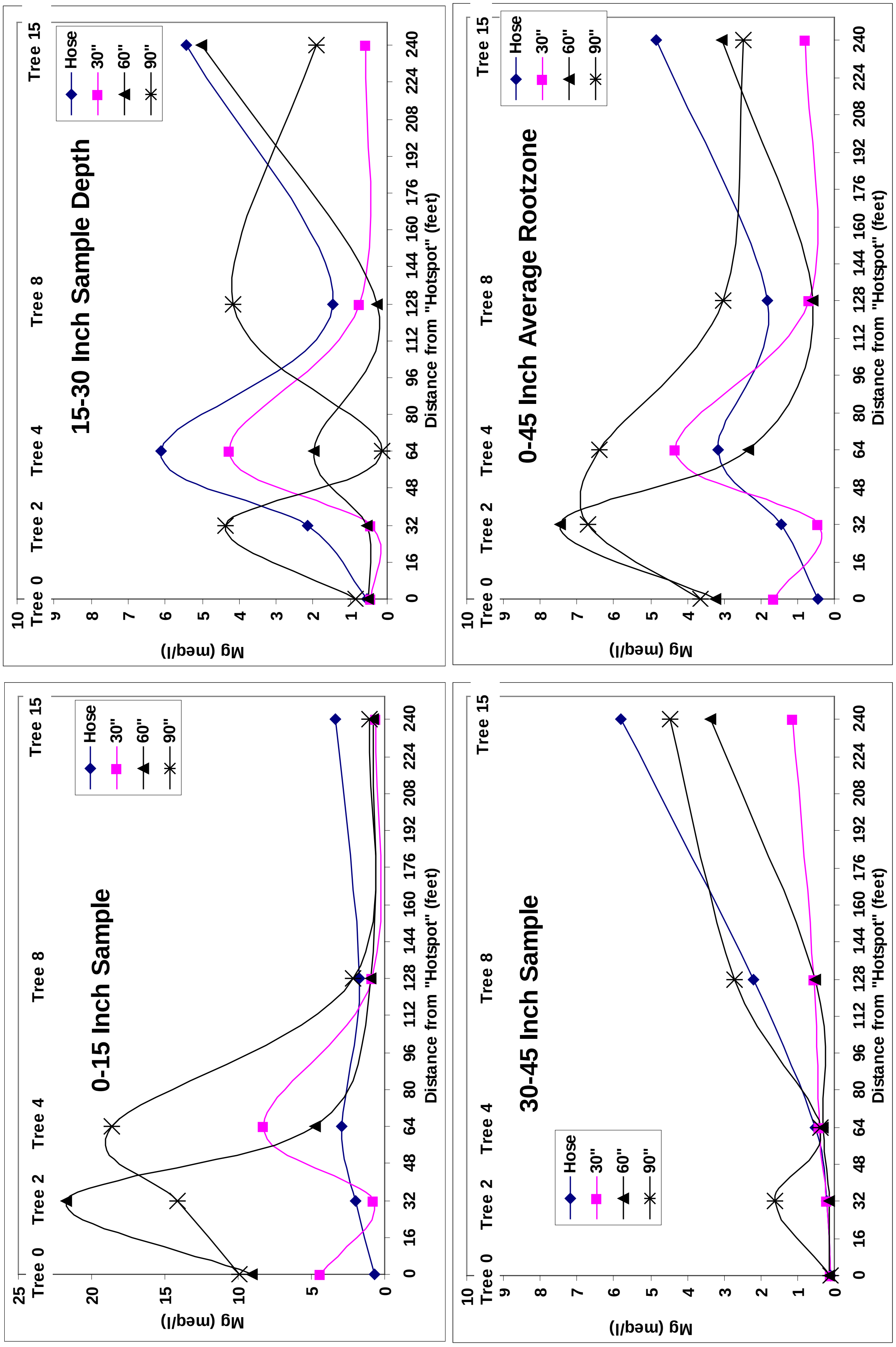


Fig.6. Laboratory determined saturation extract soluble magnesium for all depths along transect. Site 1a.

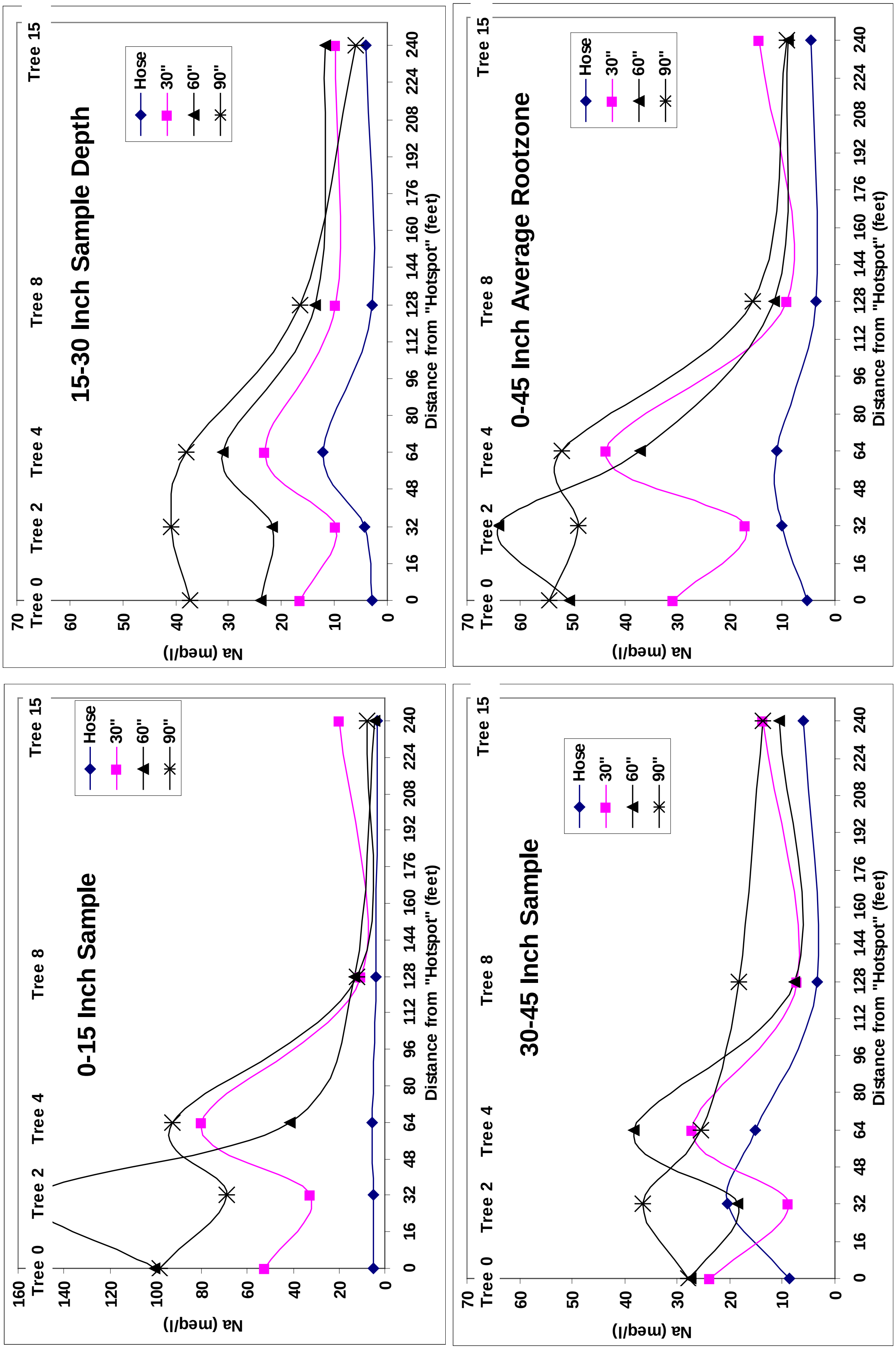


Fig.7. Laboratory determined saturation extract soluble sodium for all depths along transect. Site 1a.

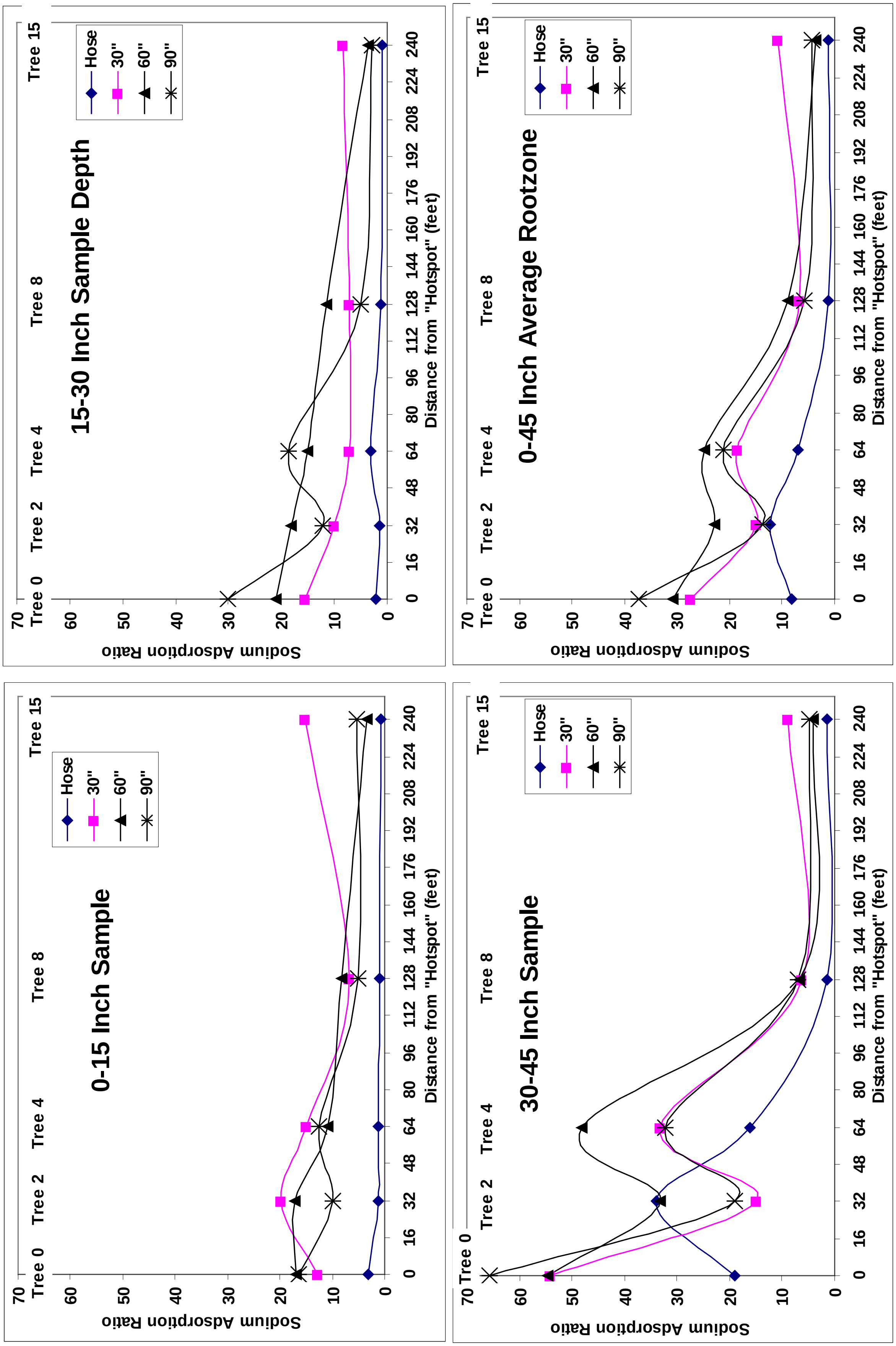
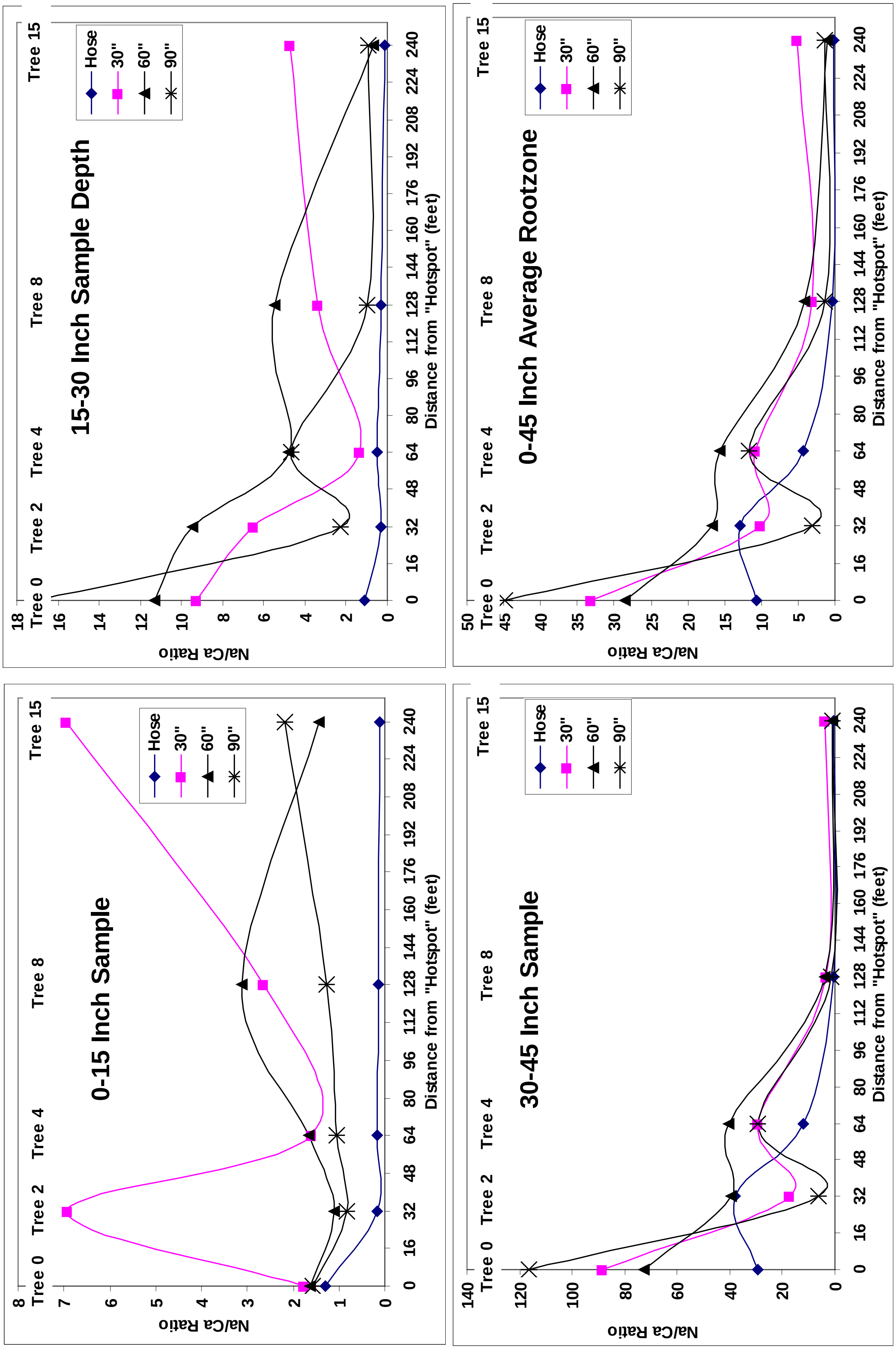


Fig.8. Sodium adsorption ratio (Na/(((Ca+Mg)/2)^0.5)) for all depths along transect. Site 1a.


0-15 Inch Sample

15-30 Inch Sample Depth

30-45 Inch Sample

0-45 Inch Average Rootzone

Fig.9. Ratio of saturation extract soluble sodium to calcium for all depths along transect. Site 1a.

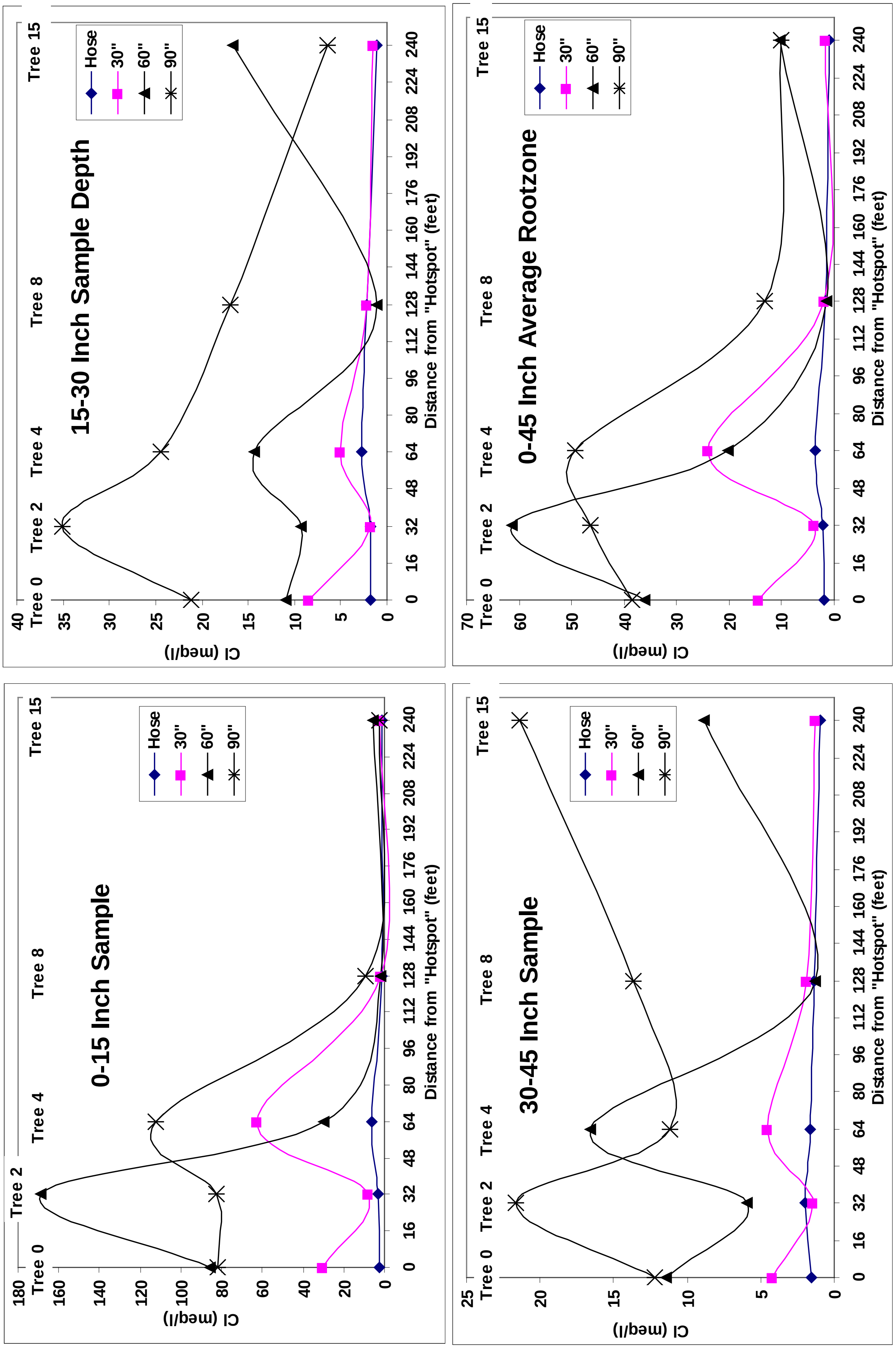


Fig.10. Laboratory determined saturation extract soluble chloride for all depths along transect. Site 1a.

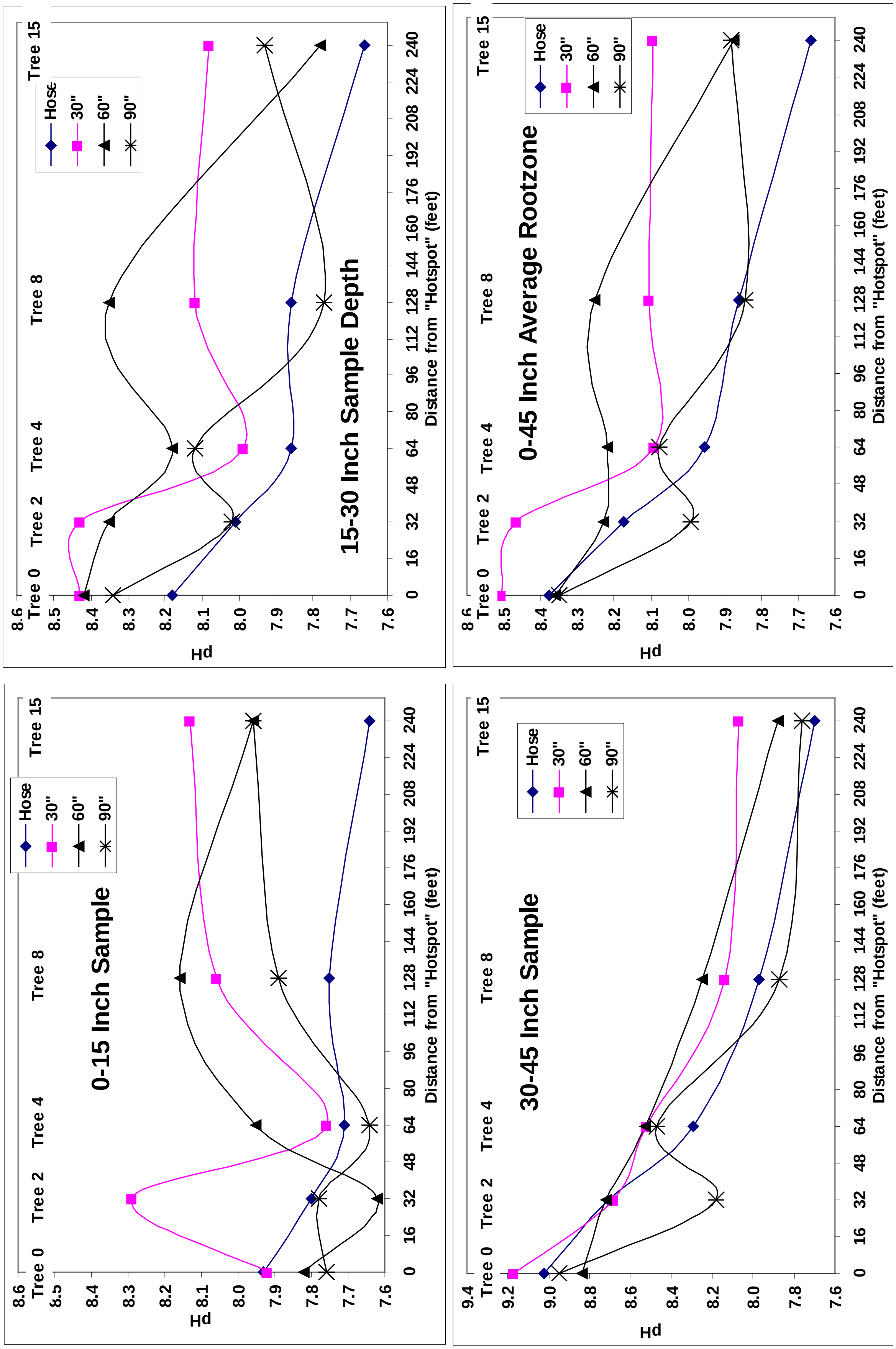


Fig.11. Laboratory determined saturation extract pH for all depths along transect. Site 1a.

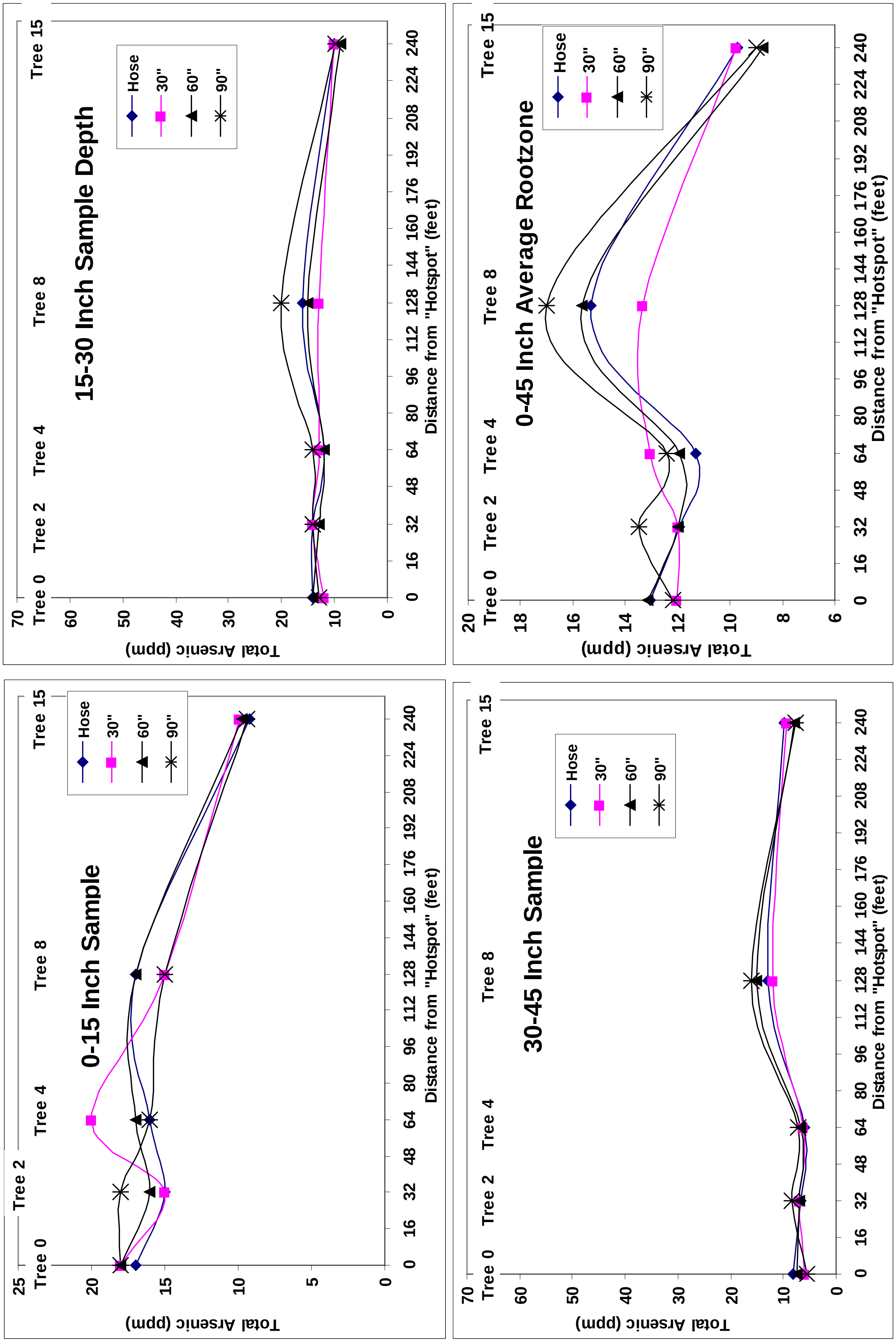


Fig.12. Laboratory determined total arsenic for all depths along transect. Site 1a.

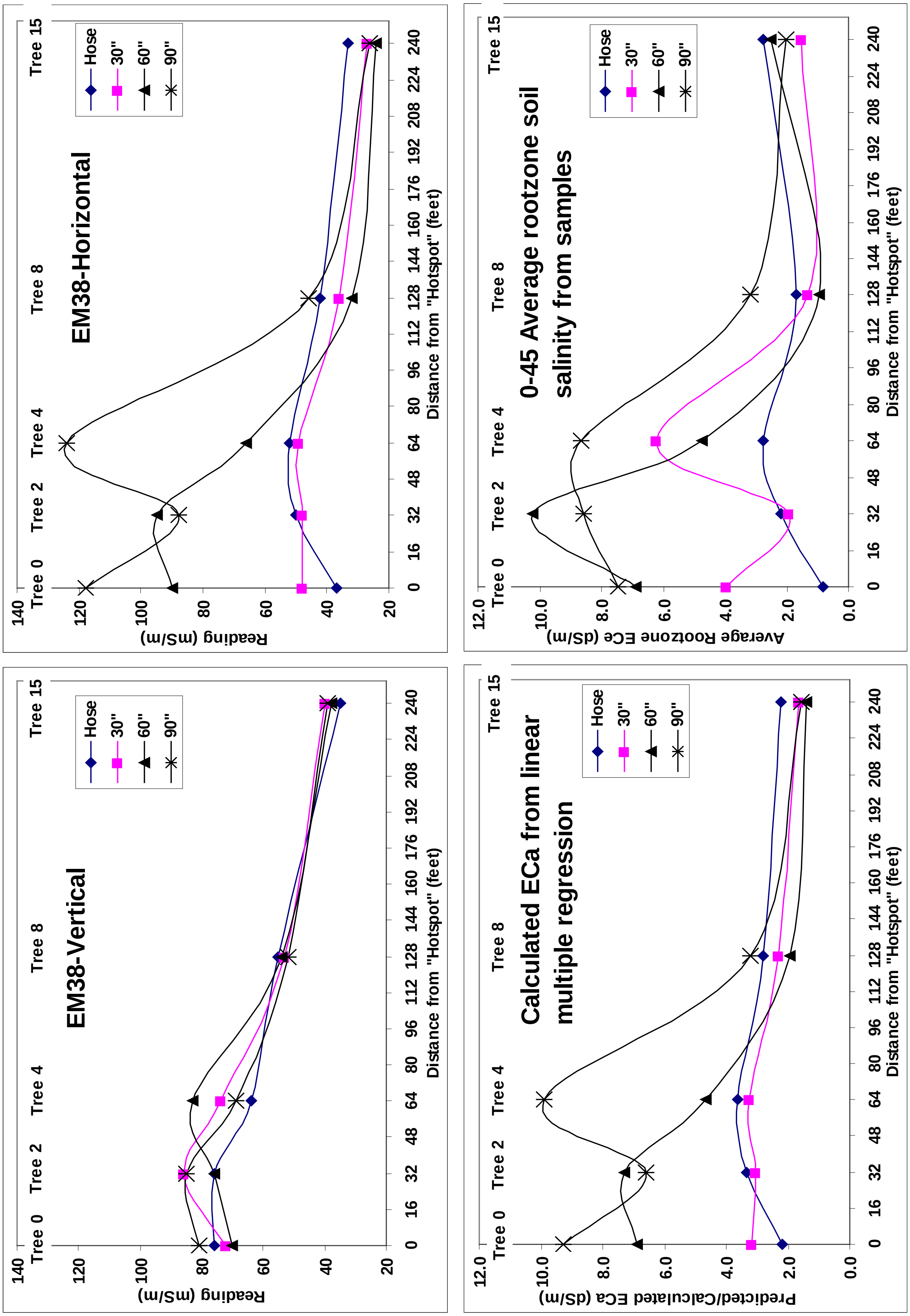


Fig.13. EM38 readings and calculated ECa along transect at various distances from the drip hose compared to the 0-45" average laboratory soil ECe. Site 1a.

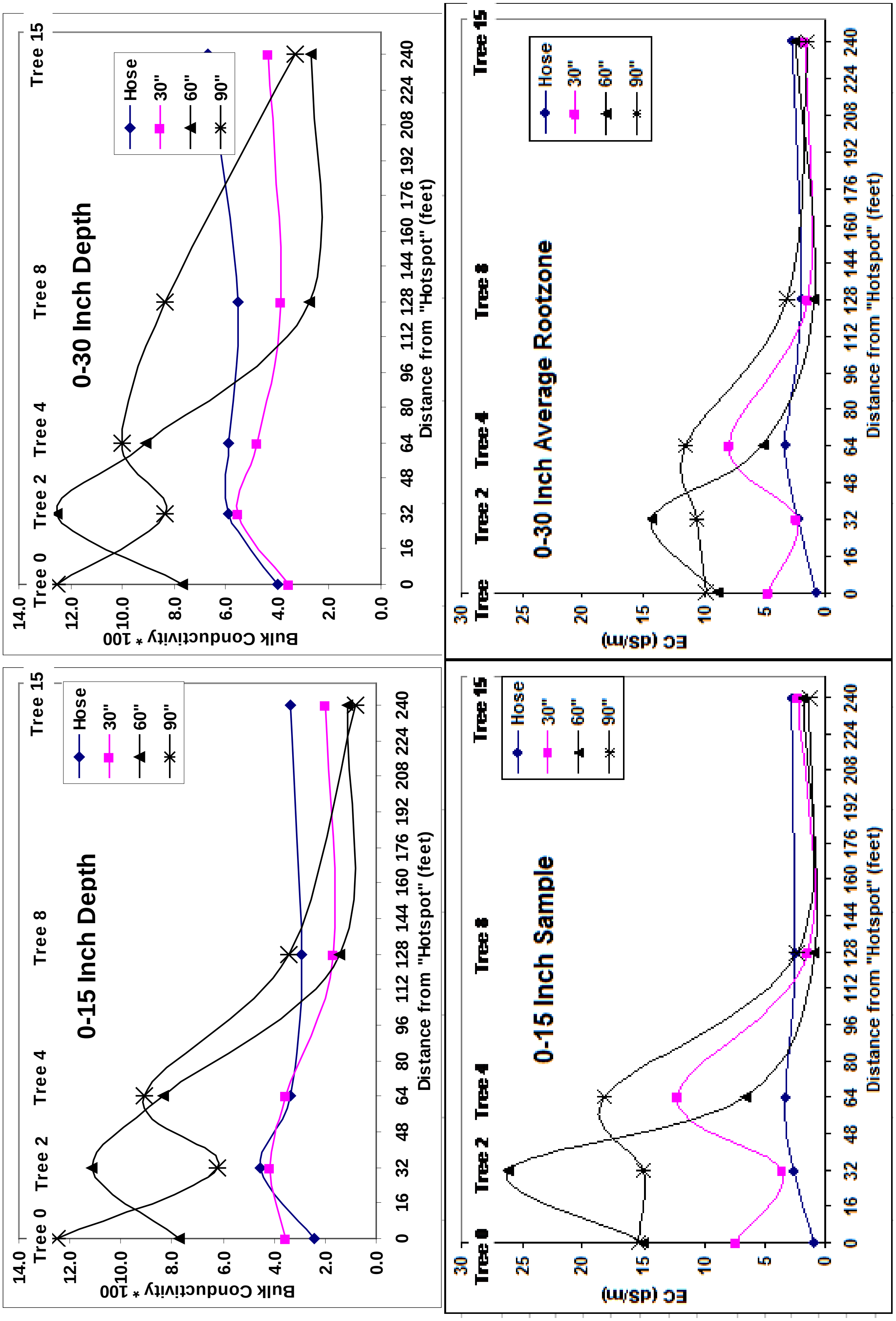


Fig.14. Bulk electrical conductivity (1/ohms * 100) as measured with ¼ inch diameter stainless steel rods placed 38 inches apart and driven to the indicated depth compared to laboratory determined soil ECe.

Except for concentration changes in arsenic and the 30-45 inch depth for soluble calcium and magnesium these charts all exhibit the same trend – high concentrations in the middle of the frost/damage zone and decreasing rapidly as you move out of the "hotspot" zone to usually slightly higher ground and better soil. The extremely high average pH and minimal soluble calcium and magnesium in the 30-45 inch soil samples indicate how easy it is to precipitate lime in this soil and lose your soluble Ca and Mg as you move deeper in the profile.

For virtually all sites "Tree 0" had been killed and was replanted, with Tree 2 being significantly stunted, Tree 4 less so but still below normal stature and Trees 8 and 15 usually at full stature and unaffected by this "salt-frost" syndrome. Tree spacing was 16 feet. Figure 13 shows that the calculated ECa from the EM38 probe provided a good estimate of the laboratory measured ECe. Figure 14 shows that a similarly good estimate was obtained with our inexpensive conductivity probe using hand-driven ¼ inch diameter steel rods placed 38 inches apart. We had hoped to insert the rods to a depth of 38 inches but hardpan/rocks prevented us going deeper than 30 inches. This method may have some promise for in-situ monitoring over the season but was not used at the other sites due to the difficulty and precision of inserting the rods into the soil.

Figure 15 shows a clear trend for elevated sodium in ¼ inch trunk corings in the cloned UCB rootstock in the damaged area used at Site 1a that was not at all shown in either the Kerman Scion or leaf tissues.

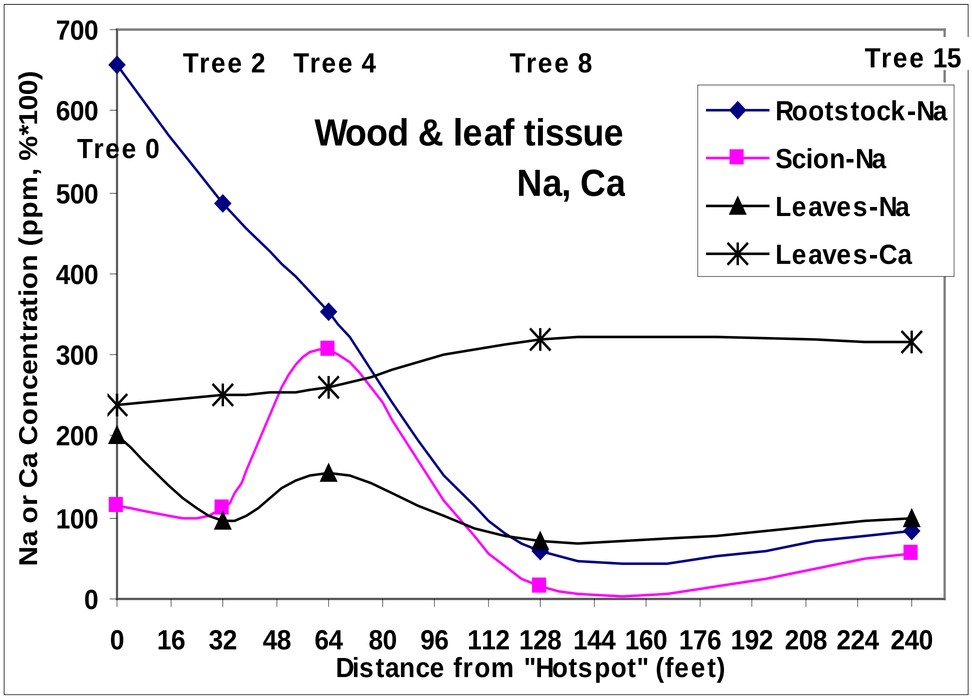


Fig. 15. Na and Ca concentration in wood or leaves along transect. Site 1a.

The sodium values for in this figure are about one-tenth of the Na bark values found by Kallsen in 2010 in frost damaged to no damaged trees, but still showed a consistent trend from affected to non-affected trees. Undoubtedly, most of the Na buildup occurs in the bark and cambium tissue, which requires sampling many trees to obtain enough sample mass for testing. Including the xylem tissue in these wood corings diluted the Na, but allowed us to obtain enough tissue to test the individual trees along our transect. At this site there is a very steep decline from over 500 ppm to less than 100 ppm in this UCB cloned rootstock. The leaf Ca at the same time increases from 2.5% in the sodic area to 3.2% in the "good" area.

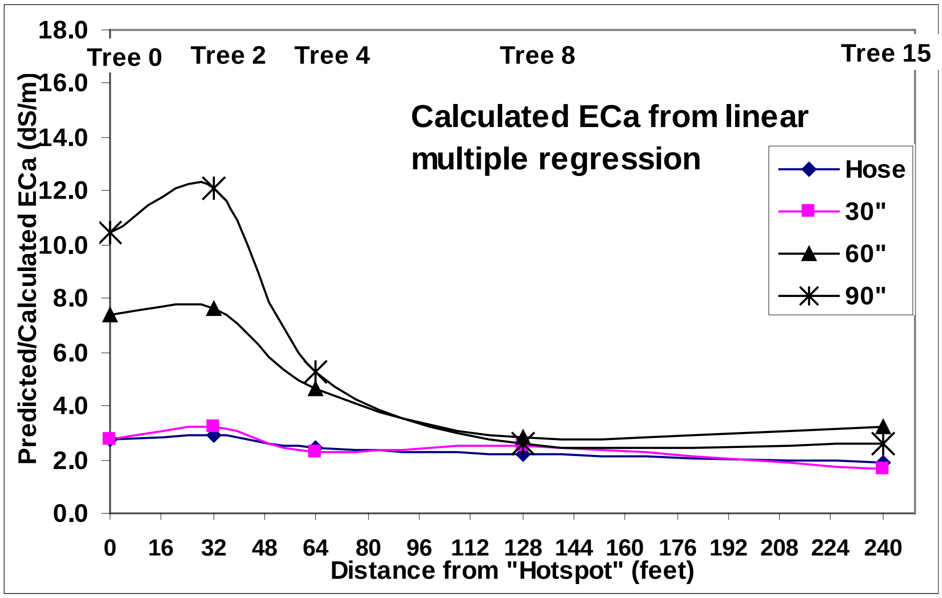


Fig.16. Calculated ECa from EM38 readings for Site 1b, ½ mile west of Site 1a.

Site 1b. looked like a carbon copy of Site 1a., which is not surprising given they were planted in the same year with the same UCB clones to a nearly identical soil type and farmed by the same grower. with Figure 16 showing a very similar salinity pattern from the "bad" to the "good" part of the transect.

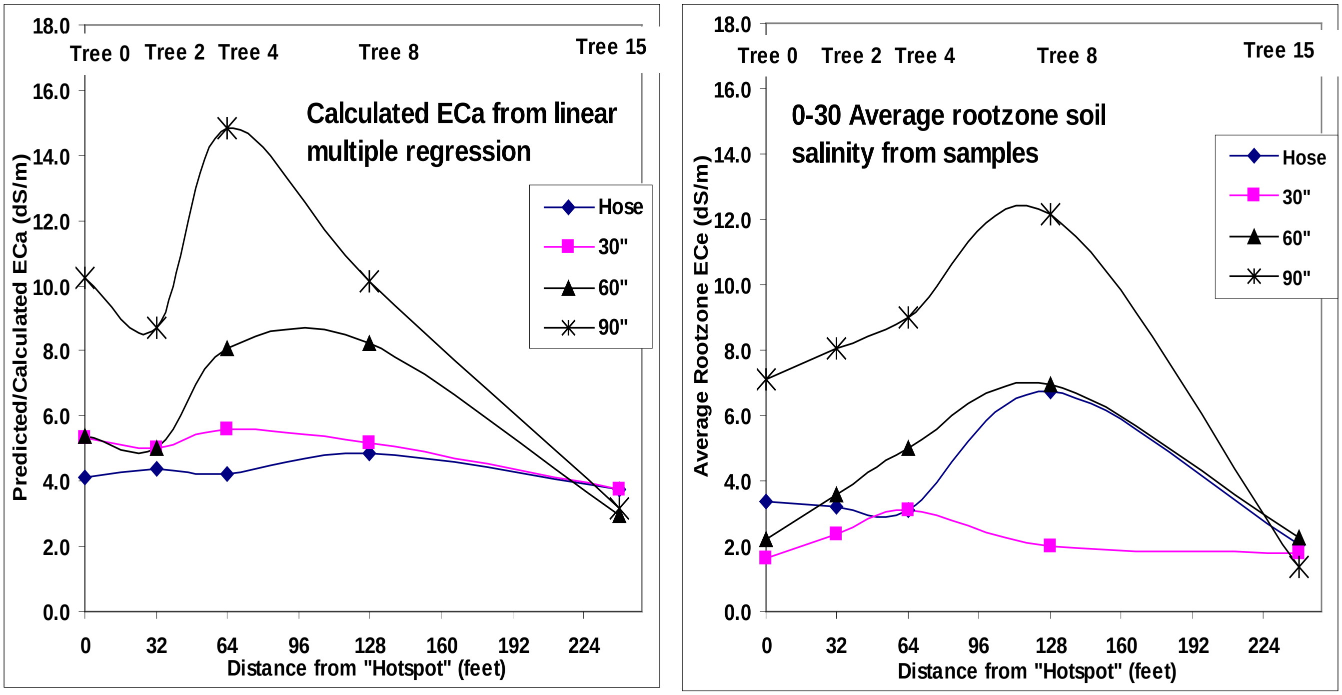


Fig.17. Calculated ECa from EM38 readings for Site 2 compared to laboratory measured ECe..

Site 2 was West of I-5 and about 12 miles NW of Site 1. Figure 17 shows the EM38 readings compared to saturation extract laboratory EC (analyzed at our Kern County Cooperative Extension shop lab for EC only). In this case the peak salinity appears between Trees 4 and 8 and does not correspond to the center of the "hotspot" marked by Tree 0. The reason for this is unclear as Tree 0 had been completely killed and replanted while Tree 4 and especially Tree 8 appeared in reasonable health. Still, the damaged area at the 60 and 90 inch distance from the hose was above an average rootzone threshold EC of 6 dS/m.

Of all sampling locations Site 3 (Figure 17, about 8 miles NE of Site 1) had one of the lowest salinities along the drip hose and at the 30 inch distance. This is not surprising as it is the oldest of all these plantings and the grower has done considerable winter leaching over the years with long sets on the drip hose. But unlike the other sites this location had no clear break into a "good" non-affected zone. There was an obvious area of greatest damage, but there was still a scattering of frost affected trees beyond this area. Thus, the results of Figure 18 are not too surprising in showing a sustained ECa of around 6 dS/m over the entire transect. This site also had more clay than the other sites – perhaps increasing problems with sufficient "dry down" of the trees in the Fall.

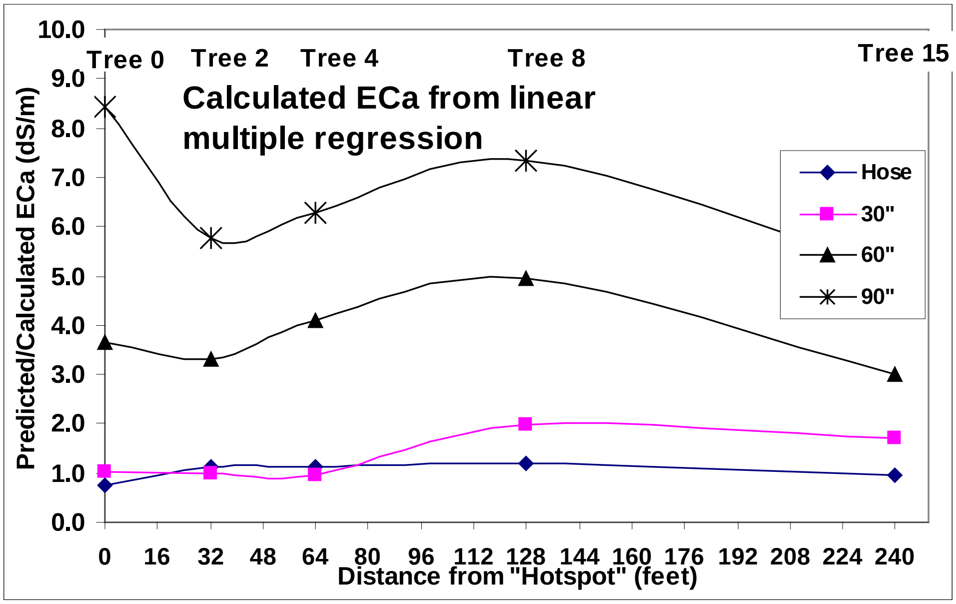


Fig.18. Calculated ECa from EM38 readings for Site 3.

Site 4 (20 miles N of Site 1) had a similar pattern of a more even salinity gradient along the transect as Site 3 (Figure 19), but staying under 5 dS/m even at 90" away from the hose. The soil at this site was the

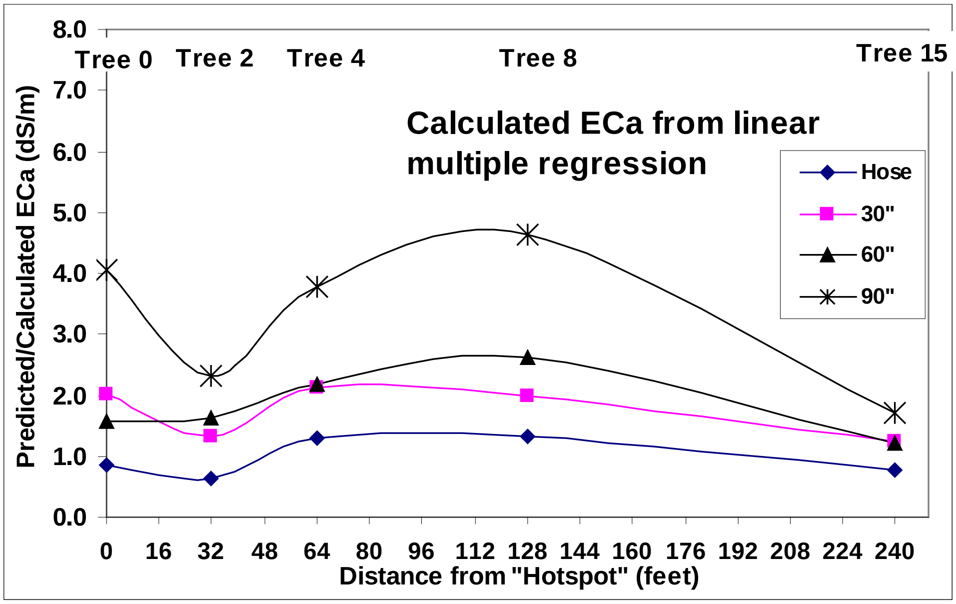


Fig.19. Calculated ECa from EM38 readings for Site 4.

sandiest of all locations but would still be considered a fine sandy clay loam. That said, this field definitely had the driest middles of any site and thus, the ECa estimate 60 and 90 inches distant from the hose may be artificially low compared to the other study sites. This field also had the fewest number of salt-frost affected trees.

Conclusions and Practical Application

We may have identified a threshold. It appears that average rootzone soil salinity greater than 6 dS/m, soluble Na greater than 40 meq/l (920 ppm) and Na/Ca ratios > 15 can increase young pistachio frost susceptibility. We will attempt to verify these thresholds with additional EM38 measurements and laboratory sampling during the 2012 season.

Acknowledgements

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