Pinyon Pine and Juniper Biochar Application to Four Eastern Nevada Soils

REPORT

BY

Jim Ippolito

USDA-ARS-Northwest Irrigation and Soils Research Laboratory

3793N 3600E

Kimberly, ID 83341

Jim.Ippolito@ars.usda.gov

(208)423-6524

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INTRODUCTION

Interest into the effects of biochar application on plant growth, soil properties and environmental contaminants has spurred a significant amount of research in recent years. As an example, a survey of recent published biochar manuscripts over the past ten years is highlighted in Figure 1, which illustrates the increased interest in biochar research.

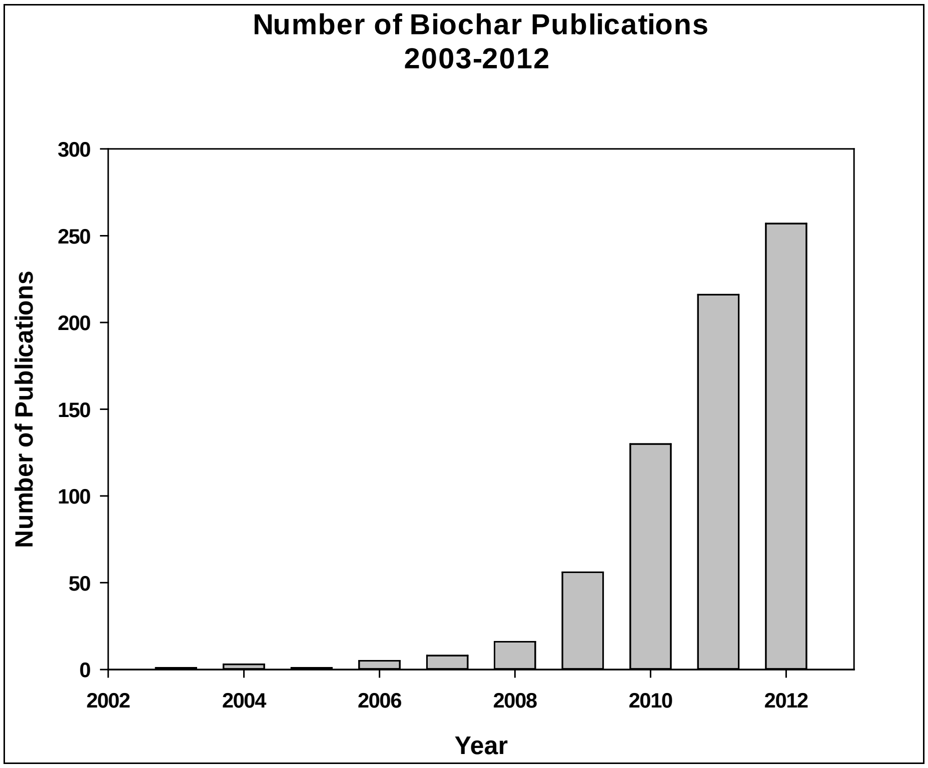


Figure 1. Number of biochar journal articles published over the past ten years.

The interest in biochar application to aridic soils is somewhat limited as compared to the bulk biochar research (from Amazonia, other tropical locations, and highly weathered soils). In short, research to understand whether biochar application to aridic soils will be beneficial is still in its infancy.

The use of local feedstocks for biochar creation/utilization makes sense from an economic standpoint. In Nevada, the encroachment of pinyon pine and juniper into ranch and farmland is an issue, with an estimated >90 million acres affected. Thus, marrying the creation of biochar from pinyon pine or juniper feedstock, and then utilizing these biochars for potential beneficial use in local soils, could create a win-win situation for Eastern Nevada and other similar locations. This current report highlights the significant differences and general trends for pinyon pine and juniper biochar application to several soils from Eastern Nevada.

MATERIALS AND METHODS

Soils were collected from four different locations within Eastern Nevada in the fall of 2011. Two soils were collected from a site associated with the Southern Nevada Water Authority (SNWA), approximately 30 miles southeast of Ely, Nevada (Figure 2). According to the NRCS, Soil SNWA #1 (approximately 38°58'10.40"N 114°25'36.30"W) is part of the Atlanta Kuntzler Association and is classified as a coarse-loamy, mixed, superactive, mesic Durinodic or Xeric Haplocalcid. This soil developed on fan aprons and skirts and is well drained. Within the top 1' of soil, organic matter content is ~1.5%, pH = 8.2, sodium adsorption ratio is ~8, calcium carbonate % is ~ 20%, and sand, silt, and clay percentages equal ~ 44-68%, 20-40%, and 12-16%, respectively.

Soil SNWA #2 (approximately 38°59'15.35"N 114°27'17.12"W; Figure 2) is part of the Huilepass Association and is classified as a loamy-skeletal, mixed, superactive, mesic Xeric Haplargid. This soil developed on barrier beaches and is well drained. Within the top 1' of soil, organic matter content is ~1.0%, pH is ~ 7.0, sodium adsorption ratio is ~3, calcium carbonate % is ~ 0.5%, and sand, silt, and clay percentages equal ~ 44%, 40%, and 16%, respectively.

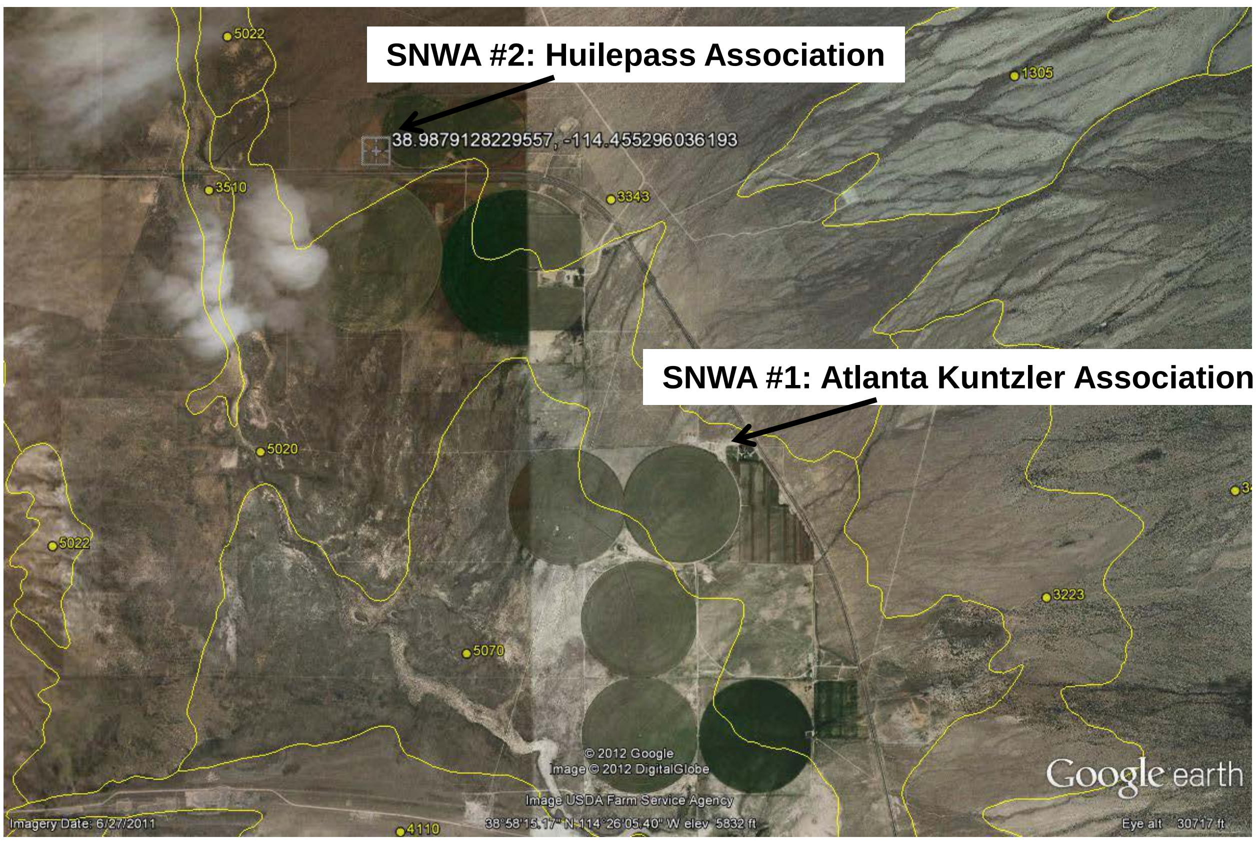


Figure 2. SNWA #1 and SNWA #2 soil locations.

The Diamond Valley (DV) soil (Figure 3), collected approximately 5.5 miles northeast of Eureka, NV (39^{o}34’27.53”N 116^{o}01’26.14”W) is part of the Shipley Complex and is classified as a Coarse-loamy over sandy or sandy-skeletal, mixed (calcareous), frigid Xeric Torriorthent. This soil formed in alluvial fans and is well drained. Within the top 1’ of soil, organic matter content is ~0.5%, pH = 8.8, sodium adsorption ratio is ~7, calcium carbonate % is ~ 4%, and sand, silt, and clay percentages equal ~ 30%, 60%, and 10%, respectively. The soil was collected in an area of the field where no vegetation was growing, although it was planted and the remainder of the field had a stand of Timothy. The land owner stated that this portion of the field needs to have the hay raked to get it to dry as moisture is captured under the windrow. Upon collection, evidence of salt and no soil structure was observed.

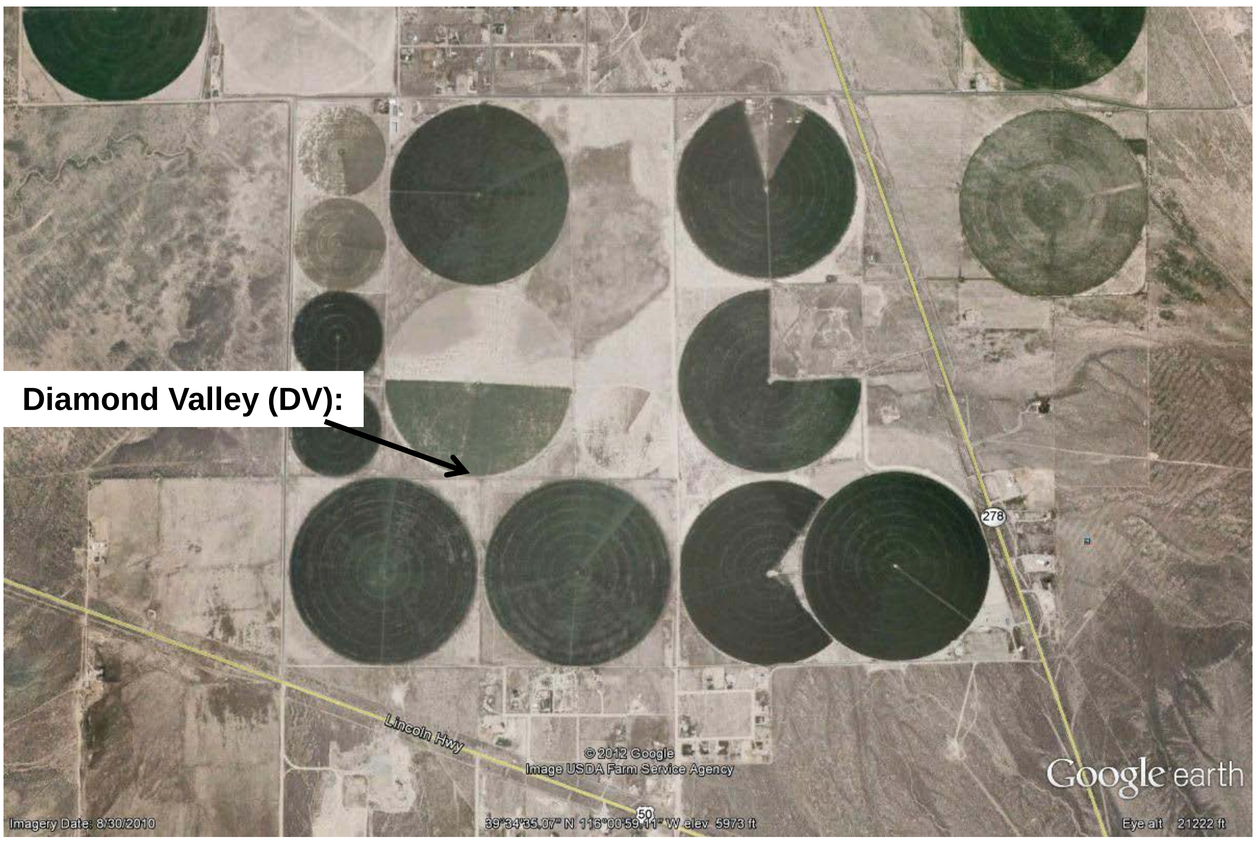


Figure 3. Diamond Valley (DV) soil location.

The Ruby Hill (RH) soil (Figure 4) was collected at the Ruby Hill Mine just West of Eureka, NV (39^{o}31’36.61”N 115^{o59}’48.00”W). The mine soils are a conglomerate of topsoil/subsoil from the mine site, thus providing an NRCS classification is obsolete. The top 30’ is relatively homogenous.

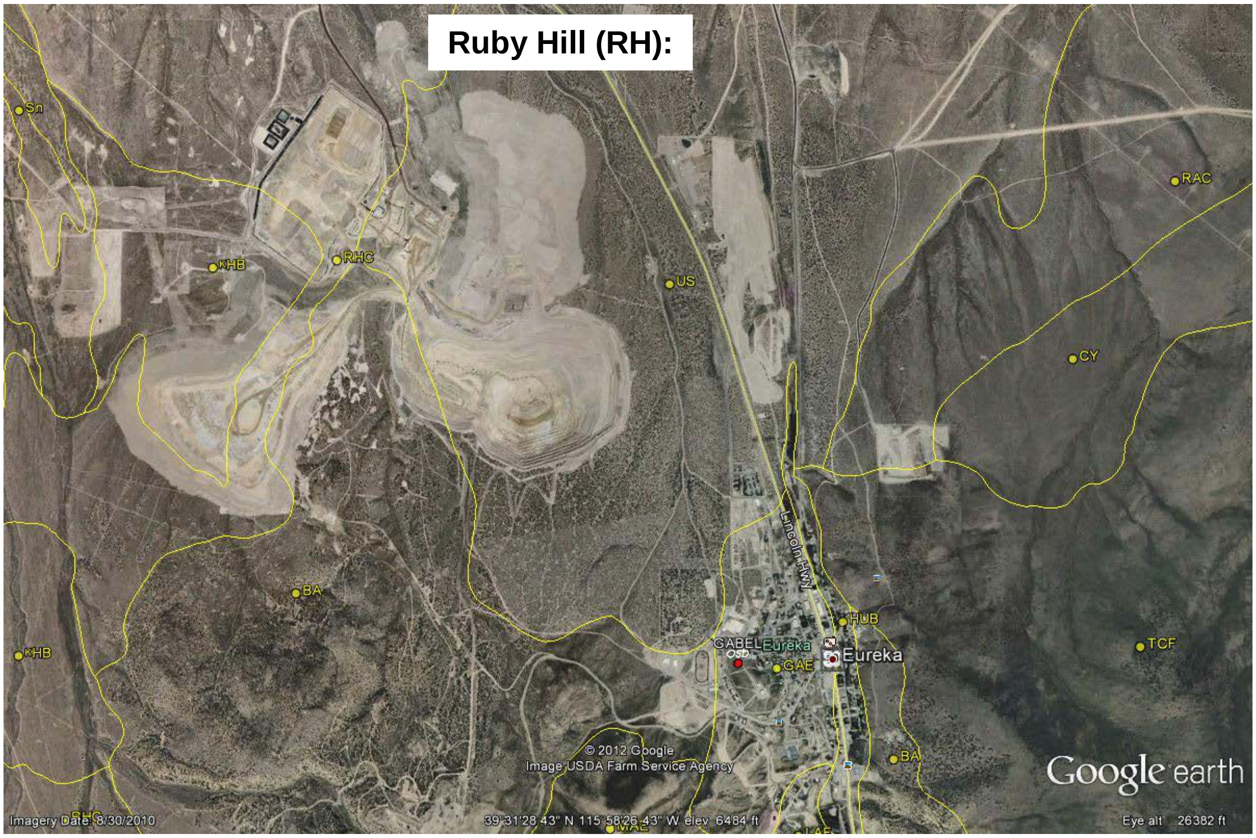


Figure 4. Ruby Hill (RH) soil location.

All soils were air-dried and then sieved to pass a ¼” mesh screen. Soils were then used for the experiment.

Pinyon pine and juniper chips were collected near Eureka, NV in early October 2011. They were delivered to the Northwest Irrigation and Soils Research Laboratory (Kimberly, ID), passed through a chipper/shredder to create finer-sized particles, and then shipped to Dr. Keri Cantrell with the USDA-ARS-Coastal Plains Soil, Water, and Plant Research Center (Florence, SC) for pyrolysis at 500 ^{o}C.

Biochar chemical characteristics are presented in Table 1. Biochar total elemental composition was determined using an $HClO_4$-HNO_3-HF-HCl digestion followed by elemental analysis using an inductively coupled plasma-atomic emission spectrometer. Total C and N were determined via dry combustion using a FlashEA1112 CN analyzer. Biochar NO3-N and NH4-N were determined using a 2M KCl extract, and pH and EC were determined using a saturated paste extract.

Table 1. Biochar chemical composition on a dry weight basis.

Property	Units	Pinyon Pine Biochar	Juniper Biochar
Ca	mg kg^{-1}	13700	31300
K	mg kg^{-1}	7400	5100
Mg	mg kg^{-1}	5240	3680
P	mg kg^{-1}	1500	1100
Fe	mg kg^{-1}	300	400
Na	mg kg^{-1}	138	198
Zn	mg kg^{-1}	60.4	21.6
Mn	mg kg^{-1}	35.7	34.1
B	mg kg^{-1}	30.5	28.2
Cu	mg kg^{-1}	8.8	8.7
Ni	mg kg^{-1}	0.72	0.40
Cd	mg kg^{-1}	0.50	0.12
Mo	mg kg^{-1}	<0.01	1.6
Pb	mg kg^{-1}	<0.005	<0.005
C	%	78.7	78.6
N	%	1.03	0.69
NO_3-N	mg kg^{-1}	1.9	1.6
NH_4-N	mg kg^{-1}	12.3	8.2
pH		8.6	8.7
EC	dS m^{-1}	0.5	0.6

The experimental setup utilized 300g of each soil plus either pinyon pine or juniper biochar applied at rates of 0, 1, 2, and 5% by weight; biochar rates were equivalent to 0, 10, 20, and 50 tons/acre. The soils and biochar were placed into plastic bags, hand mixed to uniformity, and then the bags + treatments were placed in 3” square by 3” tall pots (Figure 5). All treatments were replicated four times.

Figure 5. Biochar pots.

Pots were brought to 80% field capacity once per week with reverse osmosis water, and pot weights were recorded to determine soil moisture content prior to reverse osmosis water addition. Pots were destructively sampled at 1, 2, 3, and 4 month intervals and analyzed for soil pH and EC (using a 1:1 soil to water extract), NO_3-N (using a 2M KCl extract), Organic C (via difference between total C via dry combustion and inorganic C analysis by pressure calcimeter method), Olsen-extractable (i.e. available) P (using a $NaHCO_3$ extract), and DTPA-extractable (i.e. available) Fe, Zn, Mn, Cu, and Ni. The bags containing the soils were allowed to air dry, and then removed, crushed by hand and then with a rolling pin (soils were kept inside the bags during crushing), and the bags placed back into the pots. Ten alfalfa seeds were planted in each pot, the pots kept moist twice per day by misting with reverse osmosis water, and germination was monitored over 10 days.

Analysis of variance was performed to compare the effects of biochar type and rate on soil characteristics and alfalfa germination using Proc GLM in SAS version 9.2. Differences were examined at a significance level (α) of 0.05 with mean separation determined using Fisher's Protected LSD procedure.

RESULTS AND DISCUSSION

All results, on a month by month basis, are presented in the figures below. Soil moisture content is present as all months combined because the data was collected weekly, not monthly. Alfalfa germination is present both month by month and averaged over all months.

In all figures, differences between pinyon pine and juniper biochar are denoted in the upper figure portion. Within each individual biochar, if differences existed between application rates those differences were denoted using different lower case letters. In general, both biochars acted similarly within each soil. This would imply that making one biochar out of both materials would not impose a different soil response (with the constituents measured for this report) as compared to using both materials separately. Thus, this could be a critical time and money saving option when making biochar from these feedstocks.

Southern Nevada Water Authority Soil #1

Soil pH at months 1, 2, 3, and 4 is presented in Figure 6. The general trend was for soil pH to increase with increasing biochar application rate. However, significant differences were not always evident. In addition, the change in soil pH, if present, was only 0.1 to 0.2 standard units and thus likely not enough to warrant concern.

Soil electrical conductivity (EC) is presented in Figure 7. Overall, the general trend was for soil EC to decrease slightly with increasing biochar application rate. Biochar may have been acting a sink, sorbing excess salts from the soil solution.

Soil NO_3-N is presented in Figure 8. Biochar application effects on soil NO_3-N were less evident than for soil pH or EC. Data from months 1 through 3 showed little difference in soil NO_3-N concentrations, which was surprising given that past research of the investigator as well as others report that soil NO_3-N concentrations tend to decrease with increasing biochar application rate. A downward response in soil NO_3-N is typically due to the addition of a readily available energy (i.e. C) source for soil microorganisms, and a concomitant decrease in the soil N status as microorganisms immobilize N.

Soil organic C is presented in Figure 9. As expected, increasing biochar application rate increased soil organic C content. The organic C content appeared to remain constant over the 4 month study period.

Olsen-extractable soil P content is presented in Figure 10. No specific trends were evident. It does not appear that these particular biochars affect plant available soil P status to a great extent. Other researchers have shown that certain biochars can act as a sink for P, while other biochars act as a source.

DTPA extractable Fe, Zn, Mn, Cu, and Ni are presented in Figures 11 though 15. Increasing biochar application rate tended to increase soil available Mn, Cu, and Ni; no trends were evident for available Fe or Zn. Overall, elemental concentrations were not elevated enough to be a negative concern in terms of plant growth. In fact, this soil could be considered borderline Zn deficient for certain crop types (such as corn) where soil Zn is considered marginal when the soil DTPA test concentration is between 1.0 and 1.5 mg/kg.

Soil moisture, over all months combined, is presented in Figure 16. Biochar application rates of 1 and 2% by weight (equal to 10 and 20 tons/acre) increased soil moisture content as compared to the control or highest biochar application rate. In terms of soil moisture storage, this suggests that 10 tons per acre would be an appropriate application rate for significantly increasing soil moisture storage.

Alfalfa germination percentage for all four months, and averaged over all months, is presented in Figures 17 and 18. During month 1, increasing biochar application rate caused an increase in germination rate; results were not significant with months 2, 3, or 4. Germination success may be closely tied with biochar application timing. Averaged over all months, there was no significant difference in germination success with increasing biochar application rate.

In order to identify if soil moisture status affected germination percentage, we performed a correlation analysis between the overall averages of both datasets. No significant difference existed for the SNWA #1 soil.

<u>Southern Nevada Water Authority Soil #2</u>

Soil pH at months 1, 2, 3, and 4 is presented in Figure 19. As with soil SNWA #1, the general trend was for soil pH to increase with increasing biochar application rate. Changes in soil pH tended to be only 0.1 to 0.2 standard units and thus likely not enough to warrant concern. The increase in soil pH at Month 3 was most likely due to human error: not properly standardizing the pH meter.

Soil electrical conductivity (EC) is presented in Figure 20. Overall, the general trend was for soil EC to decrease slightly with increasing biochar application rate. As with the SNWA #1 soil, biochar may have been acting a sink and sorbing excess salts from the soil solution.

Soil NO_3-N is presented in Figure 21. Opposite of soil SNWA #1, soil NO_3-N concentrations did decrease with increasing biochar application rate. A downward response in soil NO_3-N is typically due to the addition of a readily available energy (i.e. C) source for soil microorganisms, and a concomitant decrease in the soil N status as microorganisms immobilize and utilize N for amino acid production and protein formation. The response shown in Figure 21 is a classic biochar rate response shown by past research.

Soil organic C is presented in Figure 22. As expected, increasing biochar application rate increased soil organic C content. The organic C content appeared to remain constant over the 4 month study period. A similar response was observed for the SNWA #1 soil.

Olsen-extractable soil P content is presented in Figure 23. No specific trends were evident. As with SNWA #1, it does not appear that these particular biochars affect plant available SNWA #2 soil P status to a great extent. Other researchers have shown that certain biochars can act as a sink for P, while other biochars act as a source.

DTPA extractable Fe, Zn, Mn, Cu, and Ni are presented in Figures 24 though 28. Increasing biochar application rate tended to increase soil available Fe, Mn, and Ni; increasing biochar rate appeared to cause a negative quadratic response in terms of available Zn and Cu. As with SNWA #1, elemental concentrations were not elevated enough to be a negative concern in terms of plant growth. In fact, this soil could be considered Zn deficient (and perhaps deficient for other micronutrients as well) for certain crop types (such as corn) where soil Zn is considered low when the soil DTPA test concentration is less than 1.0 mg/kg.

Soil moisture, over all months combined, is presented in Figure 29. Similar to soil SNWA #1, biochar application rates of 1 and 2% by weight (equal to 10 and 20 tons/acre) increased soil moisture content as compared to the control or highest biochar application rate. In terms of soil moisture storage, this suggests that 10 tons per acre would be an appropriate application rate for significantly increasing soil moisture storage.

Alfalfa germination percentage for all four months, and averaged over all months, is presented in Figures 30 and 31. During month 1, increasing pinyon biochar application did not have an effect on germination rate, although a decreasing trend appeared. A significant decrease in germination rate was observed with increasing juniper biochar rate during month 1. Months two and three showed no response in germination rates with biochar application. By month 4, increasing pinyon biochar rate up to 2% by weight increased germination rate over the control or 5% biochar rate, while no statistically significant differences were evident for the juniper biochar. Figure 31 shows germination rate averaged over all months. Although no significant differences existed, at least for the pinyon biochar it appears that greater application rates (such as 5% by weight or greater) could be detrimental to plant germination in this particular soil.

In order to identify if soil moisture status affected germination percentage, we performed a correlation analysis between the overall averages of both datasets. A significant difference (at an (α) of 0.05) existed for the SNWA #2 soil.

<u>Diamond Valley Soil (DV)</u>

Soil pH at months 1, 2, 3, and 4 is presented in Figure 32. As with the previous two soils, the general trend was for soil pH to increase with increasing biochar application rate. However, significant differences were not always evident. In addition, the change in soil pH, if present, was only 0.1 to 0.2 standard units and thus likely not enough to warrant concern. Month 3 soil pH values were elevated likely due to human error in not standardizing the pH meter properly.

Soil electrical conductivity (EC) is presented in Figure 33. Overall, the general trend was for soil EC to decrease slightly with increasing biochar application rate. Biochar may have been acting a sink, sorbing excess salts from the soil solution. Out of all four soils, the decrease in EC with the Diamond Valley soil initially (i.e. months 2 and 3) appeared most promising in terms of potentially remediating this soil's salt issue. However, the salt issue returned during month 4. It is important to note that the control soil salt concentrations also decreased during months 2 and 3. Salts were not lost due to leaching from the pots because all pots were lined with plastic bags. It was possible that the soils were not thoroughly mixed prior to sampling at months 2 and 3 (even though all bags were removed and hand crushed prior to sampling at every time step). None the less, greater biochar application rates do appear to cause a decrease in soil EC values (as with the previous two soils).

Soil NO_3-N is presented in Figure 34. Biochar application effects on soil NO_3-N were less evident, and the typical downward soil NO_3-N concentration with increasing biochar rate did not occur. This could have been due to the soil containing excessive NO_3-N to begin with (notice difference on the y-axis here as compared to the other three soils).

Soil organic C is presented in Figure 35. As expected and similar to soil SNWA #1 and #2, increasing biochar application rate increased soil organic C content. The organic C content appeared to remain constant over the 4 month study period.

Olsen-extractable soil P content is presented in Figure 36. There were no specific trends during months 1 and 2, but during months 3 and 4 it appeared that increasing biochar rate caused a slight increase in available P. These P concentrations would likely be considered moderate for crop growth regardless of biochar application rate.

DTPA extractable Fe, Zn, Mn, Cu, and Ni are presented in Figures 37 though 41. Increasing biochar application rate tended to increase all soil available micronutrients. As with the other two soils, elemental concentrations were not elevated enough to be a negative concern in terms of plant growth.

Soil moisture, over all months combined, is presented in Figure 42. As with the SNWA #1 and #2, it appears that the 10 tons per acre would be an appropriate application rate for significantly increasing soil moisture storage without having to apply greater biochar rates.

Alfalfa germination percentage for all four months, and averaged over all months, is presented in Figures 43 and 44. Unfortunately, we could not germinate any alfalfa seeds in this soil. This was most likely due to excessive salts present. Because of the observed change in soil EC values (at months 2 and 3), perhaps the focus of a companion study could be a column leaching study with biochar application rates no greater than 1% by weight.

Ruby Hill Soil (RH)

Soil pH at months 1, 2, 3, and 4 is presented in Figure 45. The general trend was for soil pH to increase with increasing biochar application rate up to 1 to 2% by weight, and then decrease with the 5% biochar application rate.. However, significant differences were not always evident, and the changes that were present were no greater than 0.2 standard units in either direction.

Soil electrical conductivity (EC) is presented in Figure 46. If differences were present, the change in soil EC wasn't great enough to be of concern; salt concentrations were extremely low.

Soil NO_3-N is presented in Figure 47. Although the trend was downward with increasing biochar application rates, the soil NO_3-N concentrations in the Ruby Hill soil were low enough that this soil would likely warrant a fertilizer application prior to planting.

Soil organic C is presented in Figure 48. Identical to the other three soils, soil organic C content increased with increasing biochar application rate. Furthermore, the organic C content remained constant over the 4 month study period.

Olsen-extractable soil P content is presented in Figure 49. Unlike the previous three soils, available P content increased with increasing biochar application rate. Differences in the other three soils were relatively unnoticeable likely due to greater initial P concentrations in each soil as compared to the RH soil. Regardless, in RH the soil P concentrations would be considered low for most crop species and thus a P fertilizer would be recommended before planting.

DTPA extractable Fe, Zn, Mn, Cu, and Ni are presented in Figures 50 though 54. Increasing biochar application rate tended to increase soil available Fe, Zn, and Mn; no trends were evident for available Cu and no available Ni was present in the soil at any time. Overall, elemental concentrations were not elevated enough to be a negative concern in terms of plant growth. In fact, this soil would likely be considered deficient in several micronutrients.

Soil moisture, over all months combined, is presented in Figure 55. All biochar application rates increased soil moisture content as compared to the control. In terms of soil moisture storage, as with the previous three soils, the findings suggest that a 10 ton per acre application rate would be the least amount of biochar necessary to provide a significant increase in soil moisture storage.

Alfalfa germination percentage for all four months, and averaged over all months, is presented in Figures 56 and 57. Germination tended to increase with increasing biochar application rate. In this particular soil, germination success may be closely tied with biochar application timing. During month 1 for example, the 5% pinyon biochar application had a 68% germination success rate over 10 days as compared to only a 32% success rate with the control. Such large germination differences were less evident over time. Averaged over all months, there was no significant difference in germination success with increasing biochar application rate. However, the trend was for increased germination with increasing biochar application rate.

In order to identify if soil moisture status affected germination percentage, we performed a correlation analysis between the overall averages of both datasets. A significant difference (at an (α) of 0.05) existed for the RH soil.

Overall Findings:

Both pinyon pine and juniper biochar acted similarly in the four soils studied over the four-month study period. If changes in soil pH were evident, pH was altered by no more than 0.2 units. Soil EC tended to decrease with increasing biochar application. This could have been due to biochar acting as a sink and sorbing excess salts from the soil solution. More work is needed before biochar can be utilized in the Diamond Valley soil as the EC values are still in excess. Soil NO_3-N changes were mixed, with some soils responding with the classic reduction in NO_3-N due to microbial immobilization; two soils didn't respond at all in terms of soil NO_3-N changes and increasing biochar application rates. Soil organic C increased with increasing biochar application rate in all four soils. This response was expected because we added an organic C source, namely biochar. Plant-available P concentrations were generally not affected by increasing biochar application rate. The initial available-P concentrations in three of the four soils were likely too great and masked subtle additions of P from biochar; this however was not the case with the Ruby Hill soil, which is in general lacking many nutrients necessary for plant growth. Increasing biochar application rates in all soils caused some micronutrients to increase. However, micronutrient increases were not great enough to offset potential crop growth issues with low soil micronutrient availability (i.e. not enough biochar was added, even at 5% by weight – 50 tons/acre – to increase certain micronutrients in certain soils). Soil moisture content tended to be at its greatest with the 1% biochar application rate. A correlation analysis was also performed between average alfalfa germination means for the entire study period versus average soil moisture content for the entire study period, utilizing data from the SNWA #1, SNWA #2, and RH soil. A significant relationship (α of 0.05) was found, suggesting that increases in soil moisture due to increasing biochar application may be tied directly to increases in alfalfa germination success. This may be one of the most significant findings of this study, as future work could either utilize this knowledge of biochar application rates to bracket increases in soil water status and plant growth under drought conditions.

FIGURES

SNWA #1 Soil

Figure 6. Soil pH

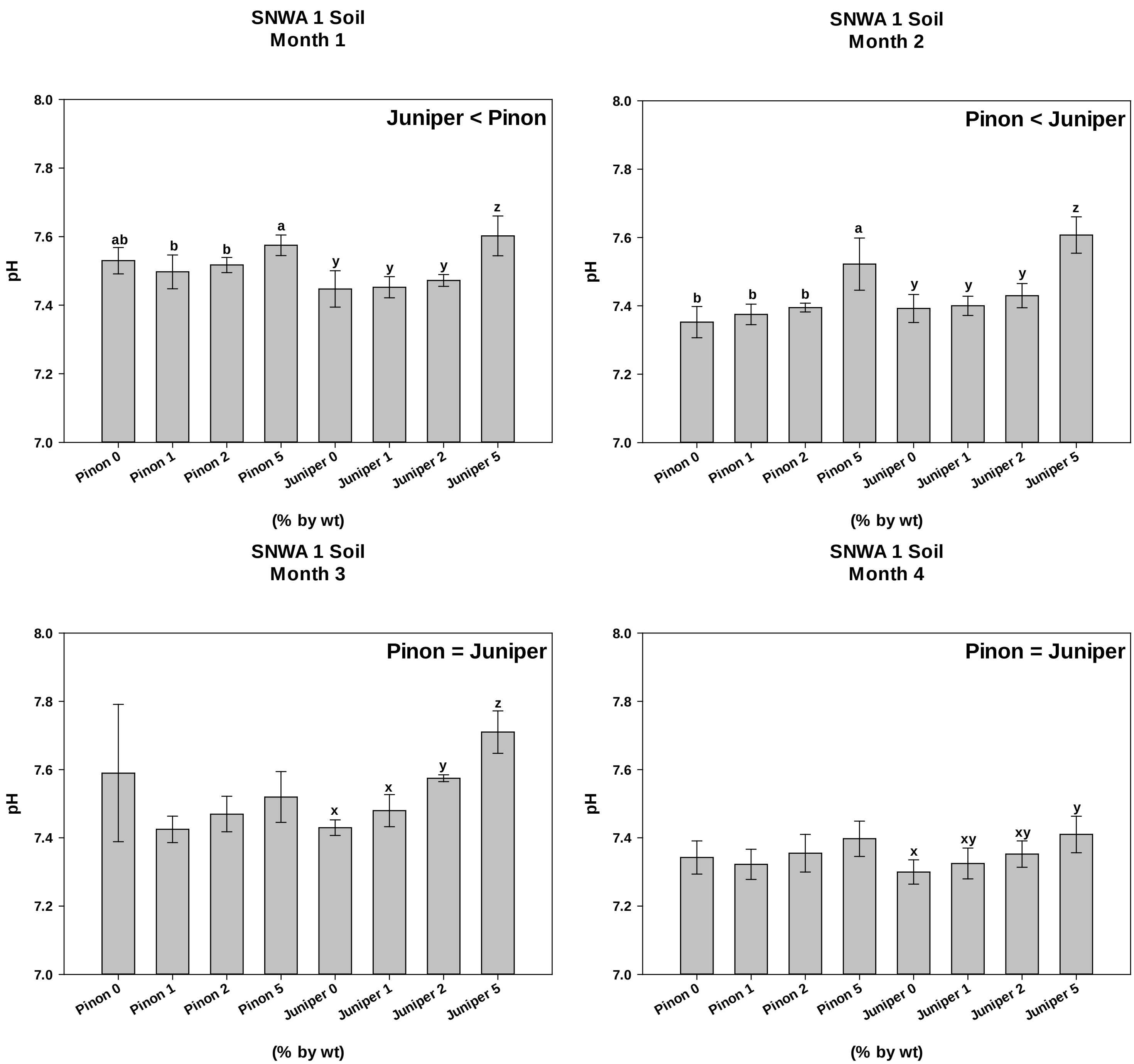


Figure 7. Soil Electrical Conductivity (EC)

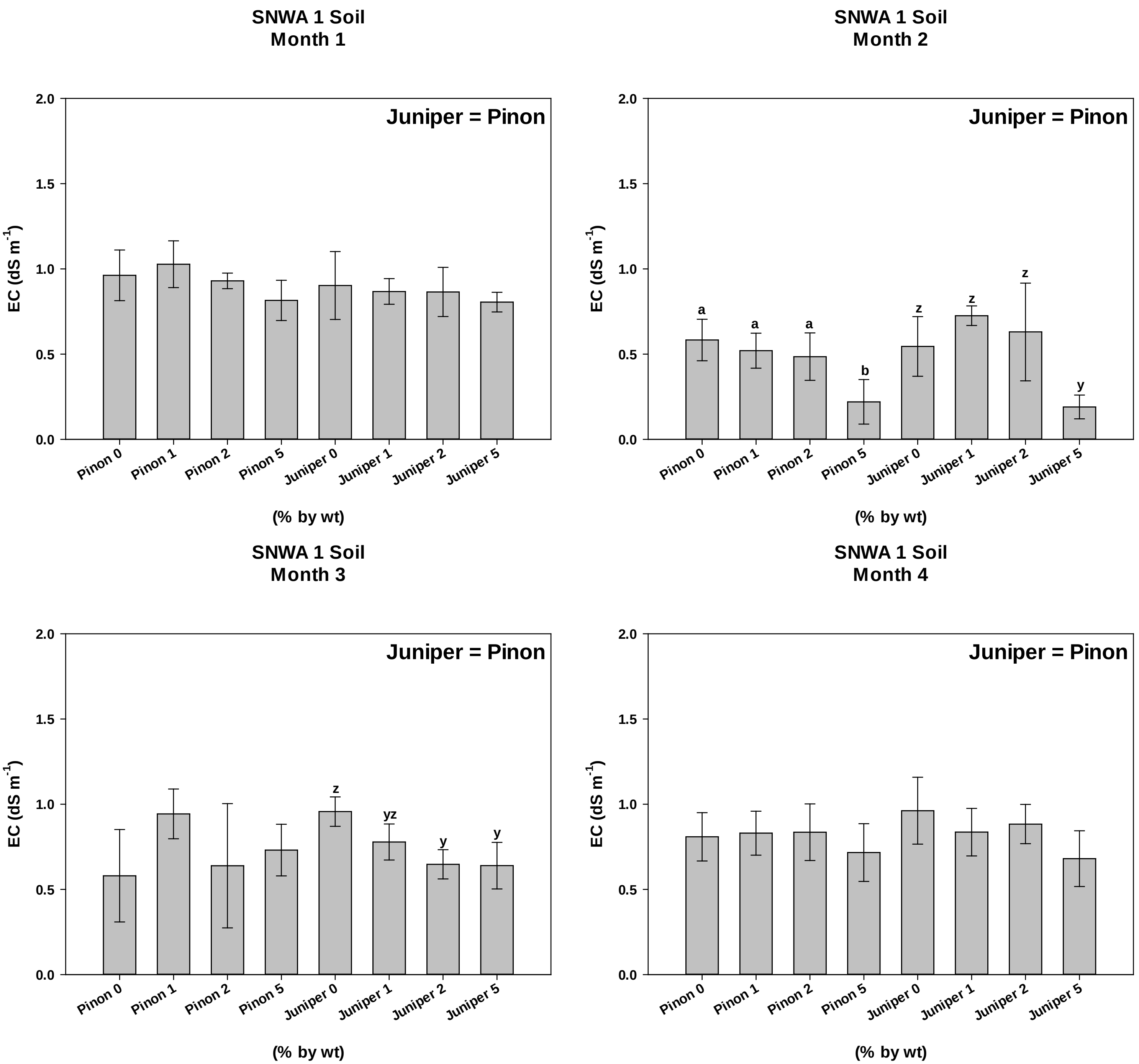


Figure 8. Soil Nitrate-Nitrogen (NO_3-N)

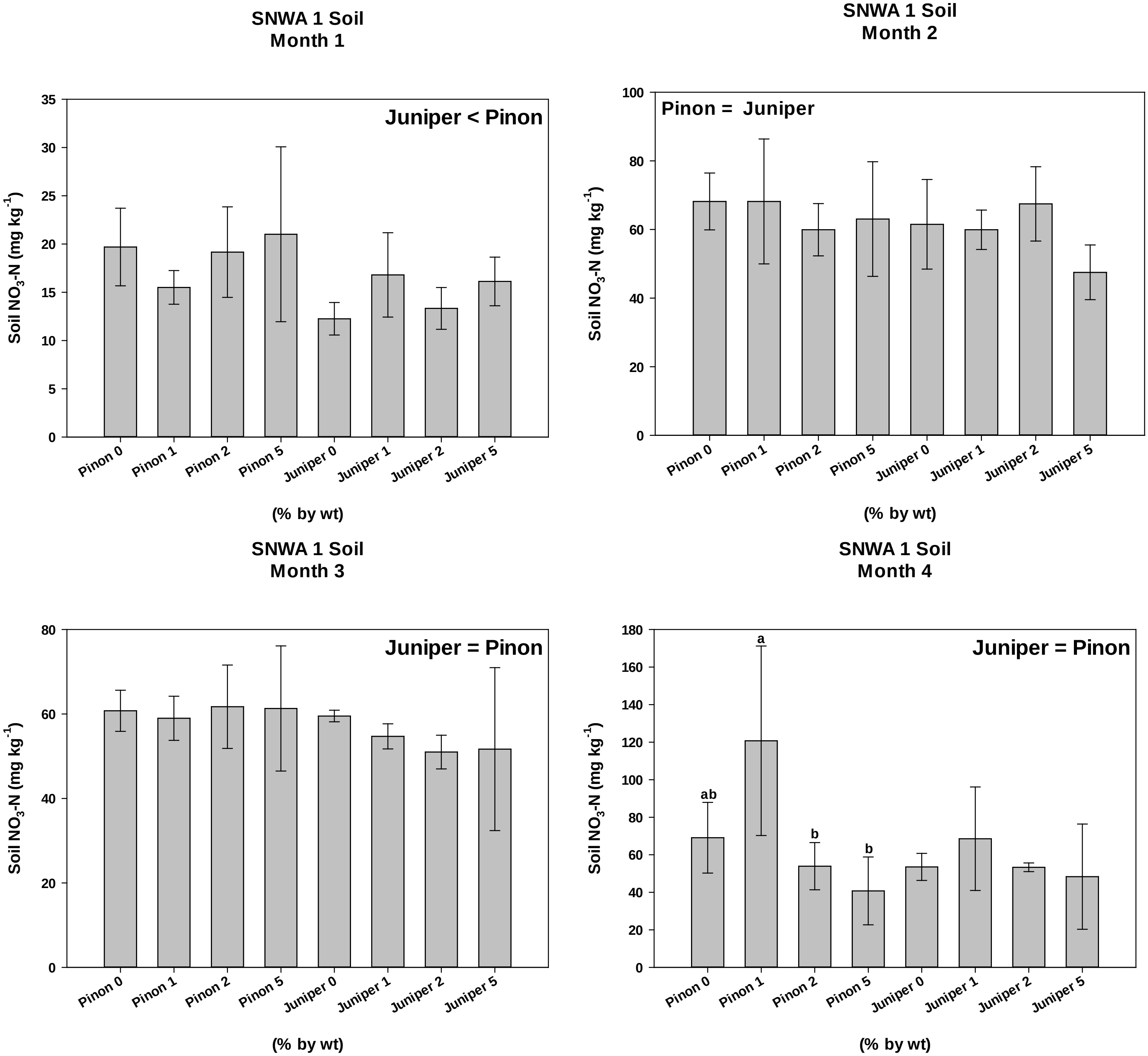


Figure 9. Soil Organic Carbon (C)

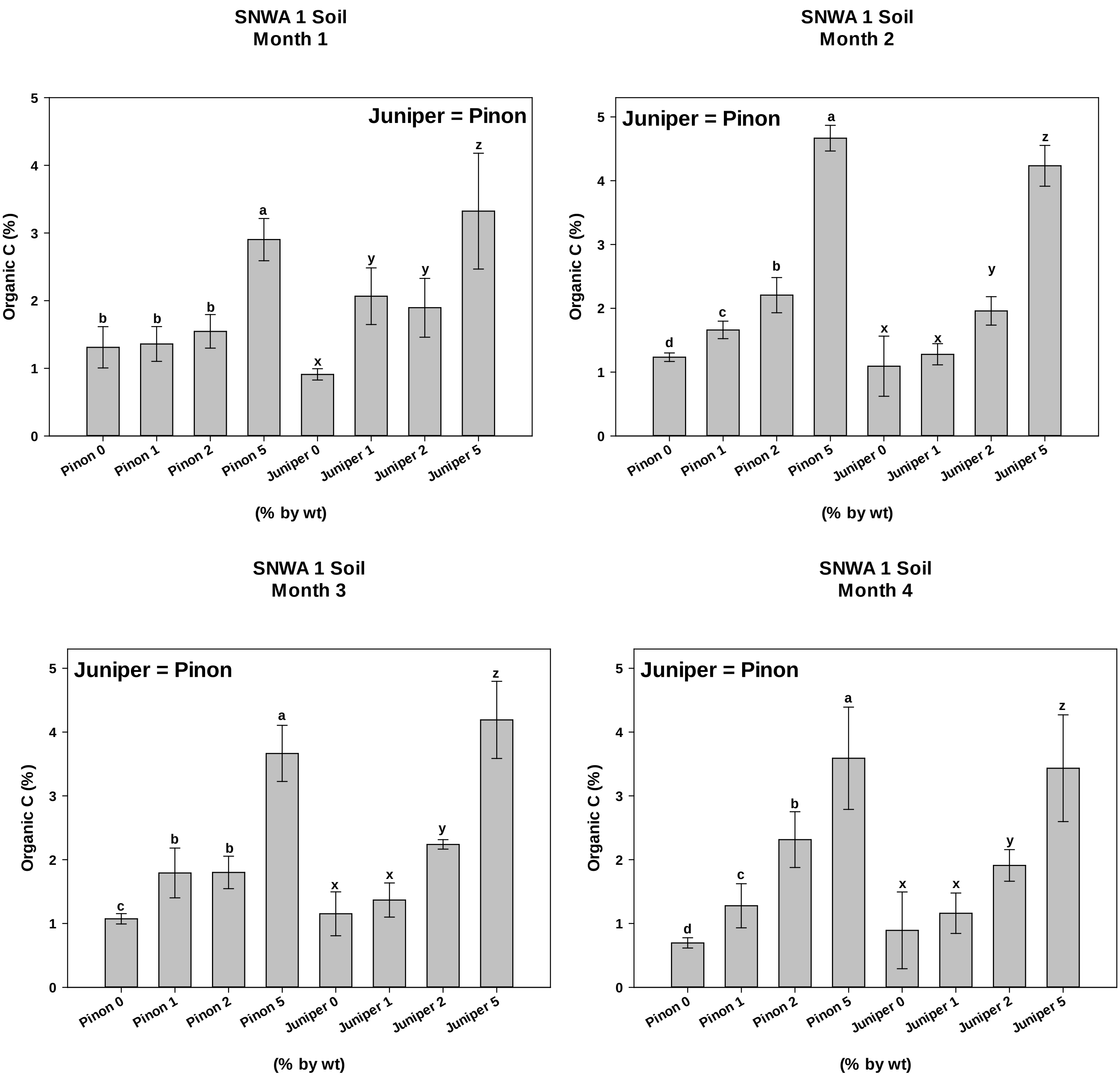


Figure 10. Olsen-Extractable (i.e. Plant-Available) Phosphorus (P)

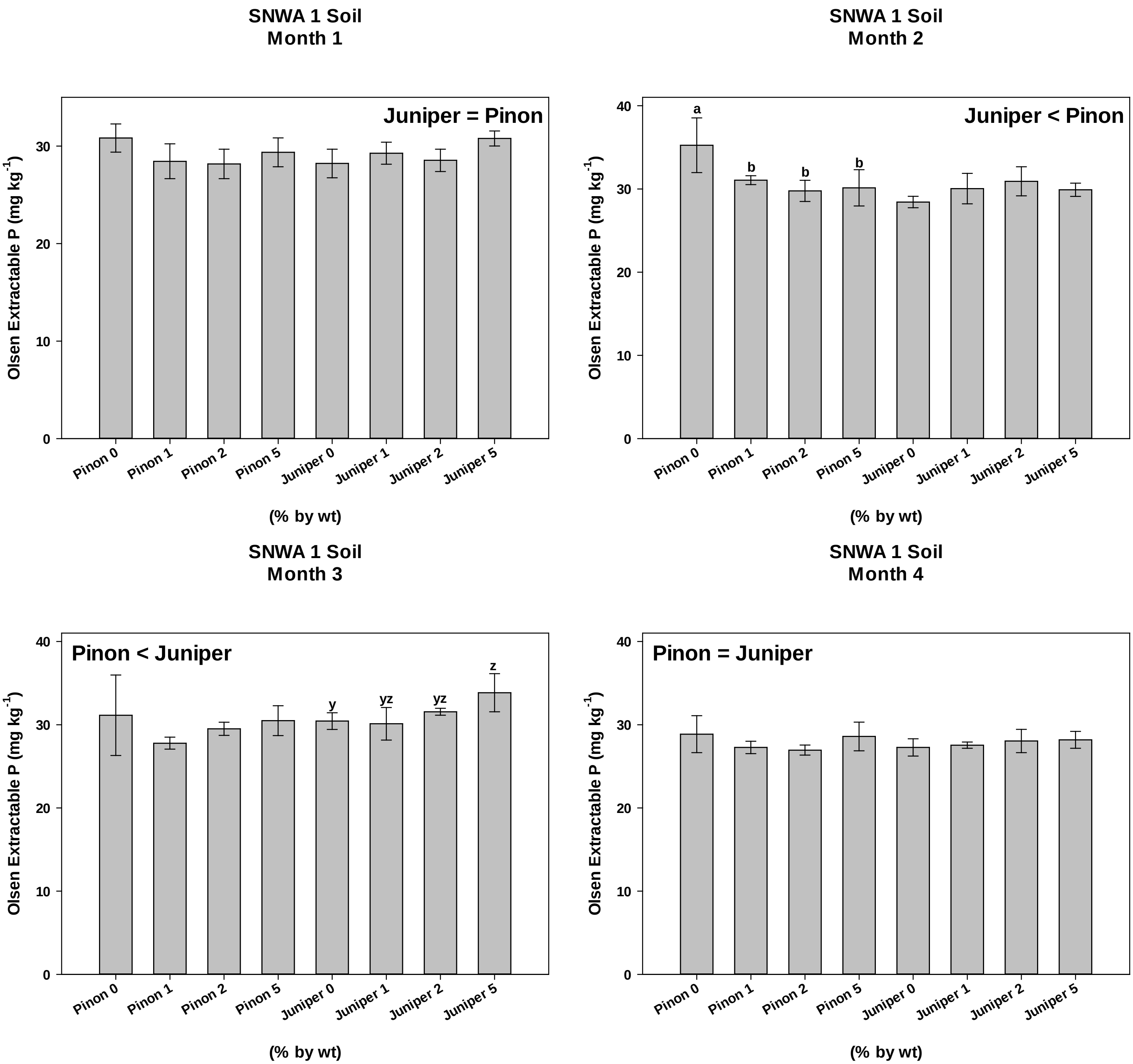


Figure 11. DTPA-Extractable (i.e. Plant-Available) Iron (Fe)

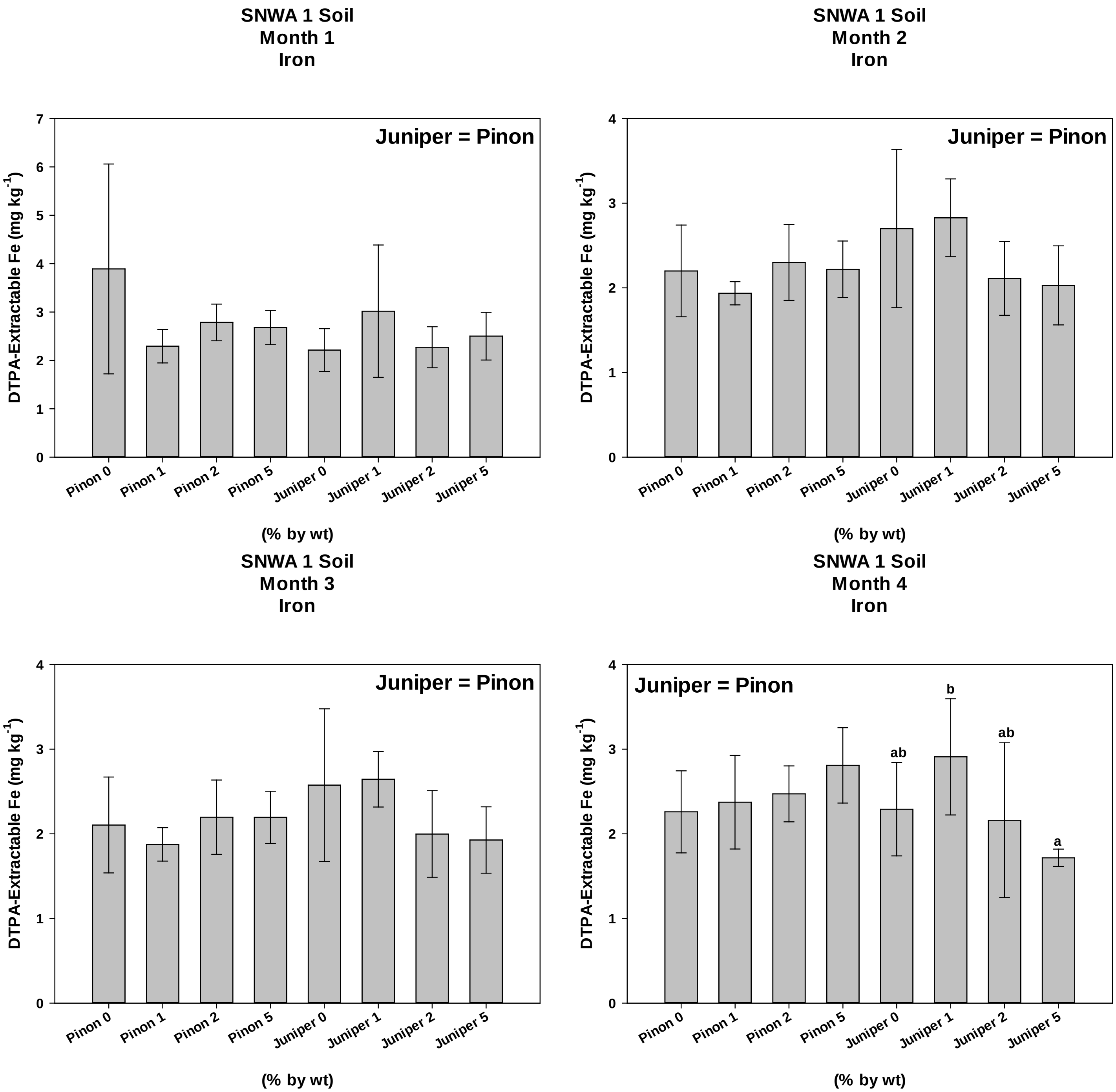


Figure 12. DTPA-Extractable (i.e. Plant-Available) Zinc (Zn)

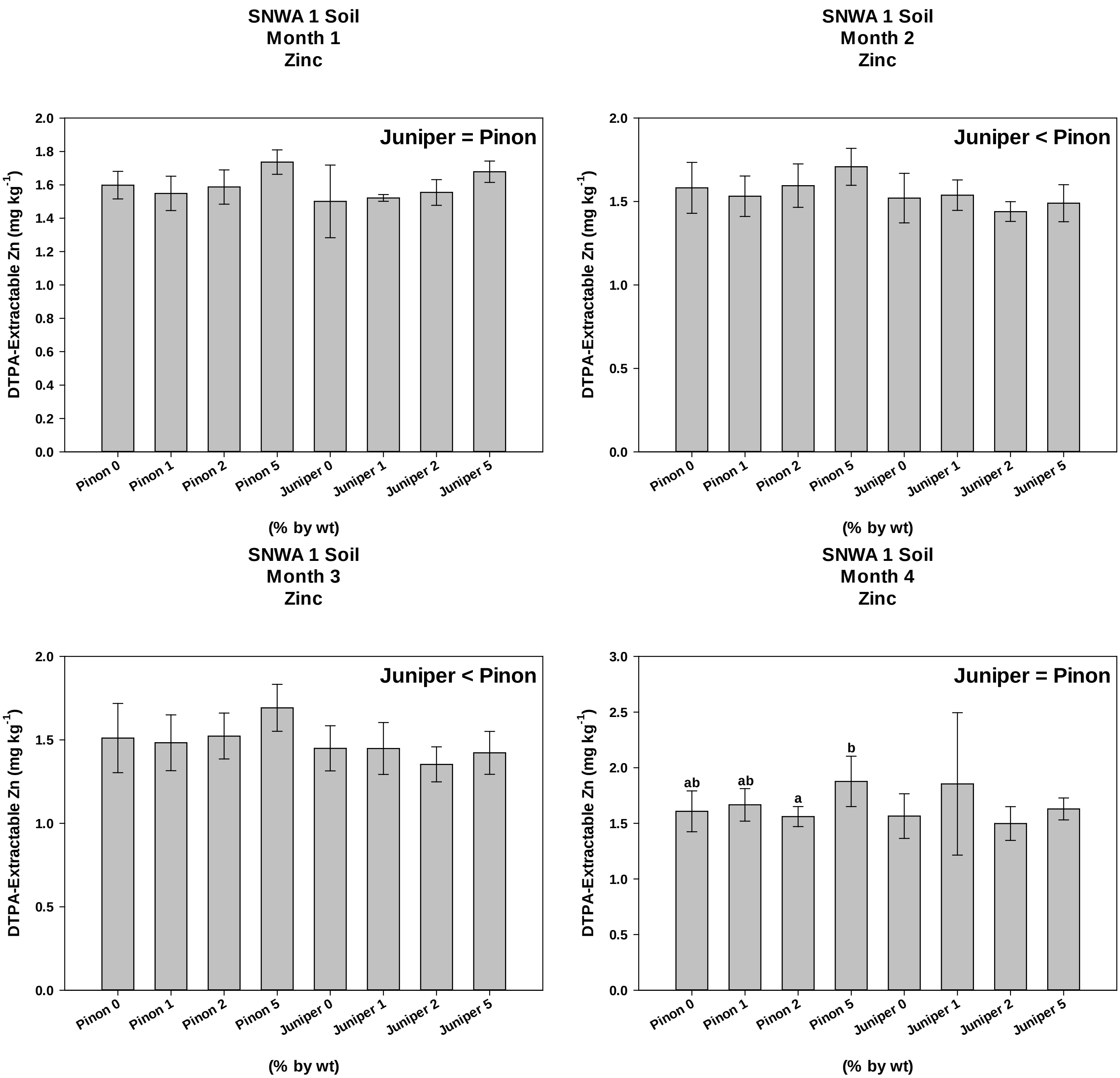


Figure 13. DTPA-Extractable (i.e. Plant-Available) Manganese (Mn)

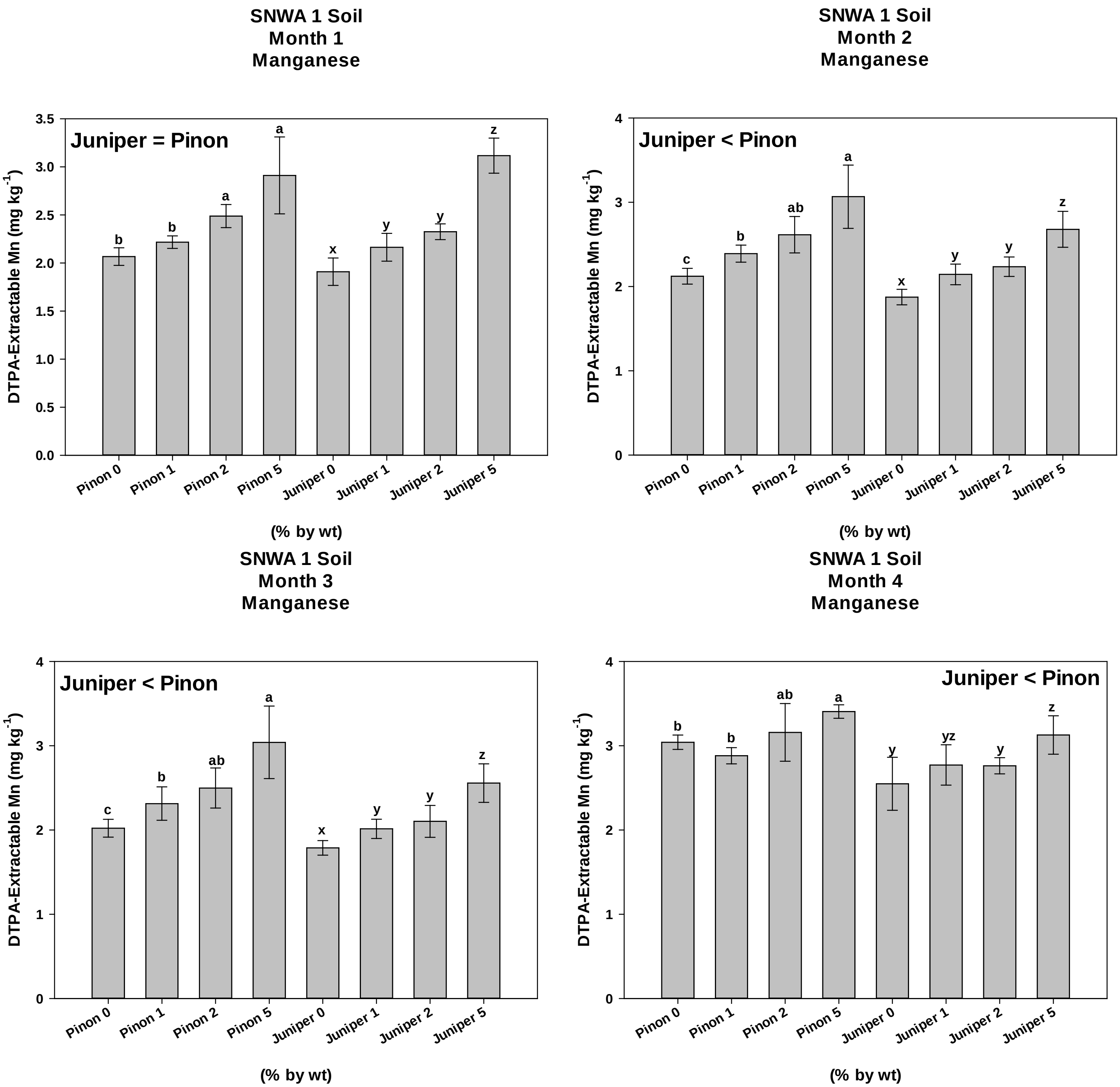


Figure 14. DTPA-Extractable (i.e. Plant-Available) Copper (Cu)

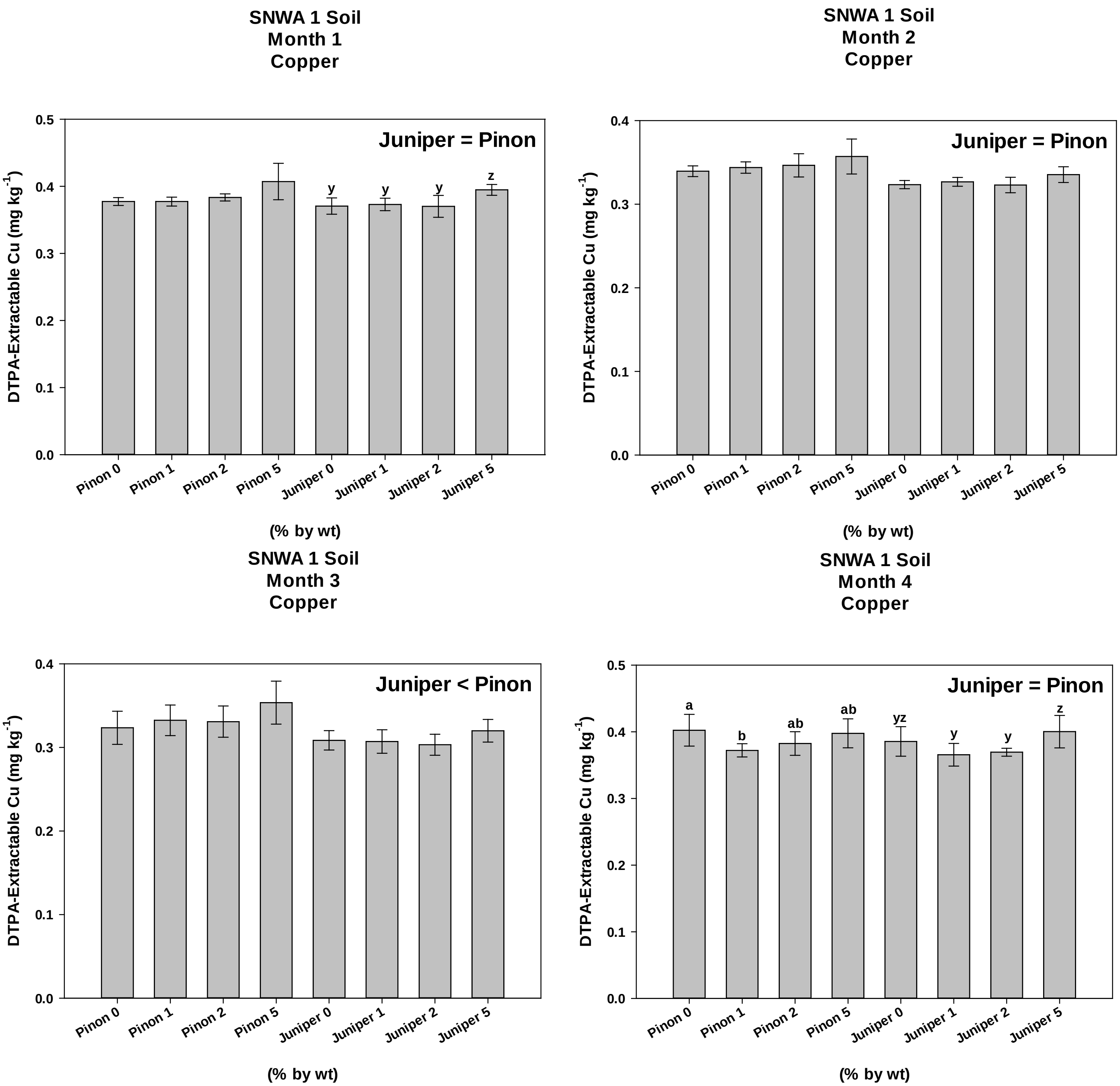


Figure 15. DTPA-Extractable (i.e. Plant-Available) Nickel (Ni)

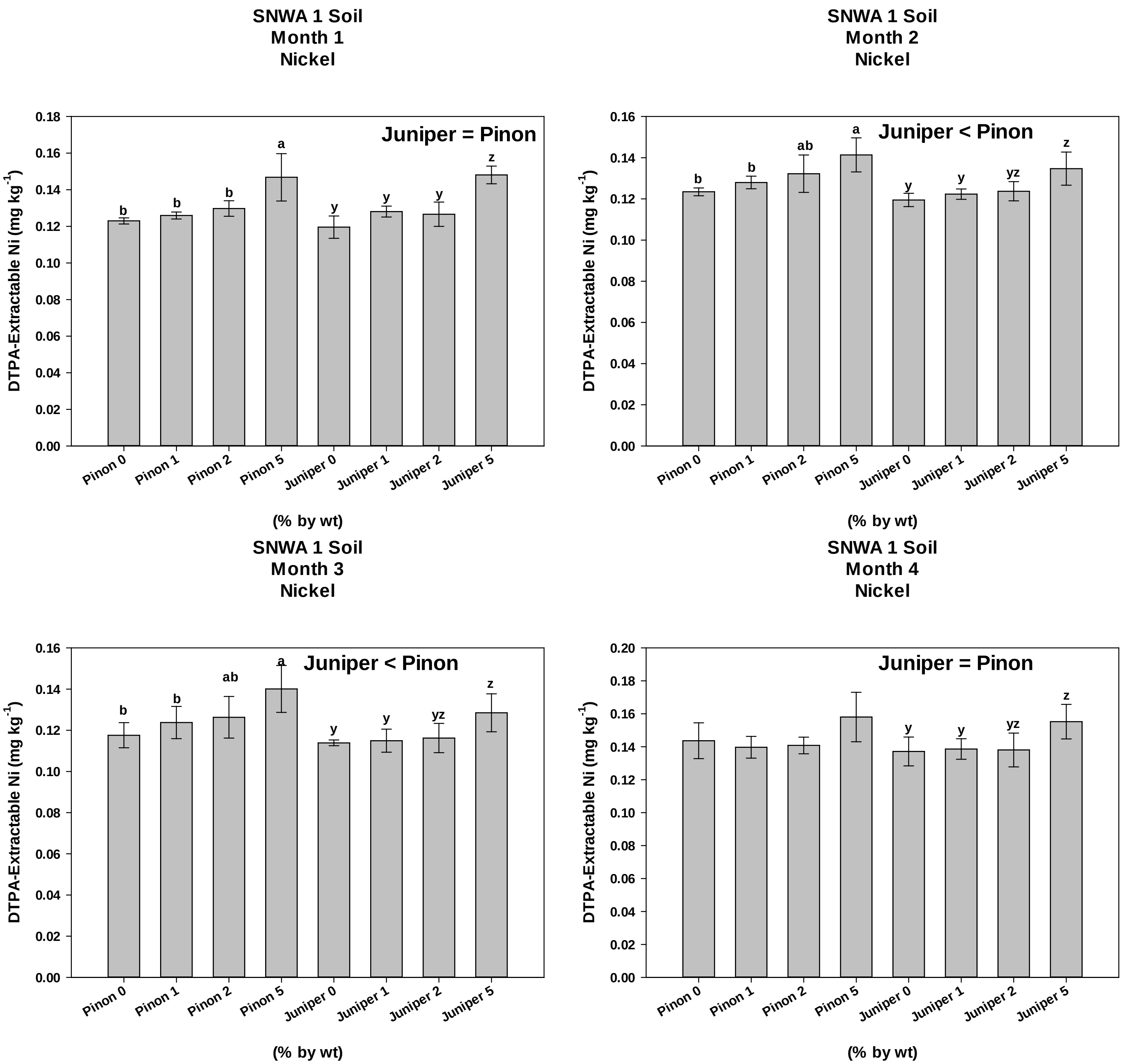


Figure 16. Soil Moisture

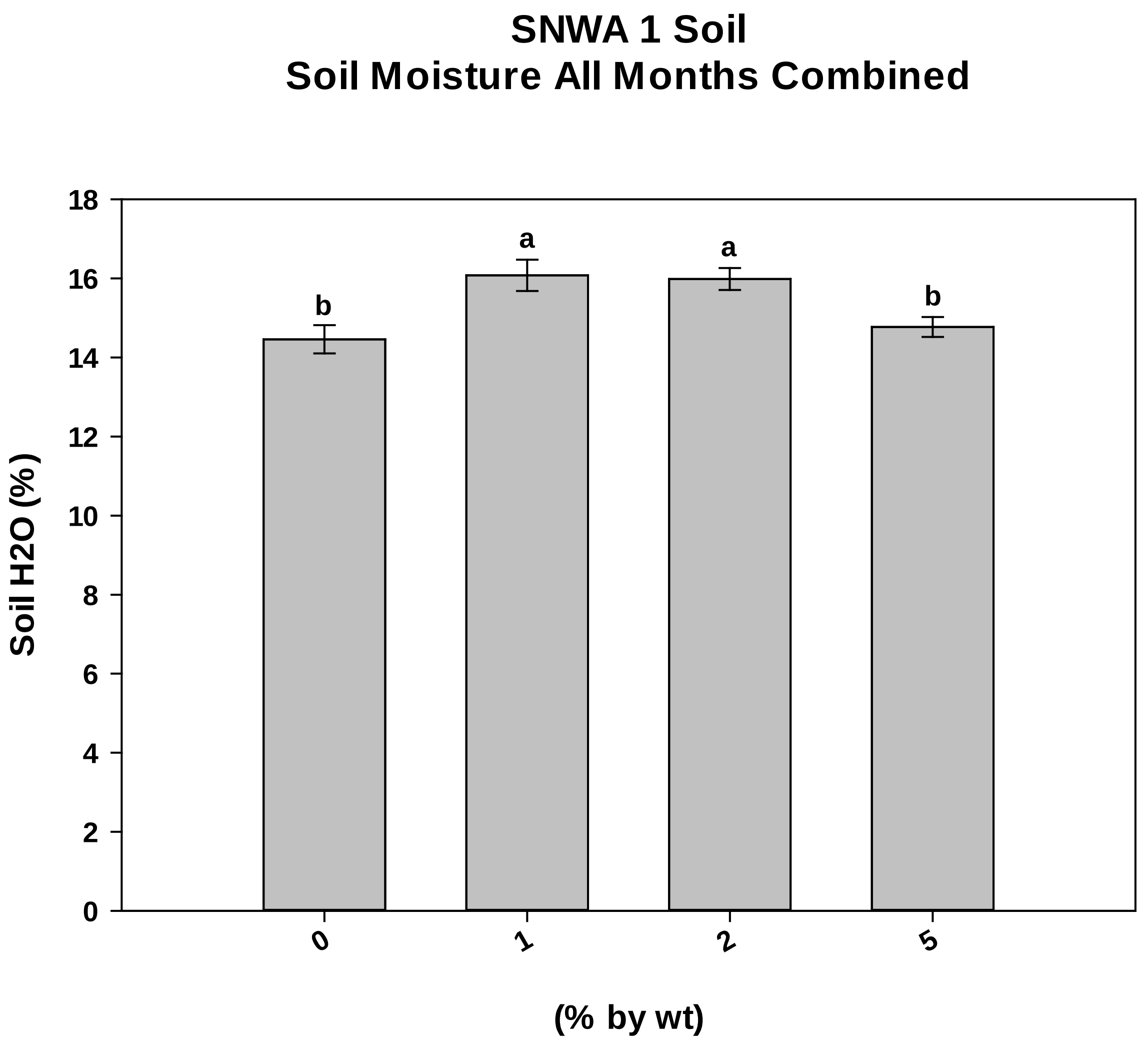


Figure 17. Alfalfa Germination

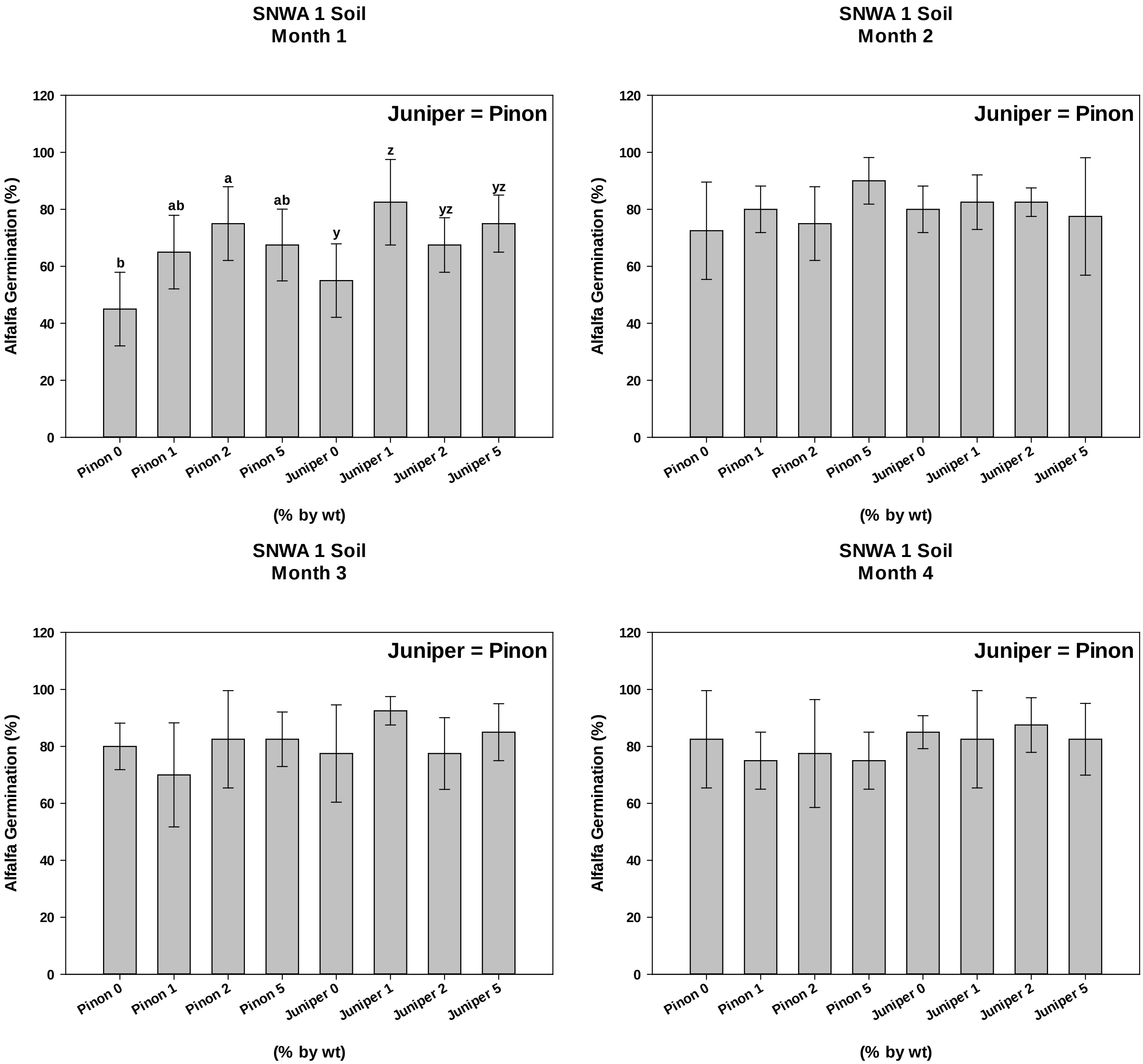
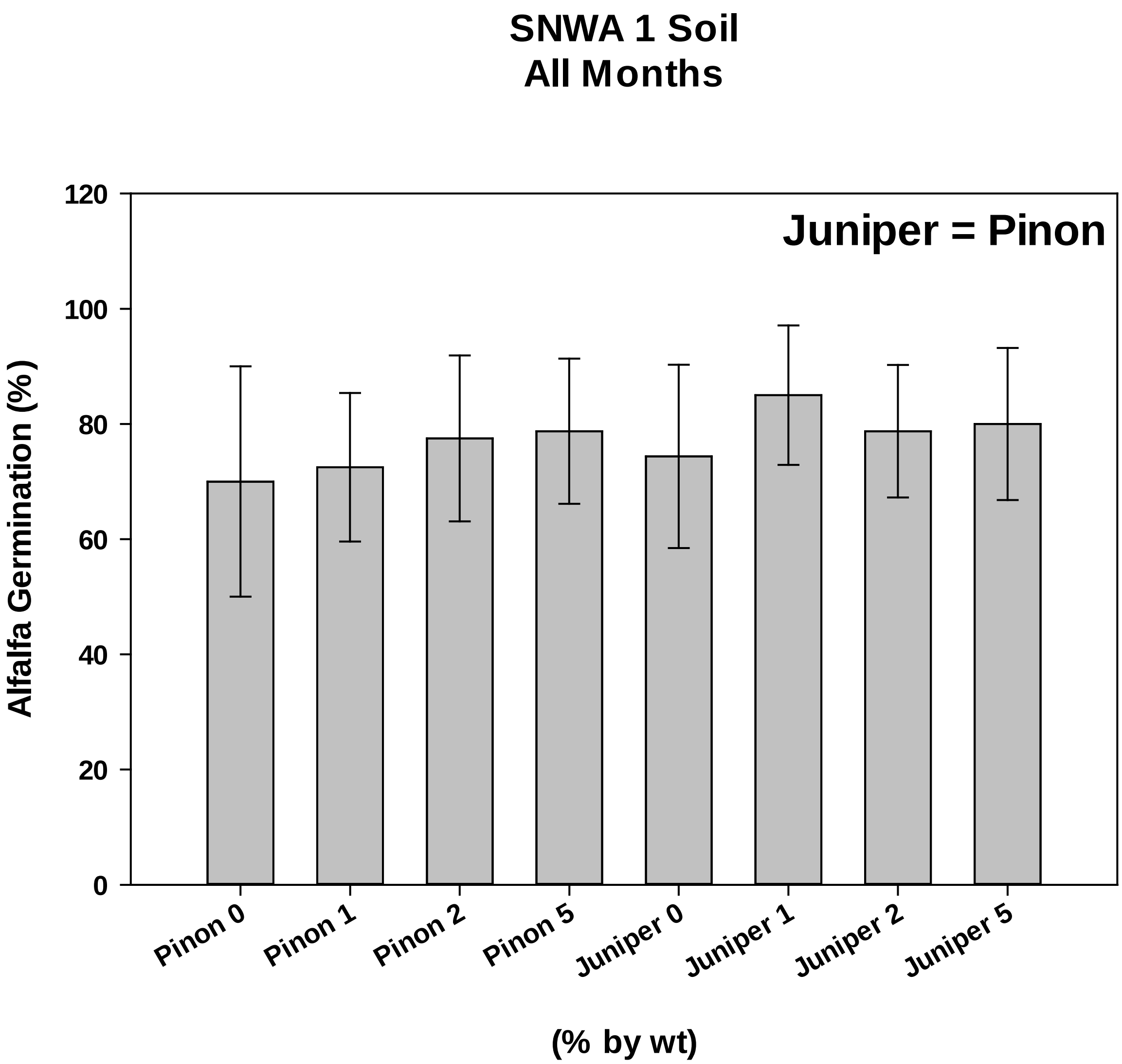


Figure 18. Alfalfa Germination All Months



SNWA #2 Soil

Figure 19. Soil pH

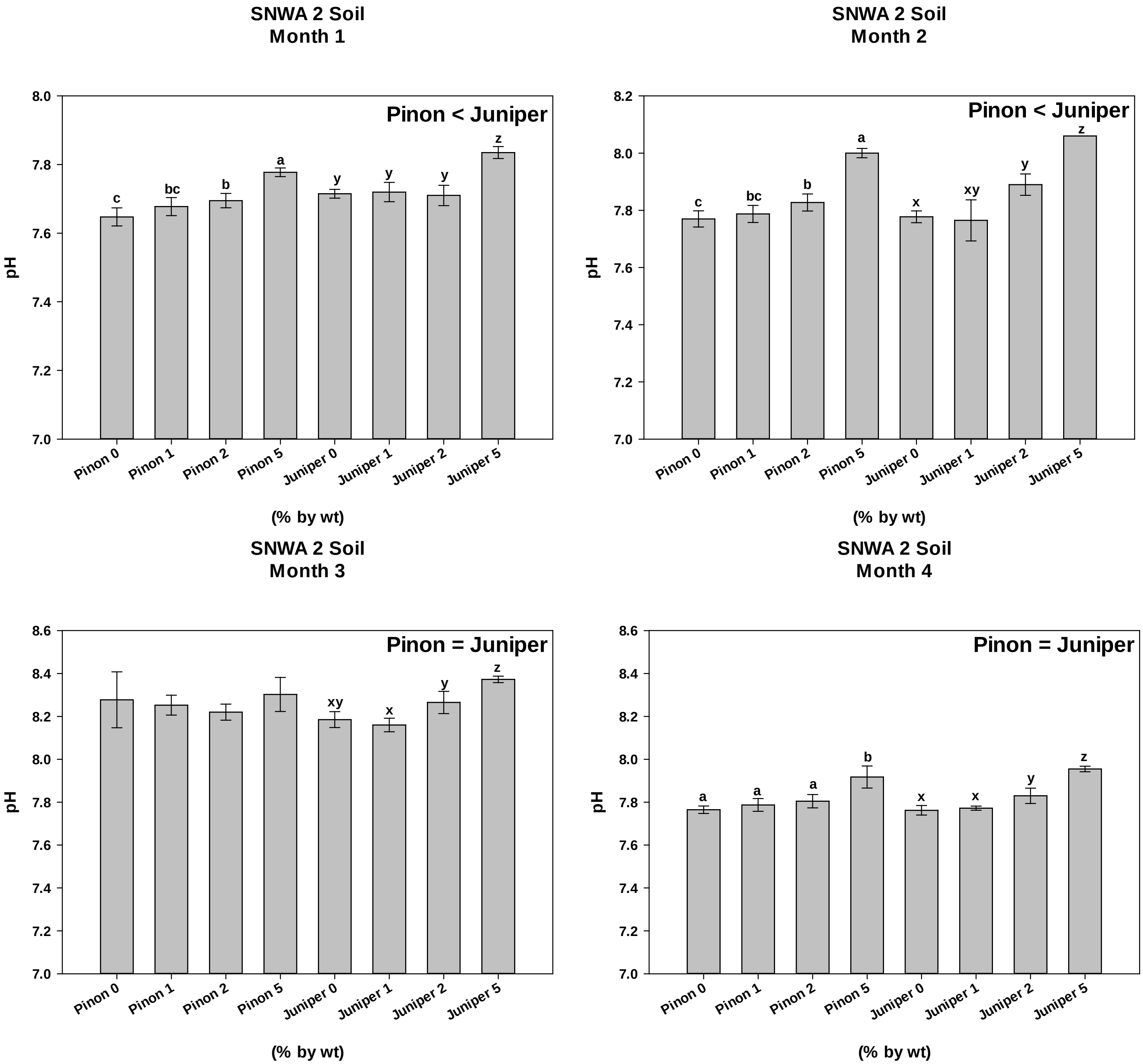


Figure 20. Soil EC

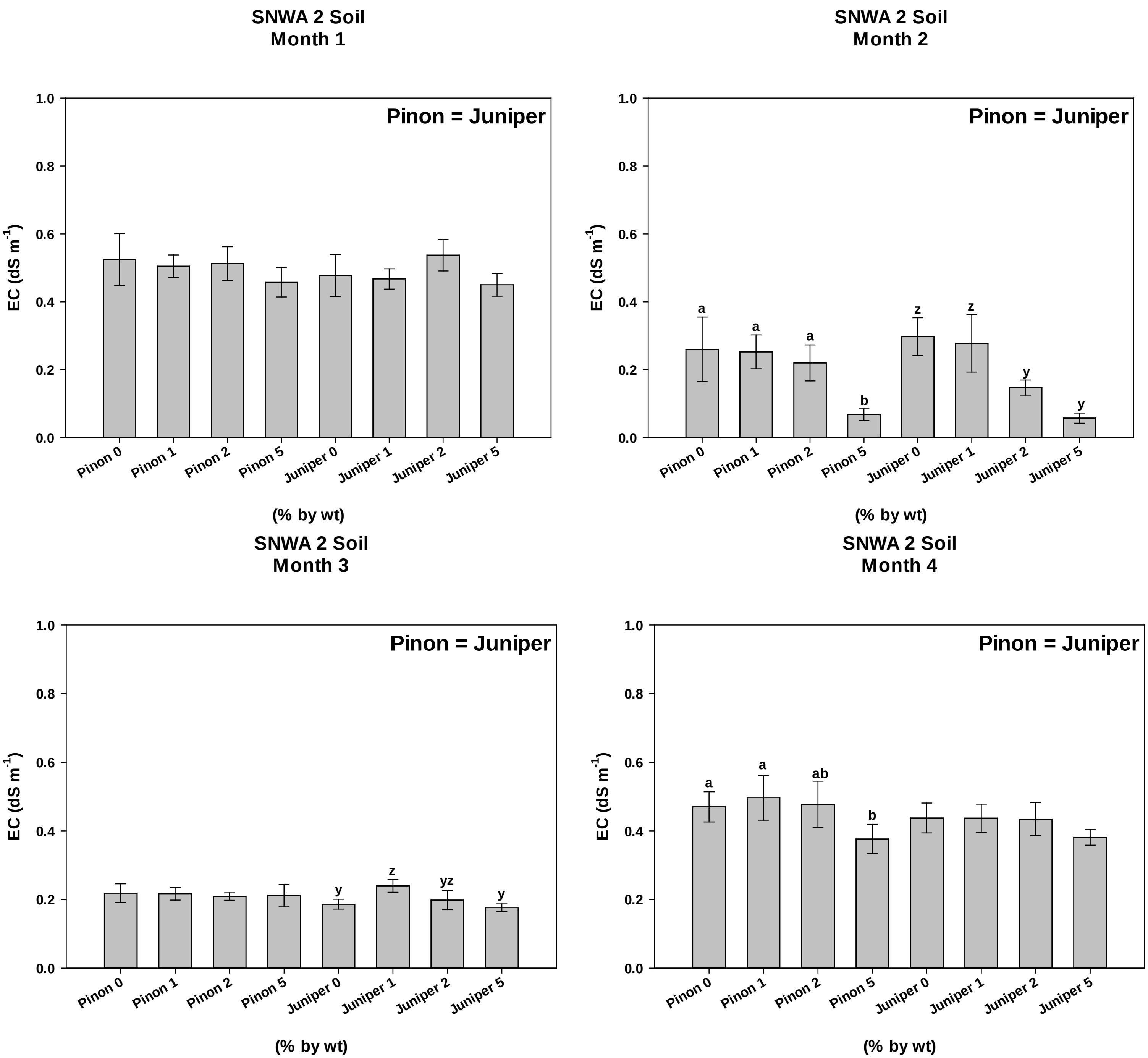


Figure 21. Soil NO_3-N

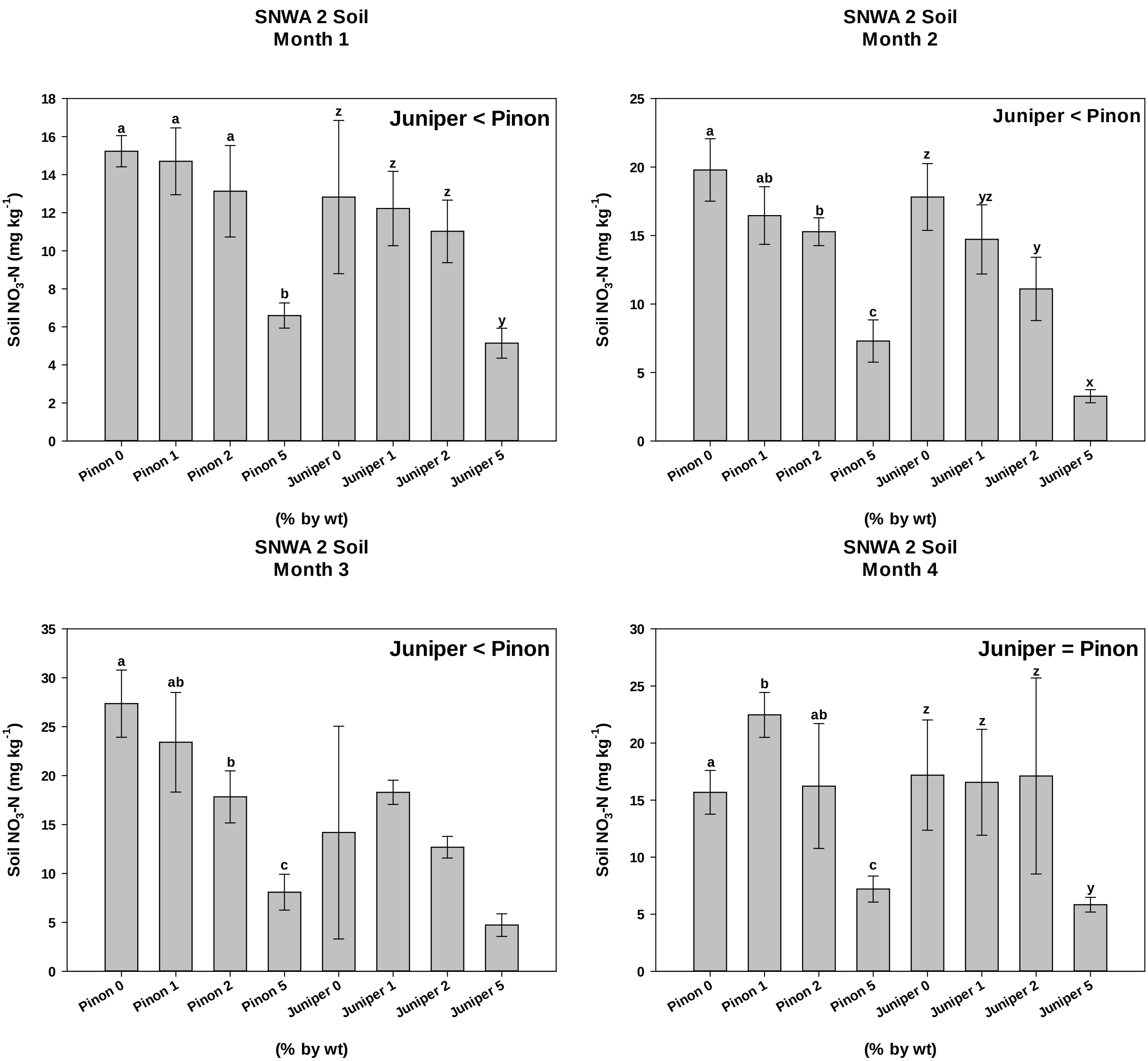


Figure 22. Soil Organic Carbon (C)

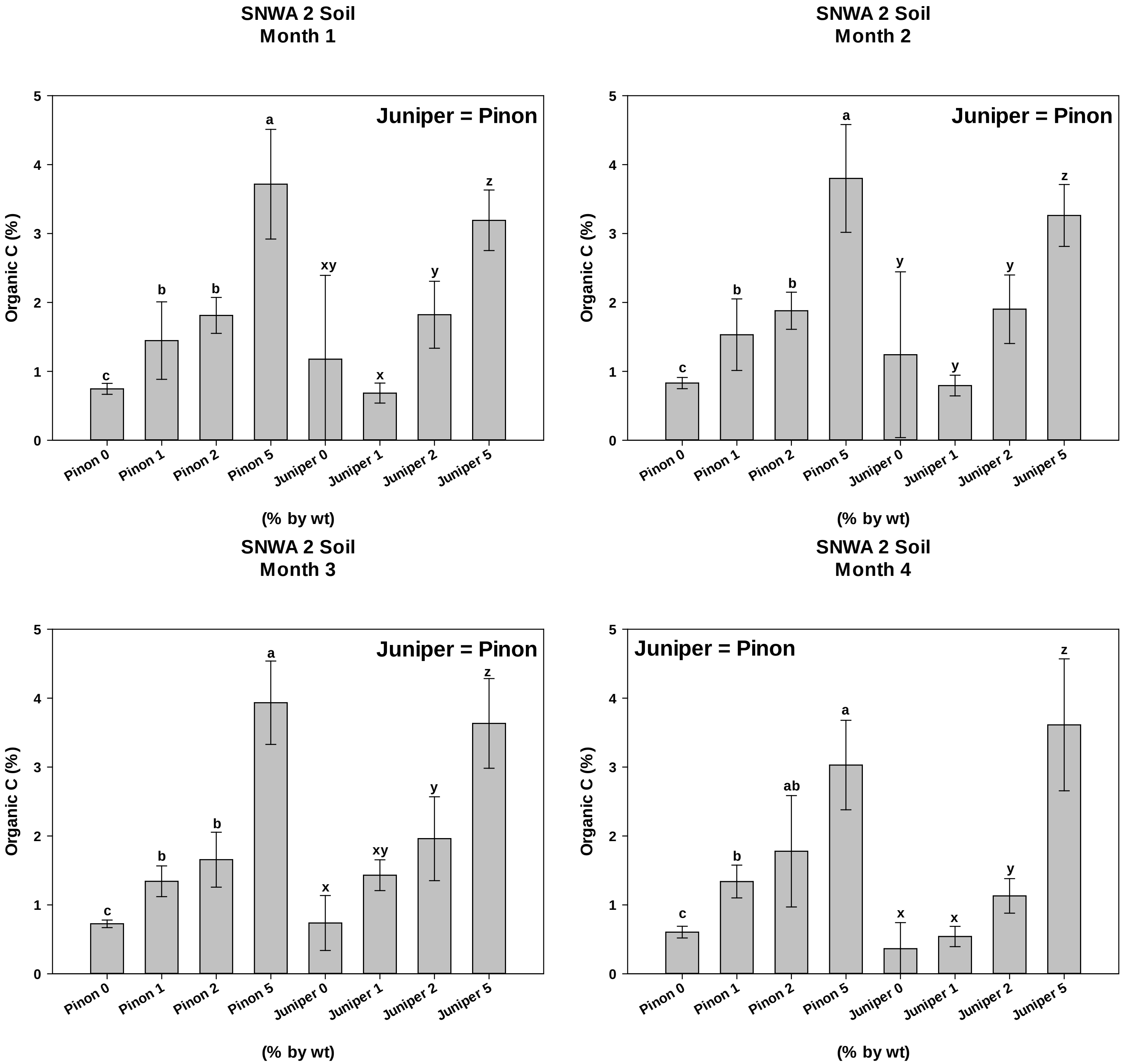


Figure 23. Olsen-Extractable (i.e. Plant-Available) Phosphorus (P)

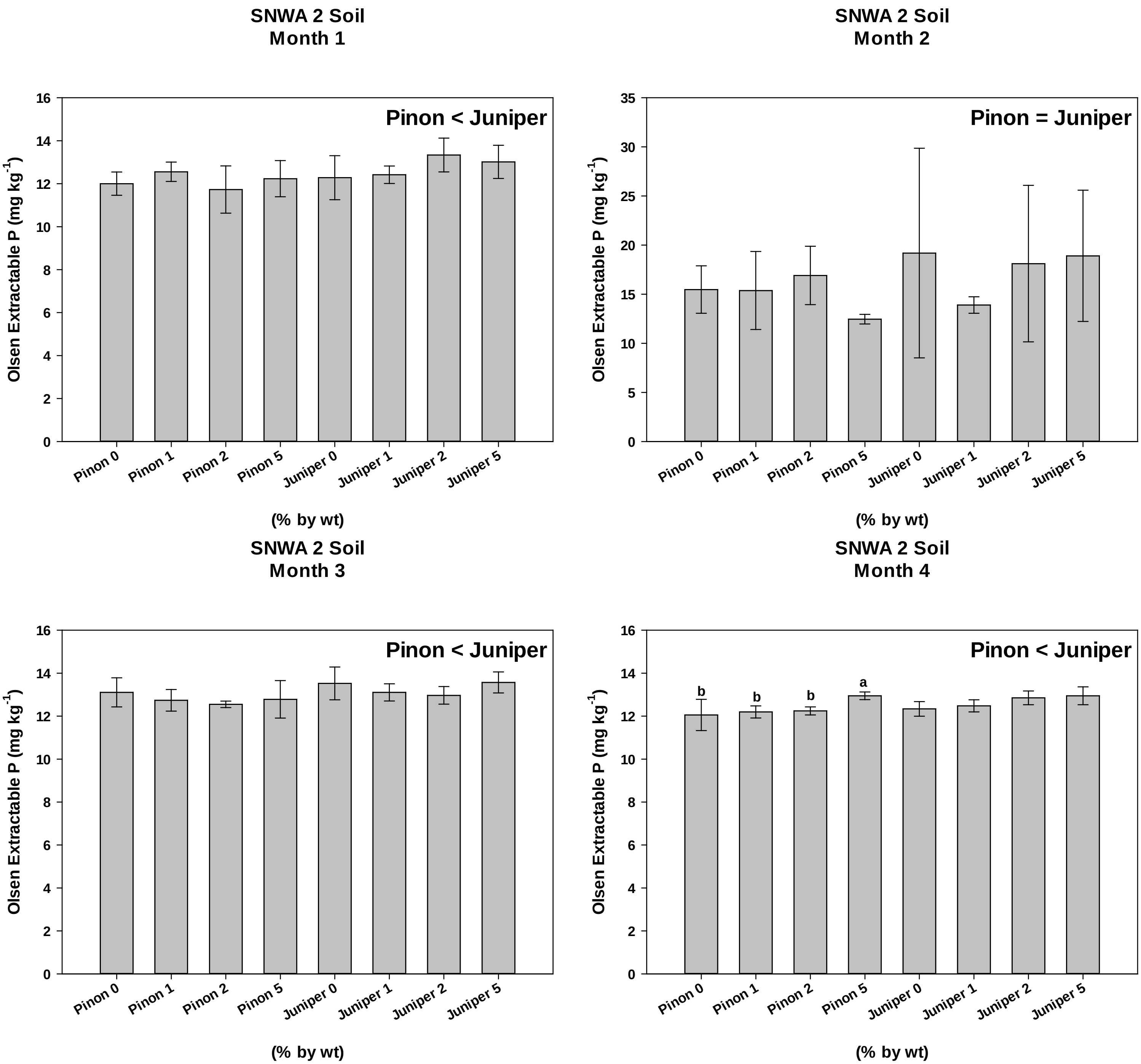


Figure 24. DTPA-Extractable (i.e. Plant-Available) Iron (Fe)

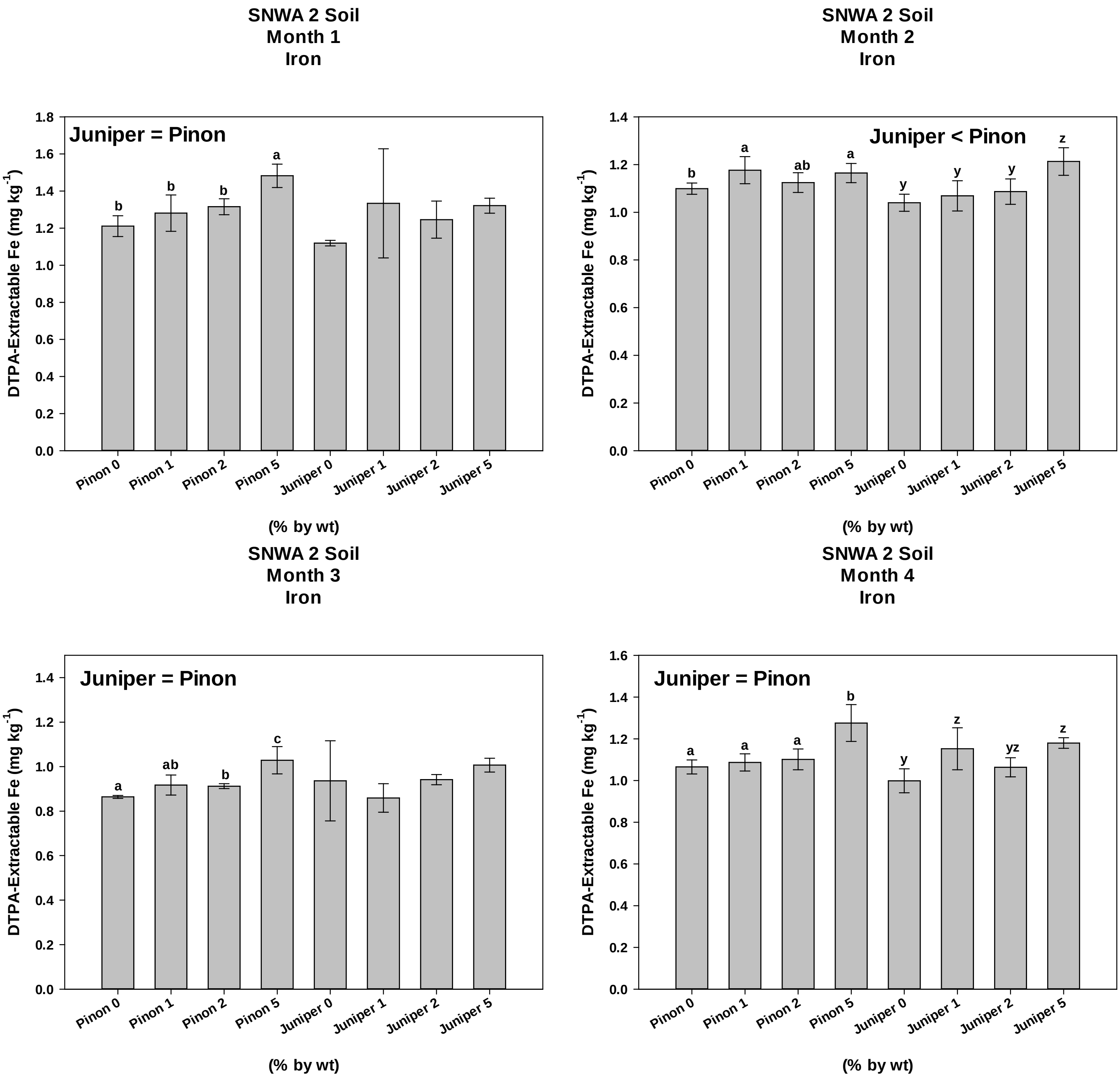


Figure 25. DTPA-Extractable (i.e. Plant-Available) Zinc (Zn)

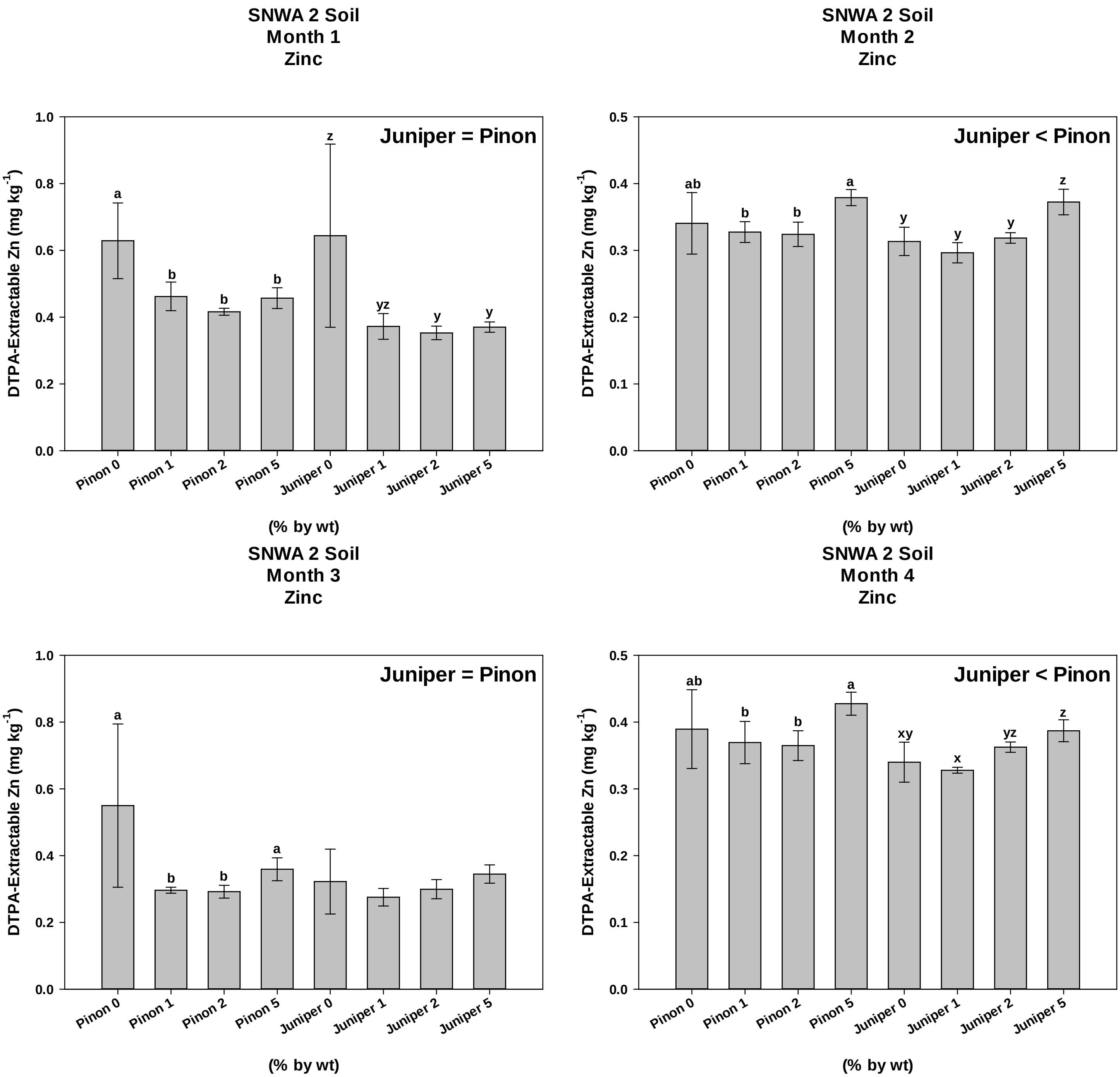


Figure 26. DTPA-Extractable (i.e. Plant-Available) Manganese (Mn)

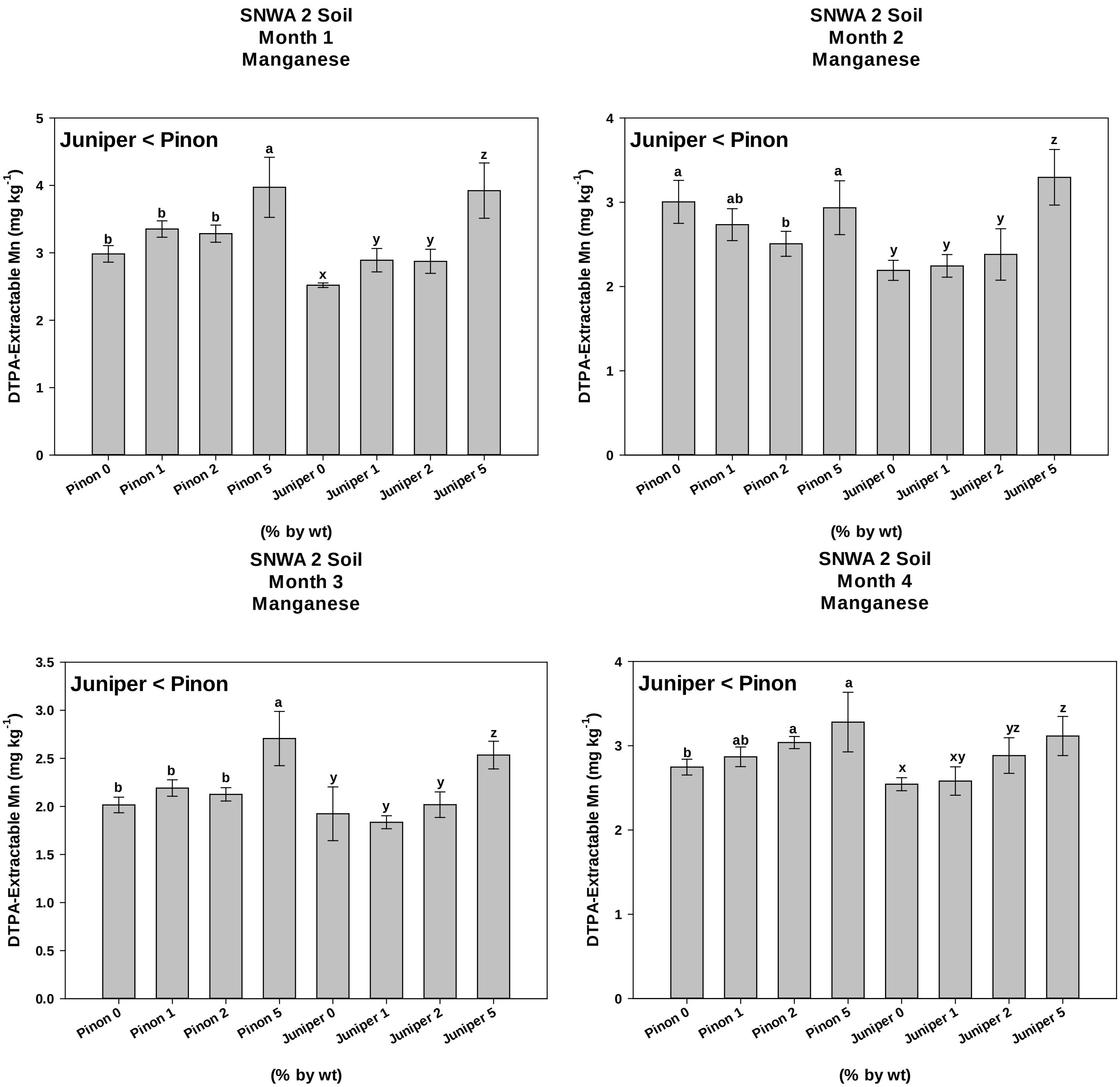


Figure 27. DTPA-Extractable (i.e. Plant-Available) Copper (Cu)

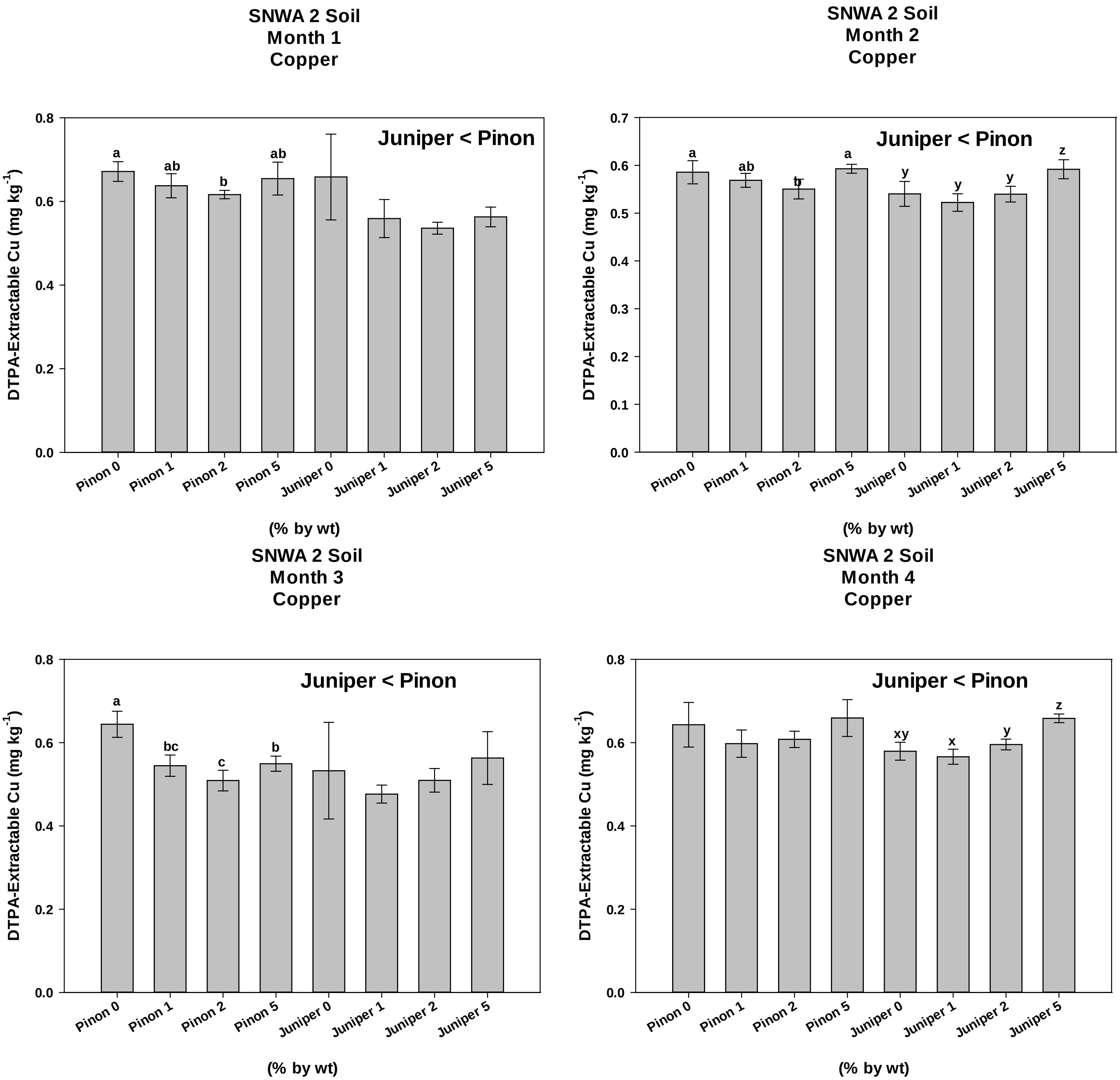


Figure 28. DTPA-Extractable (i.e. Plant-Available) Nickel (Ni)

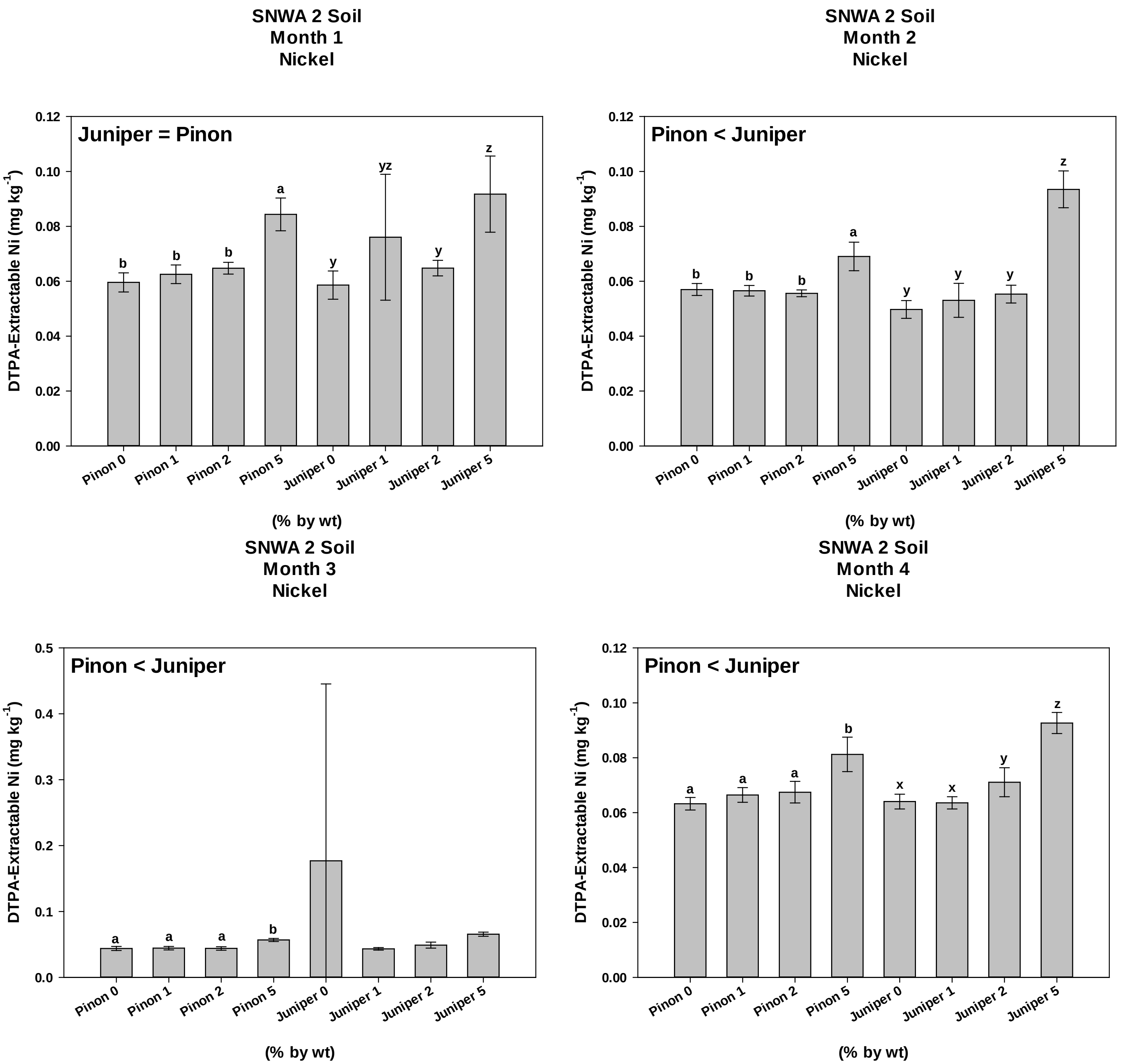


Figure 29. Soil Moisture

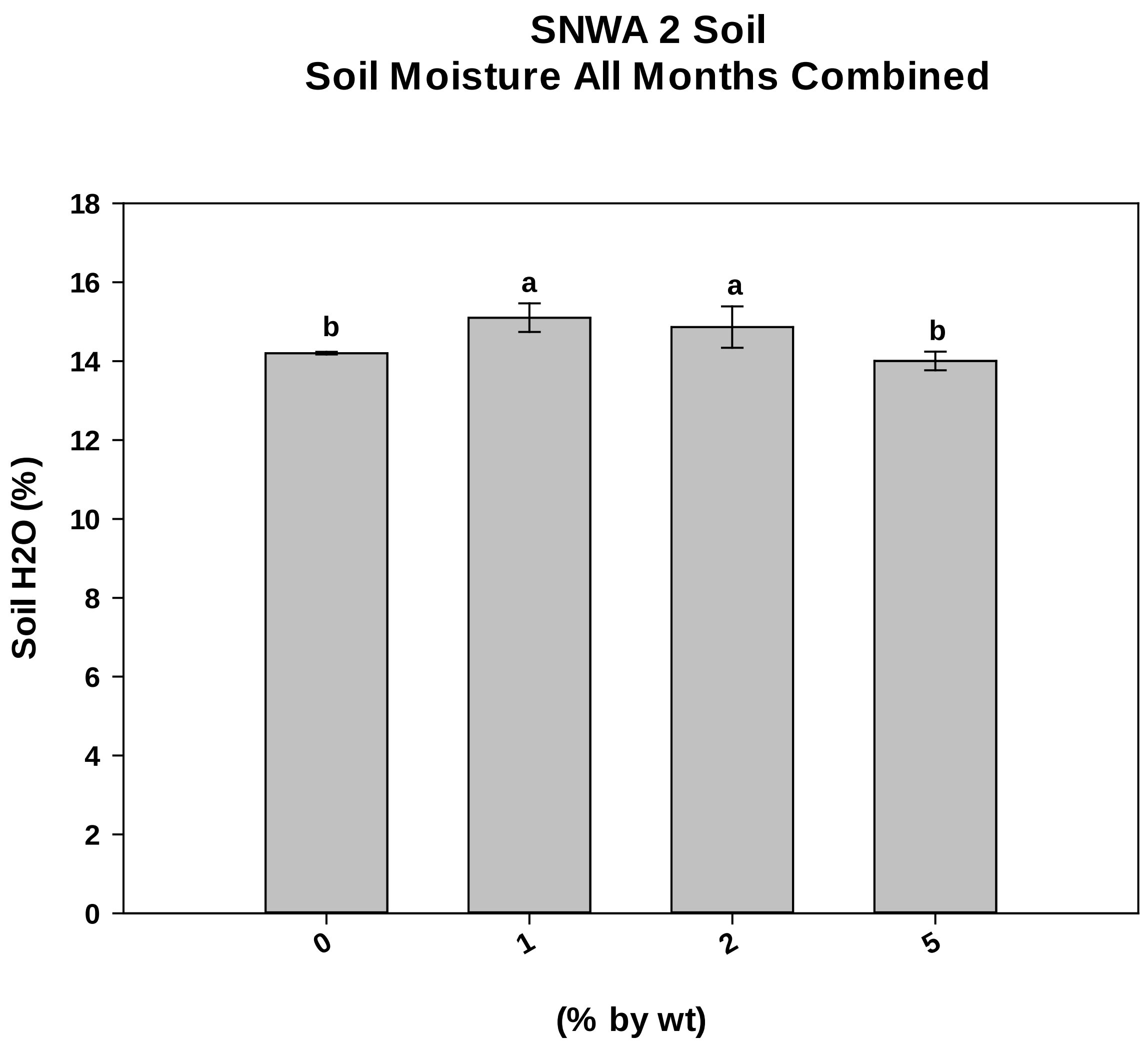


Figure 30. Alfalfa Germination

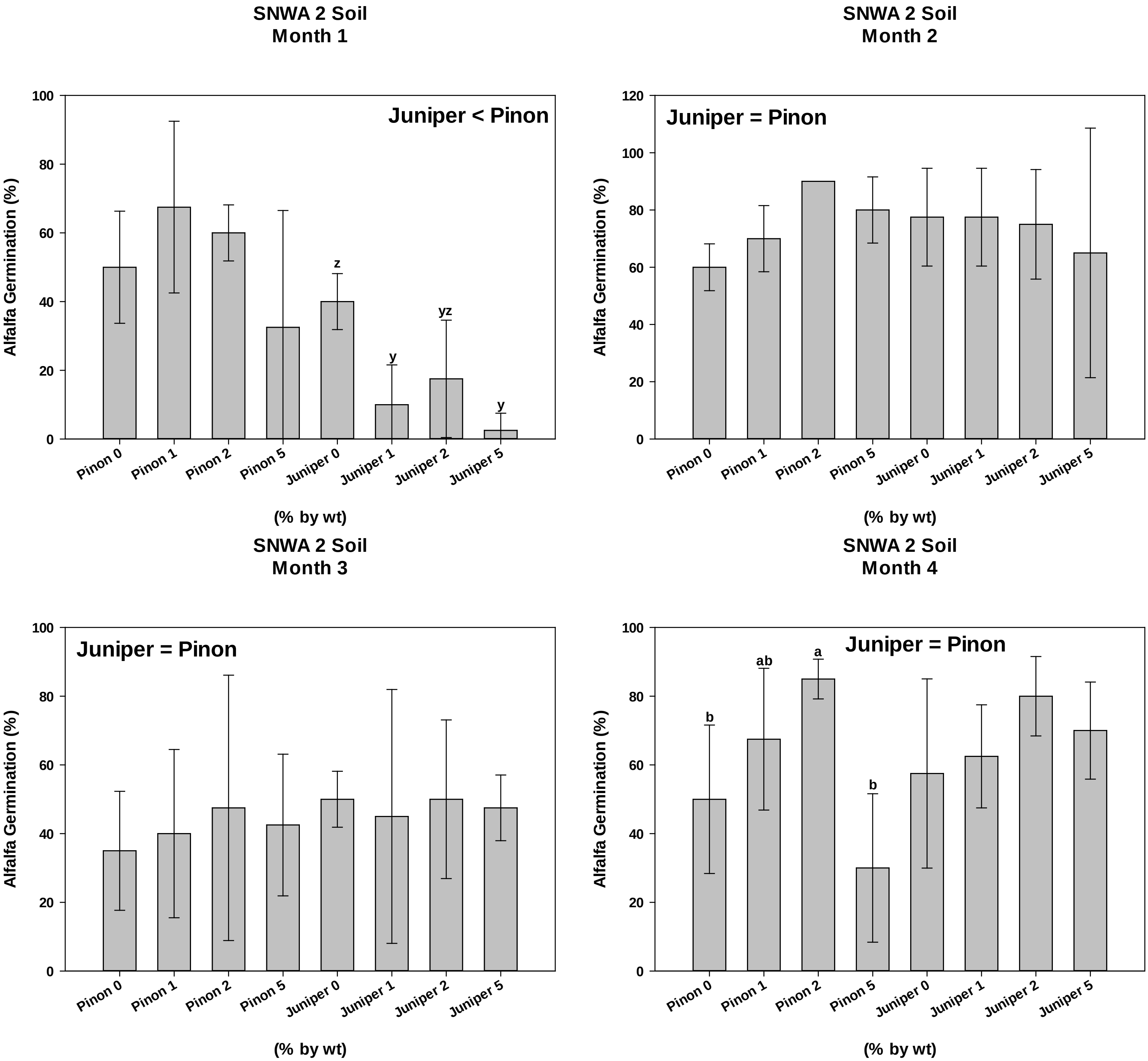
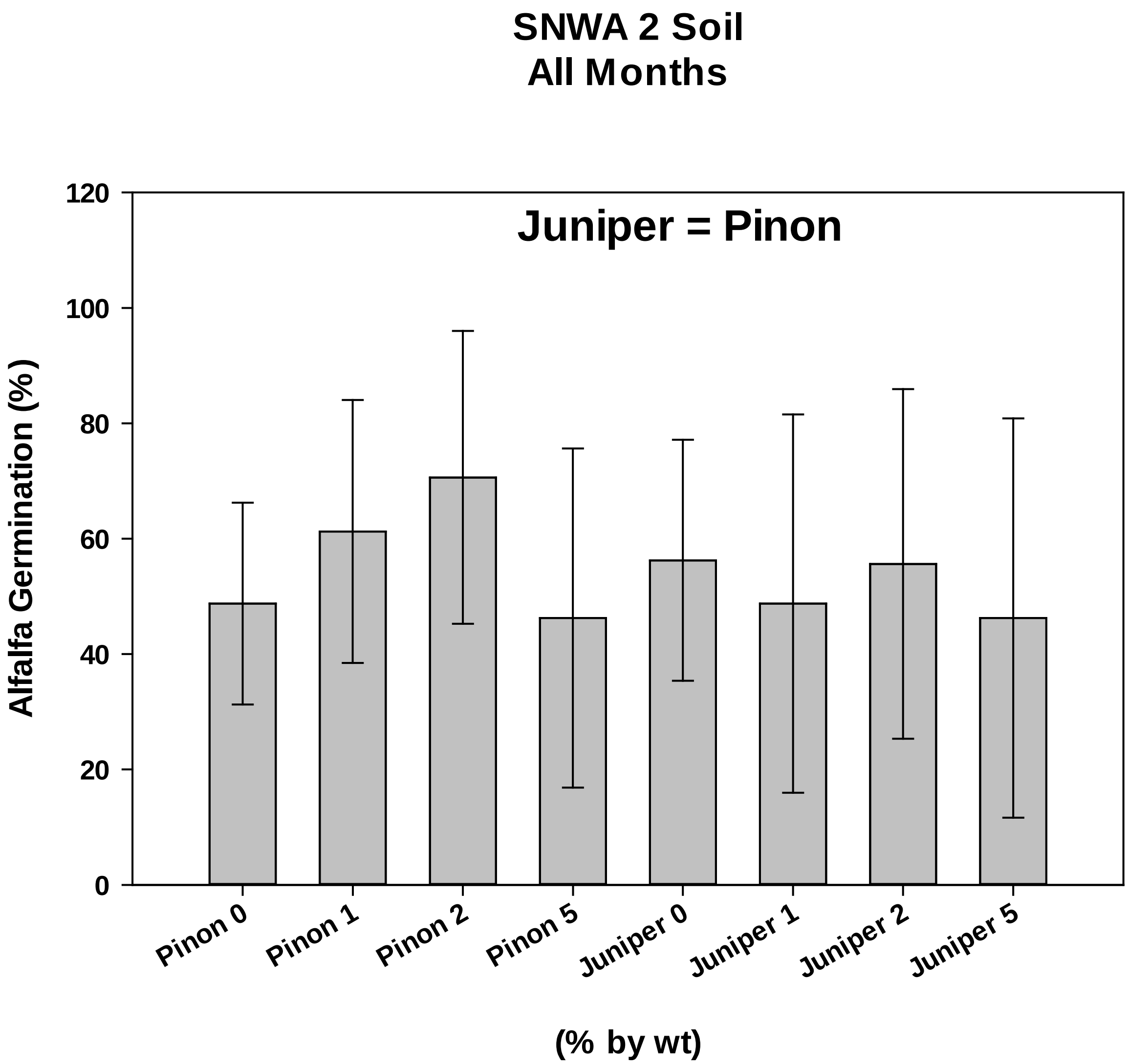


Figure 31. Alfalfa Germination All Months



Diamond Valley Soil

Figure 32. Soil pH

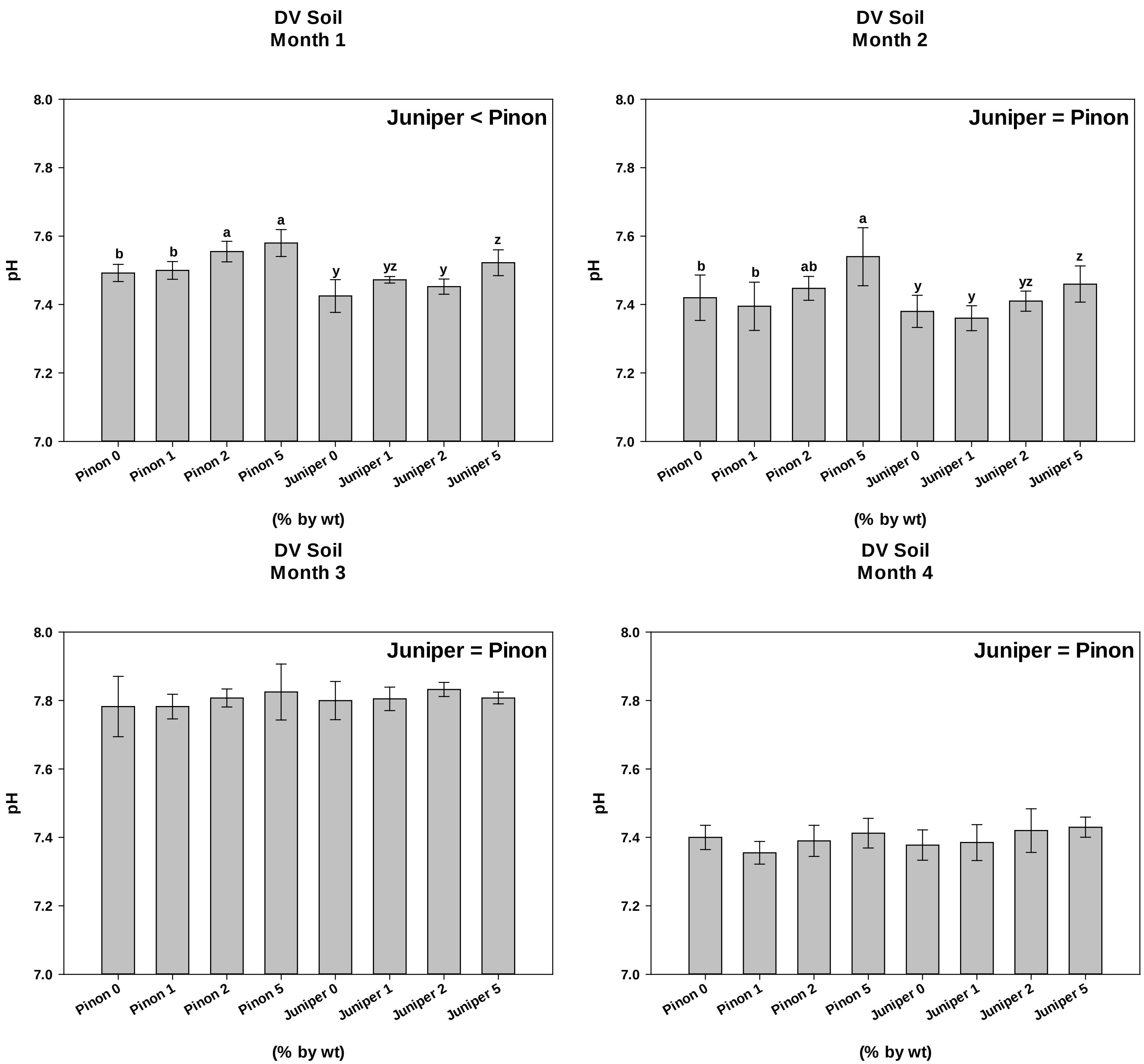


Figure 33. Soil EC

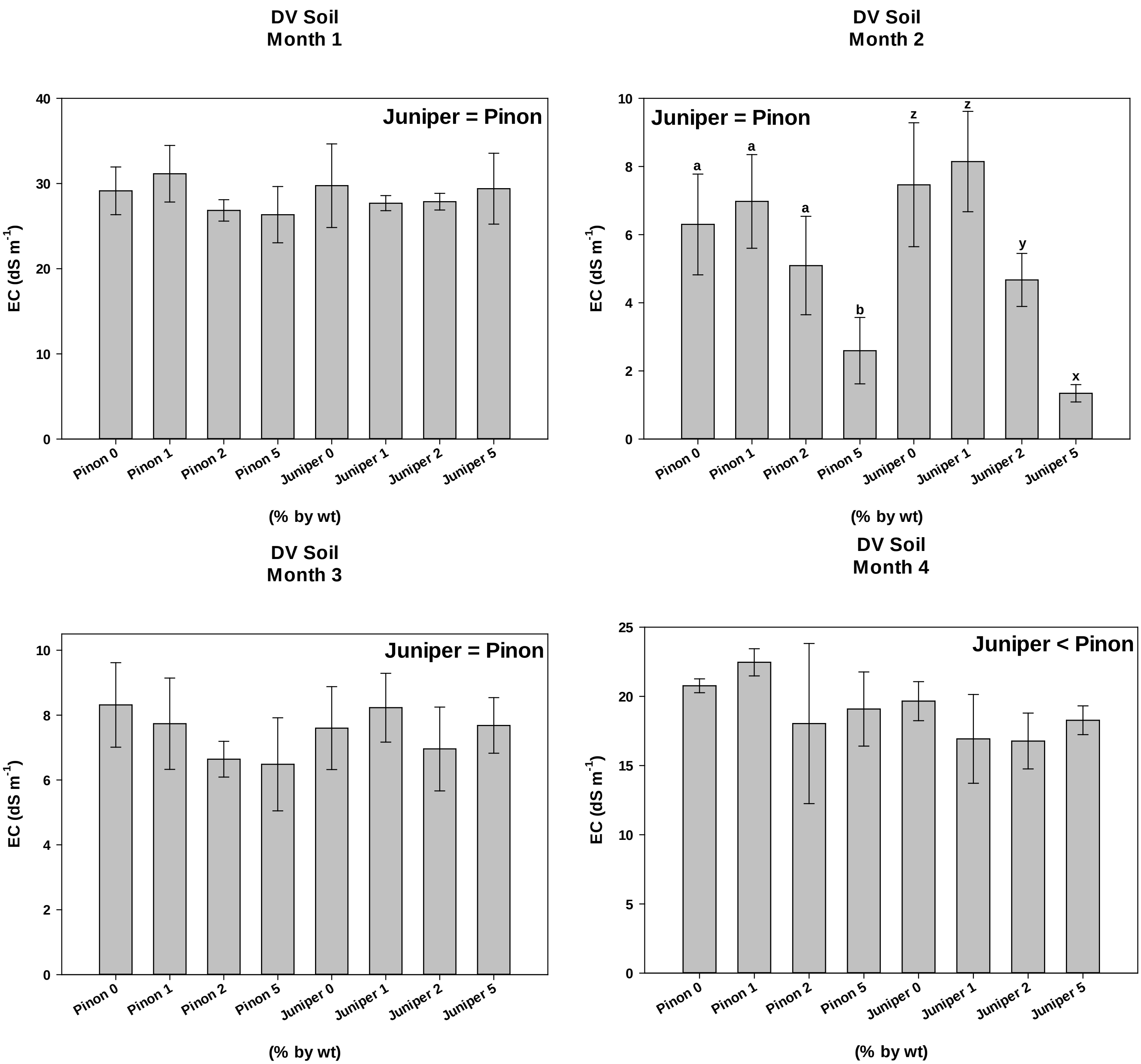


Figure 34. Soil NO_3-N

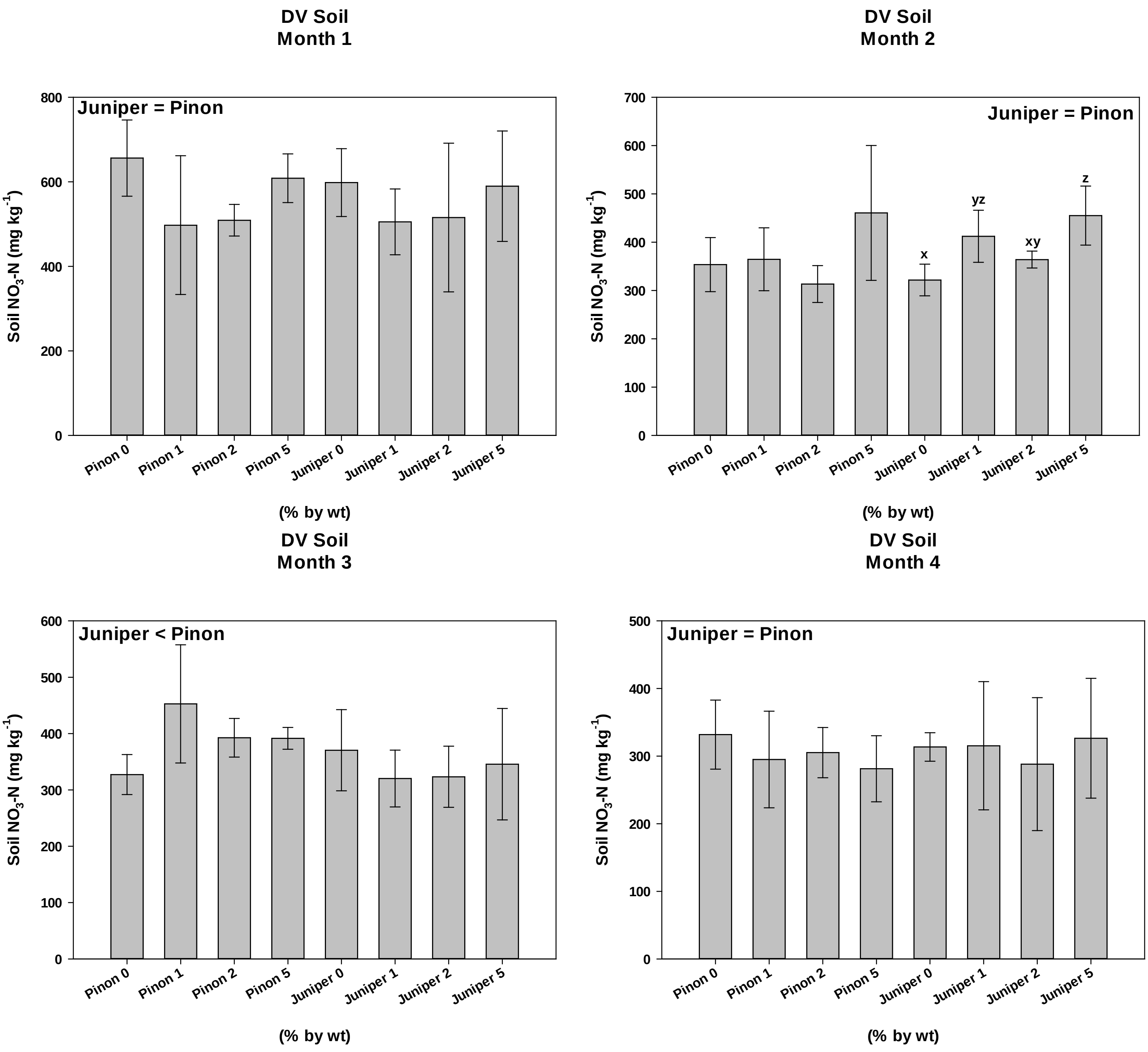


Figure 35. Soil Organic Carbon (C)

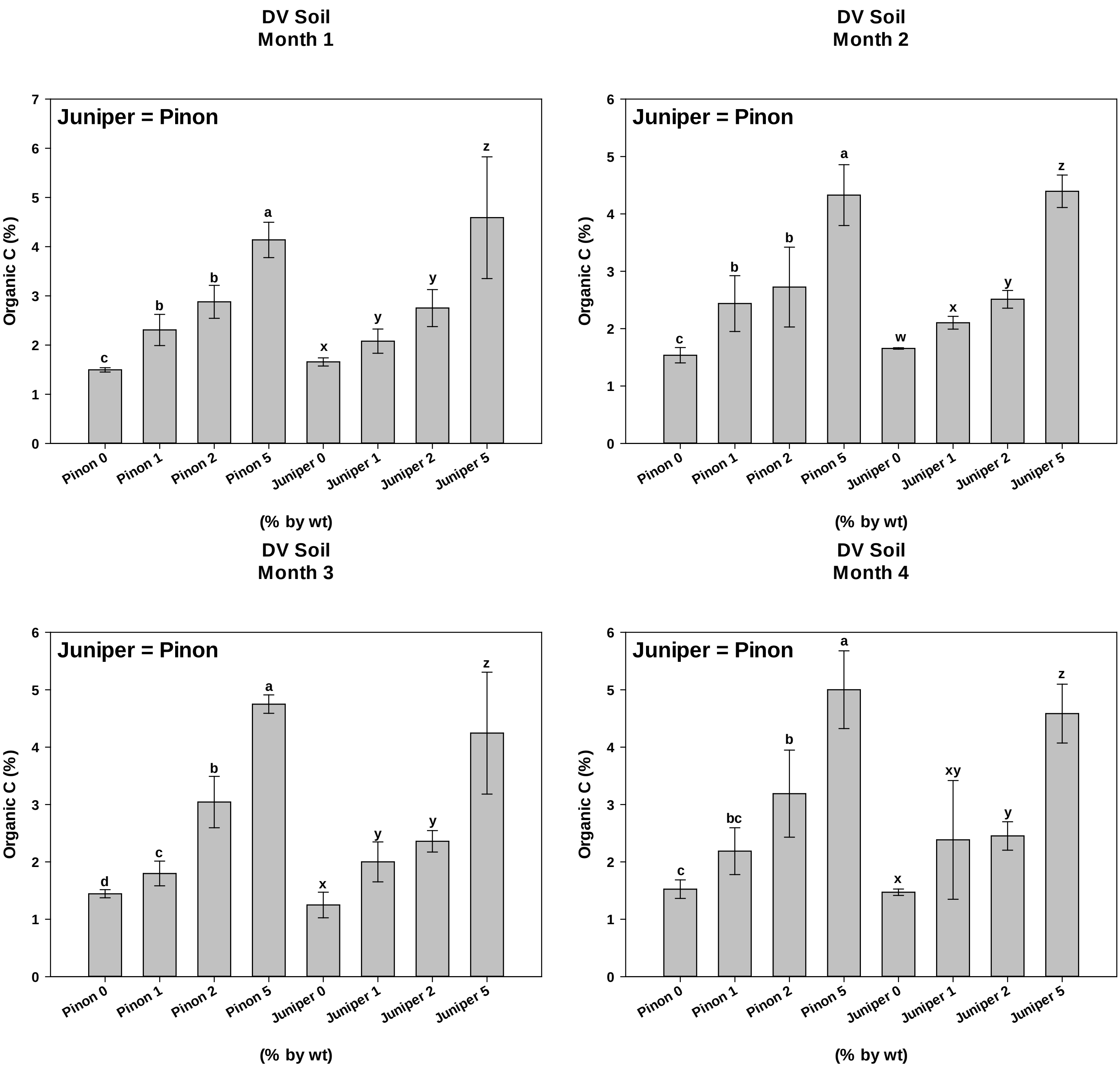


Figure 36. Olsen-Extractable (i.e. Plant-Available) Phosphorus (P)

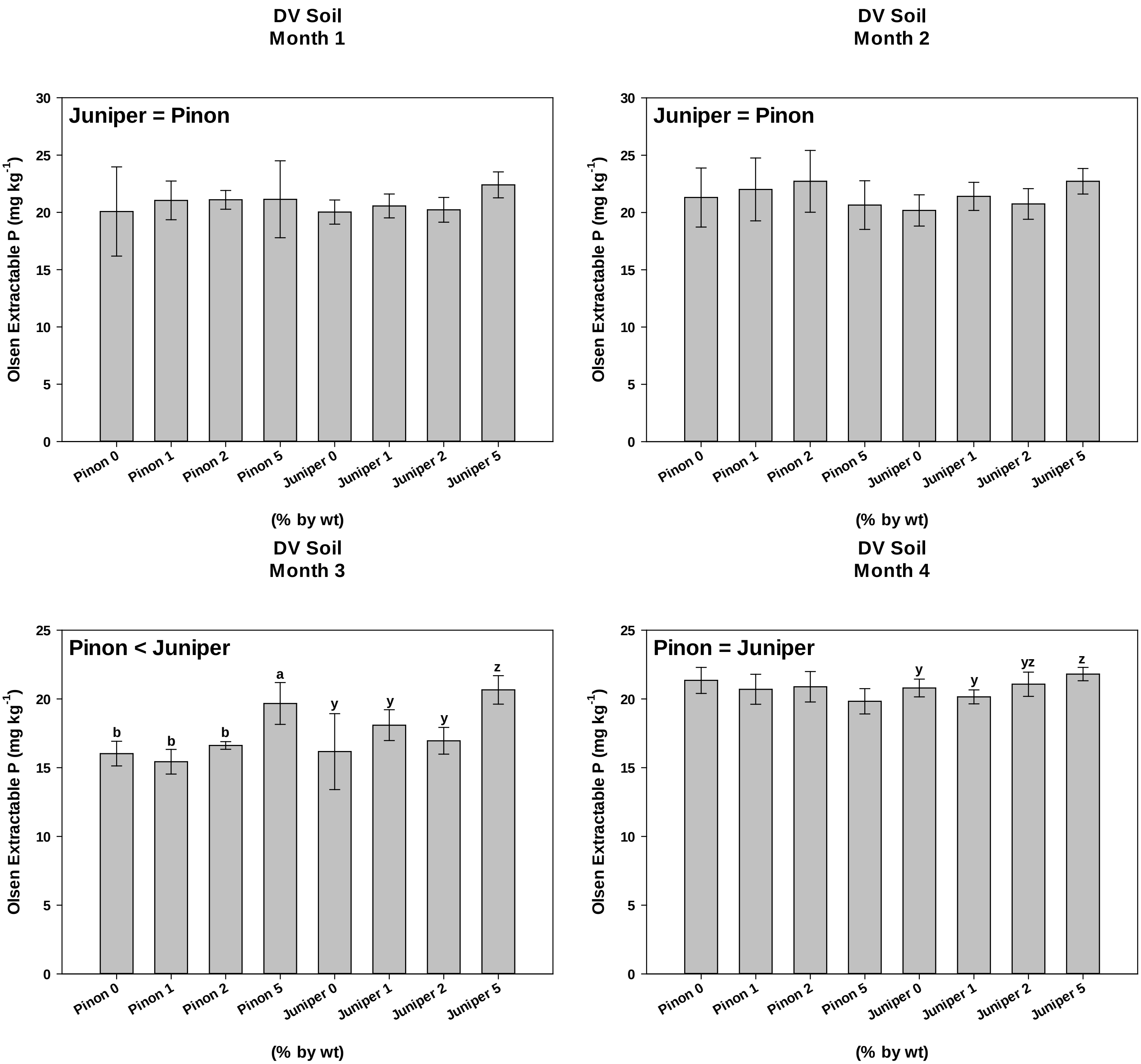


Figure 37. DTPA-Extractable (i.e. Plant-Available) Iron (Fe)

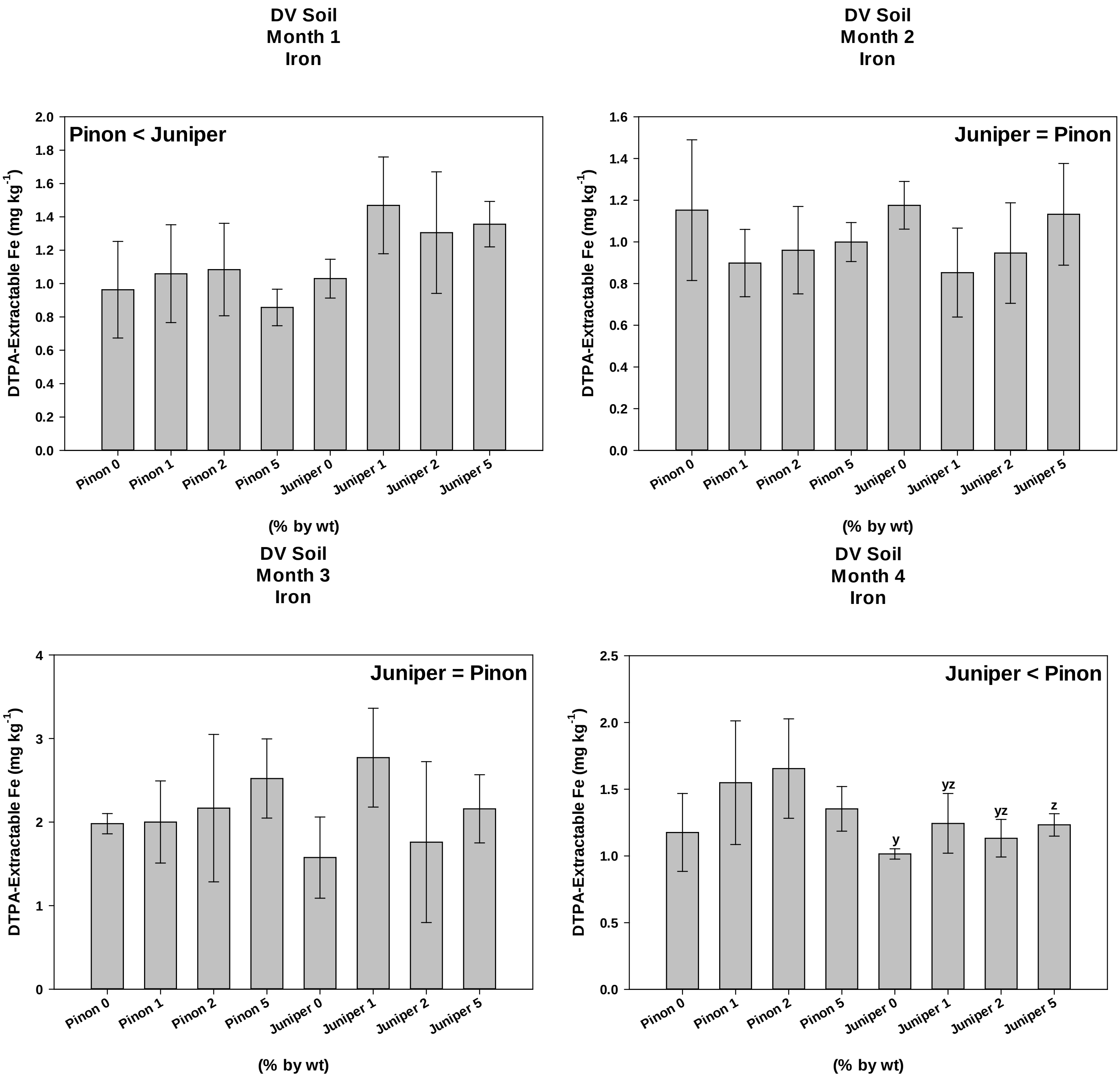


Figure 38. DTPA-Extractable (i.e. Plant-Available) Zinc (Zn)

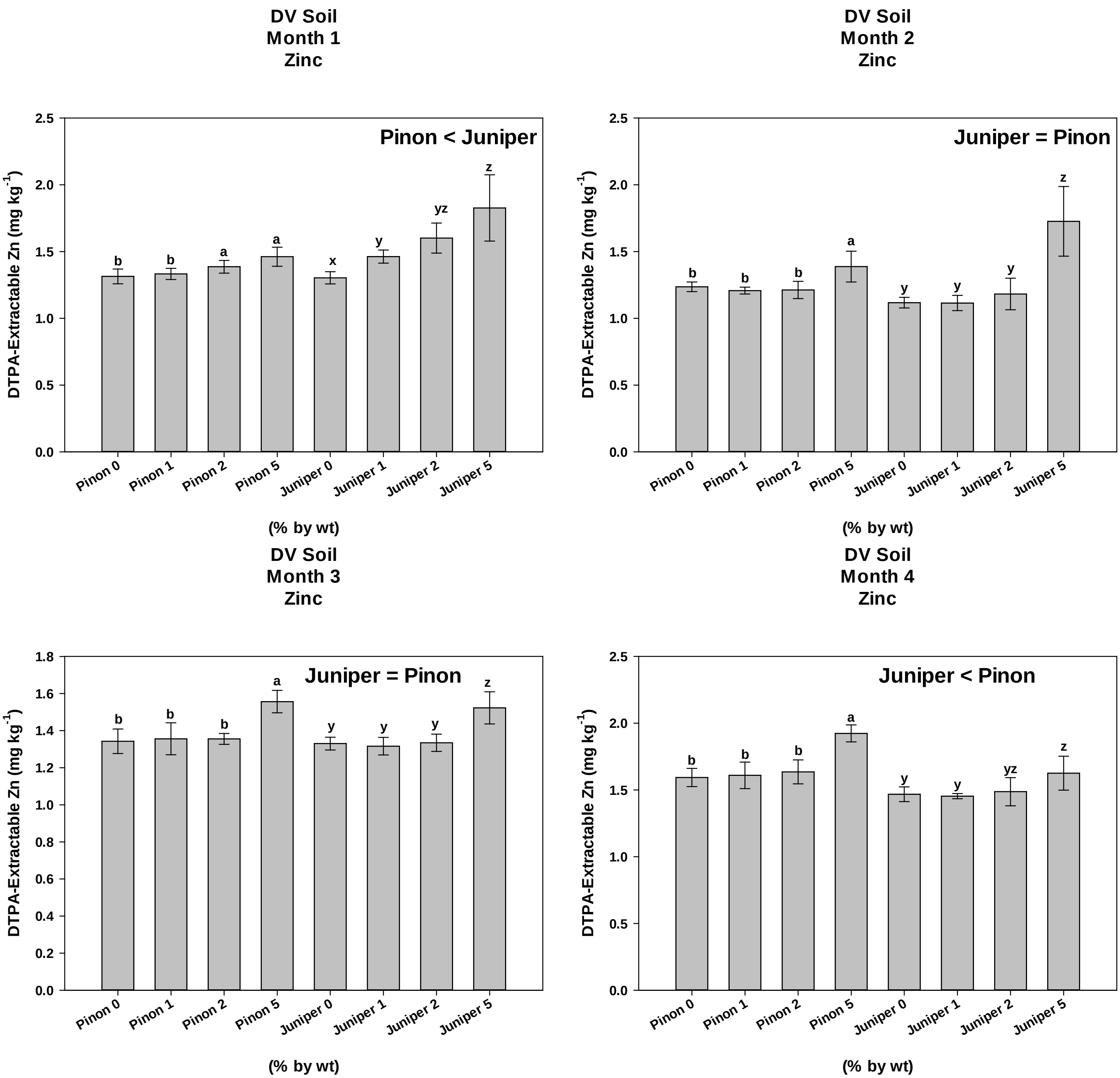


Figure 39. DTPA-Extractable (i.e. Plant-Available) Manganese (Mn)

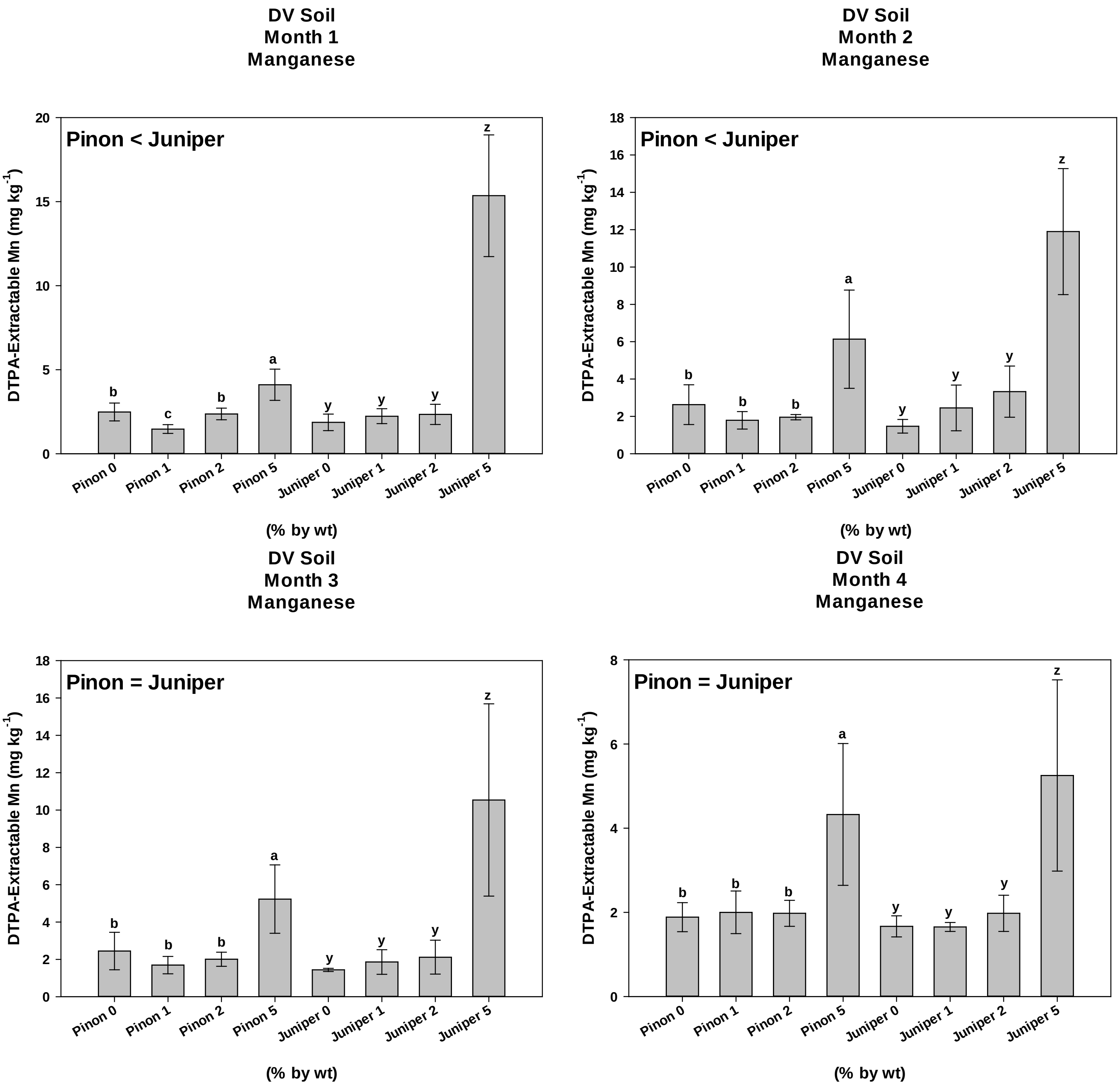


Figure 40. DTPA-Extractable (i.e. Plant-Available) Copper (Cu)

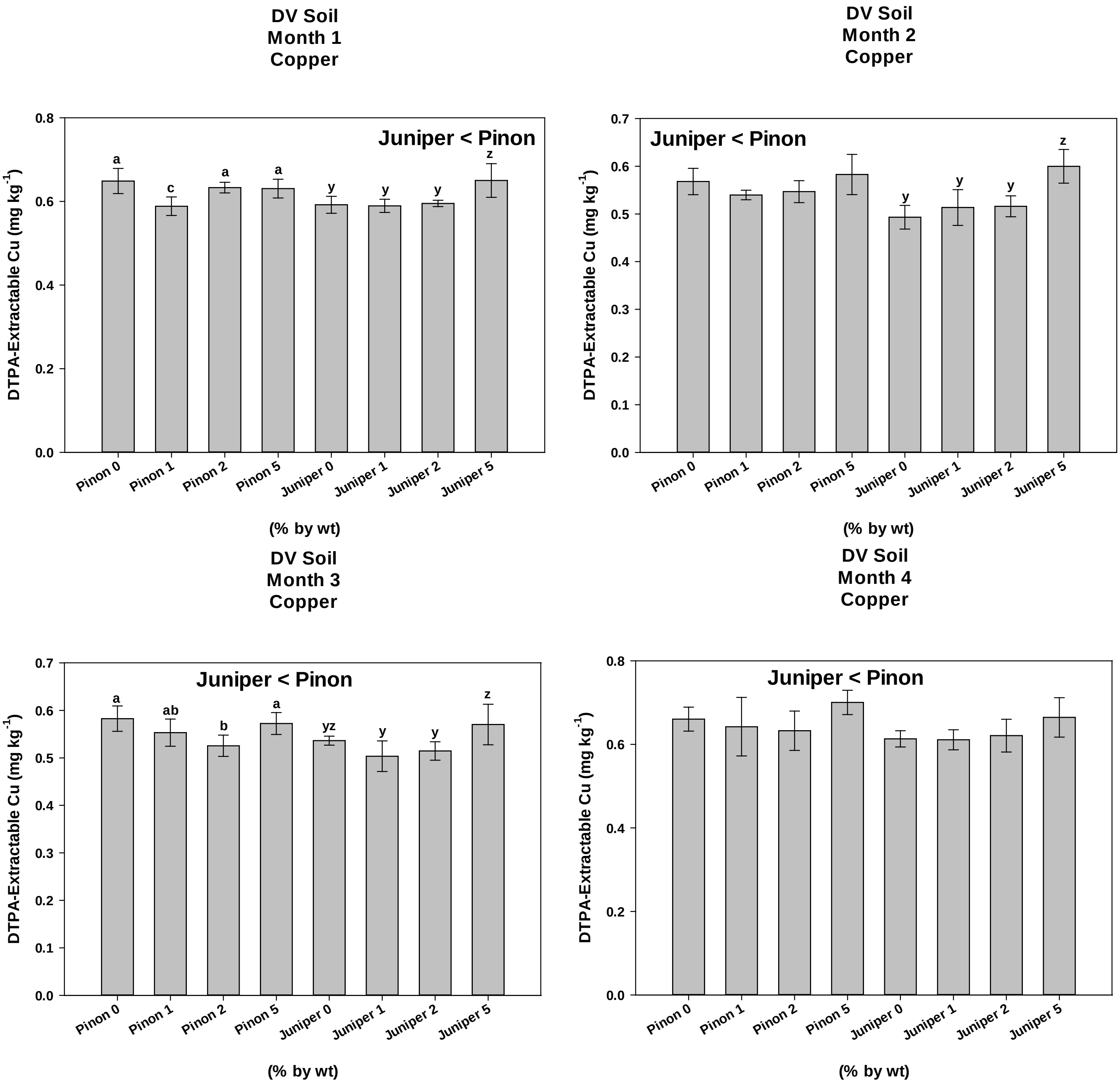


Figure 41. DTPA-Extractable (i.e. Plant-Available) Nickel (Ni)

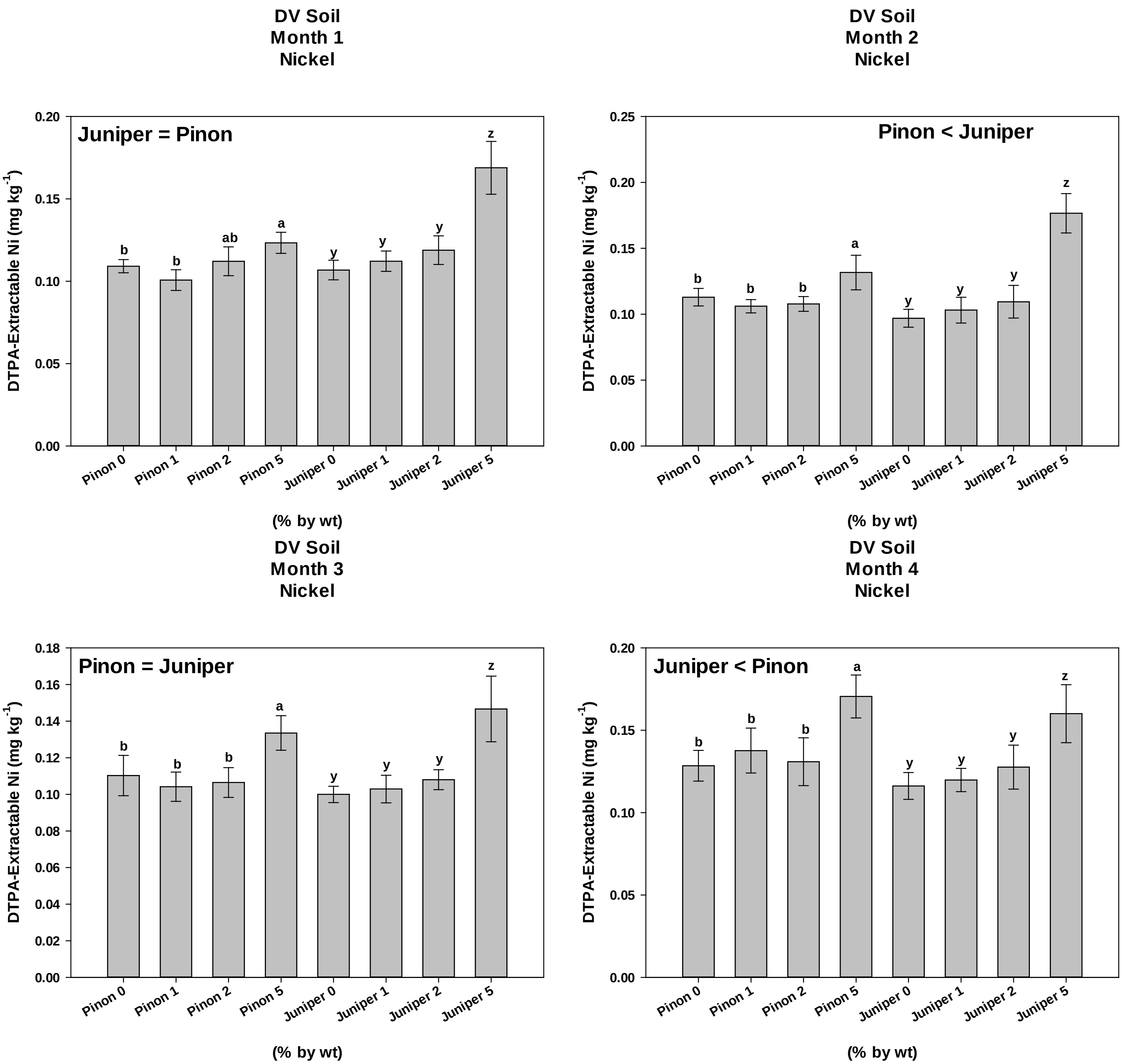


Figure 42. Soil Moisture

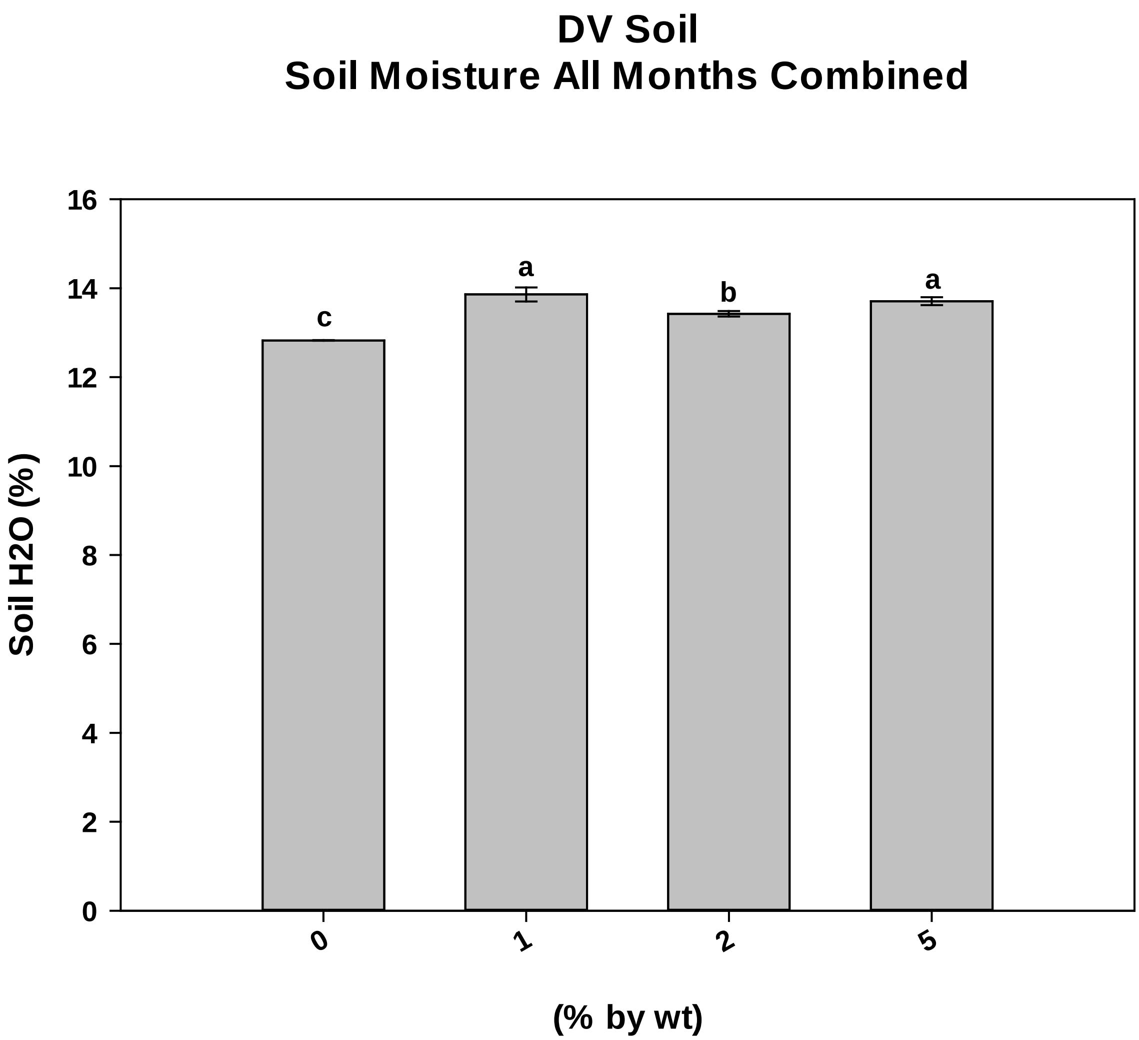


Figure 43. Alfalfa Germination

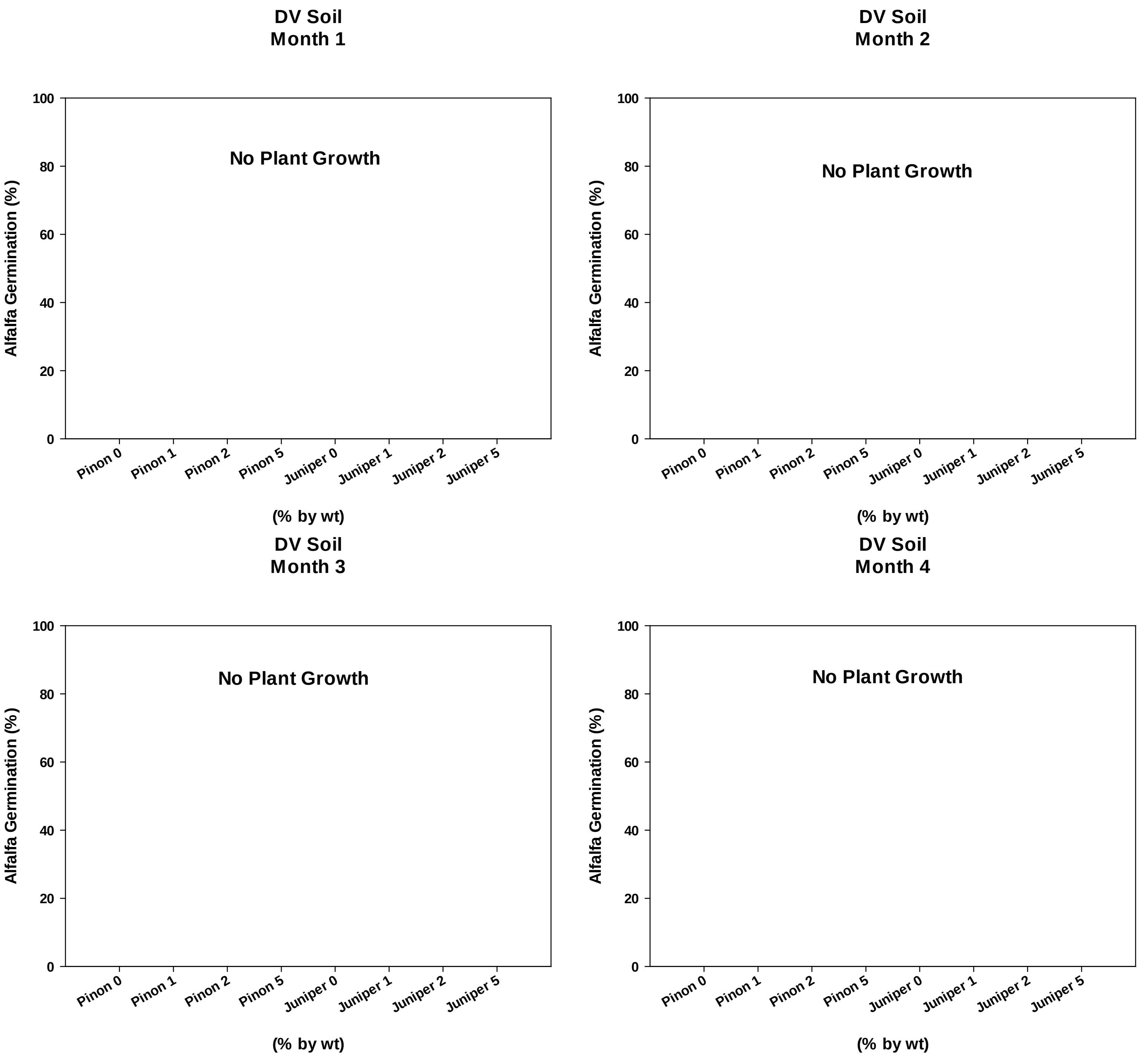
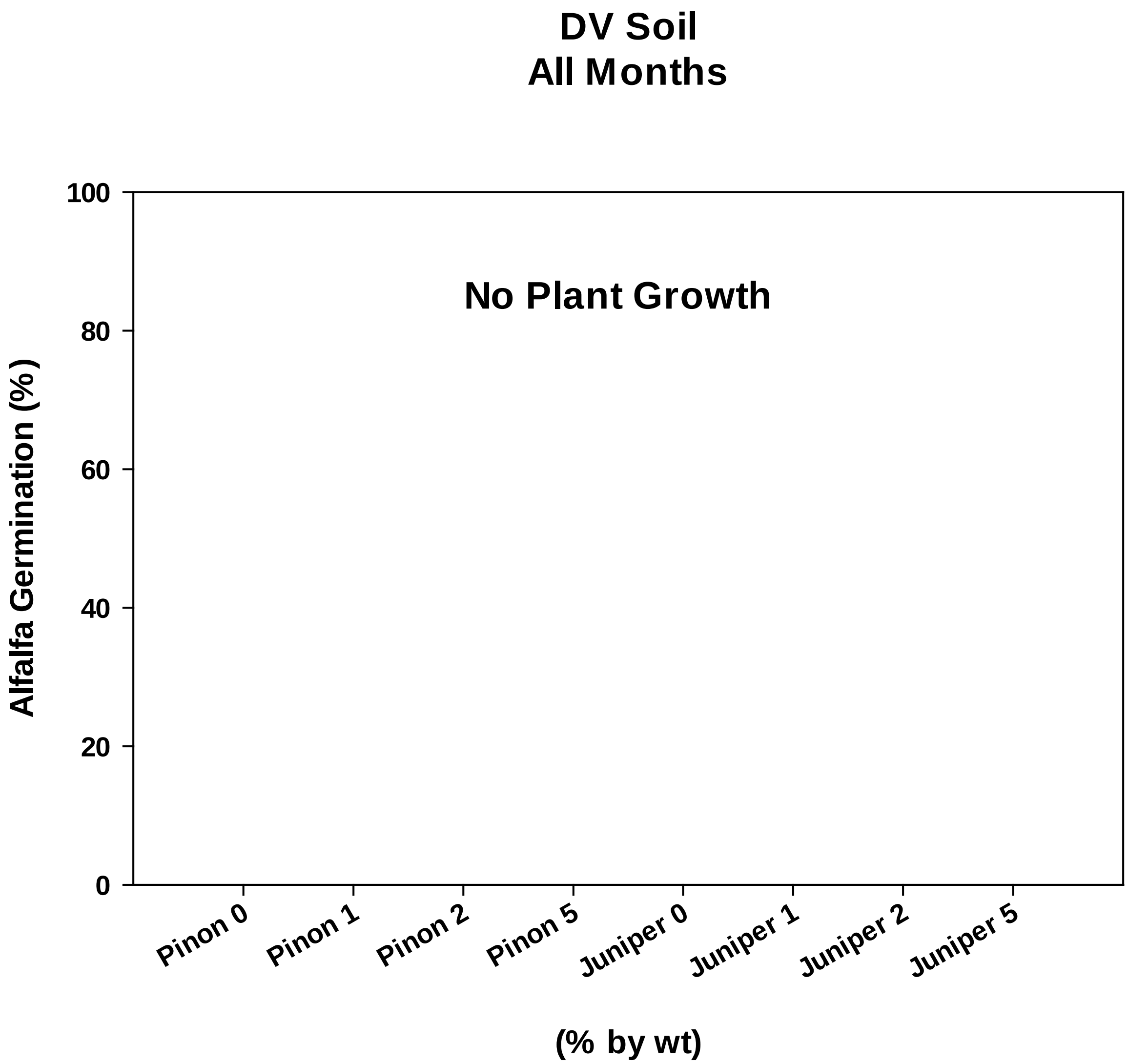


Figure 44. Alfalfa Germination All Months



Ruby Hill Soil

Figure 45. Soil pH

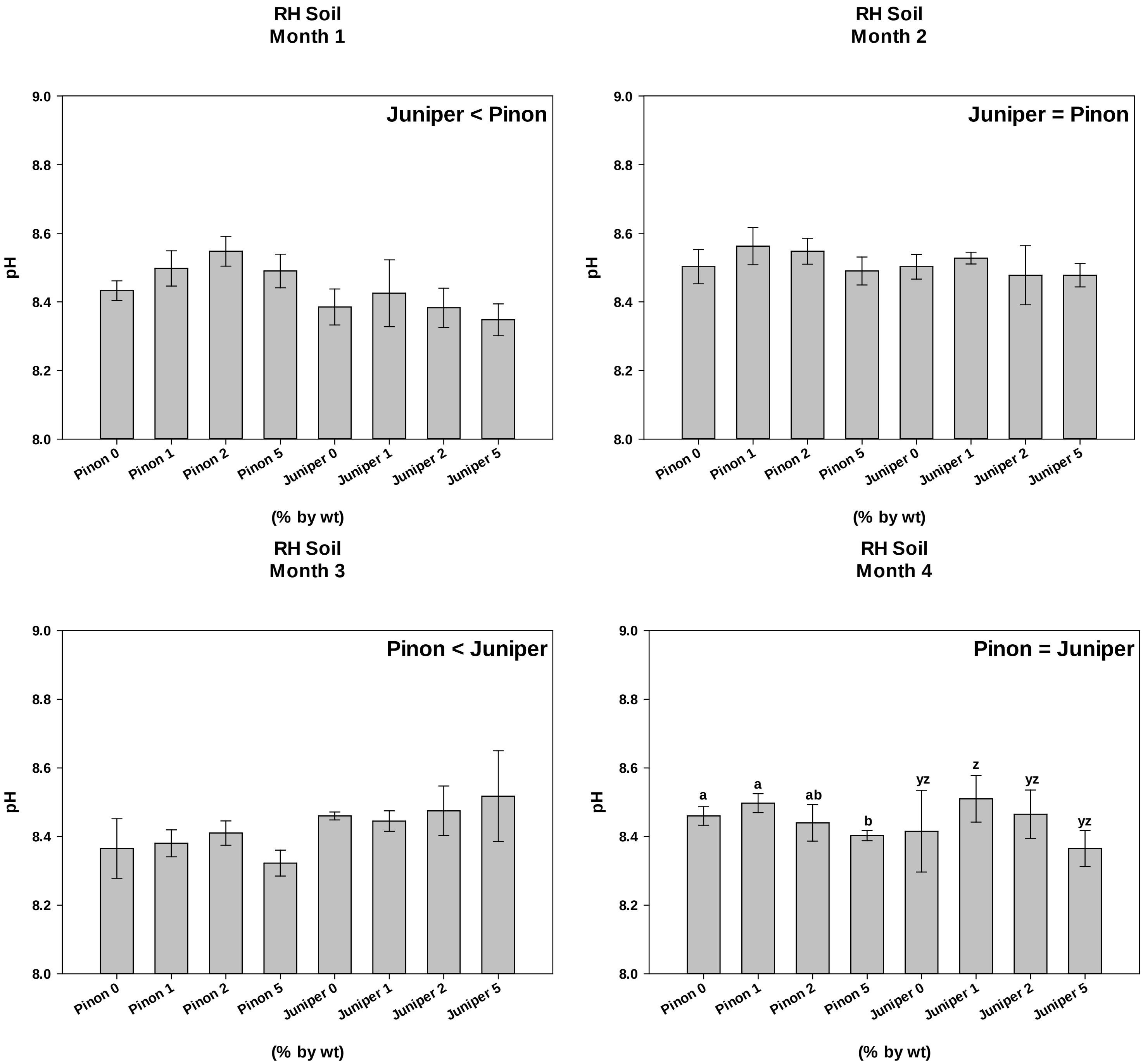


Figure 46. Soil EC

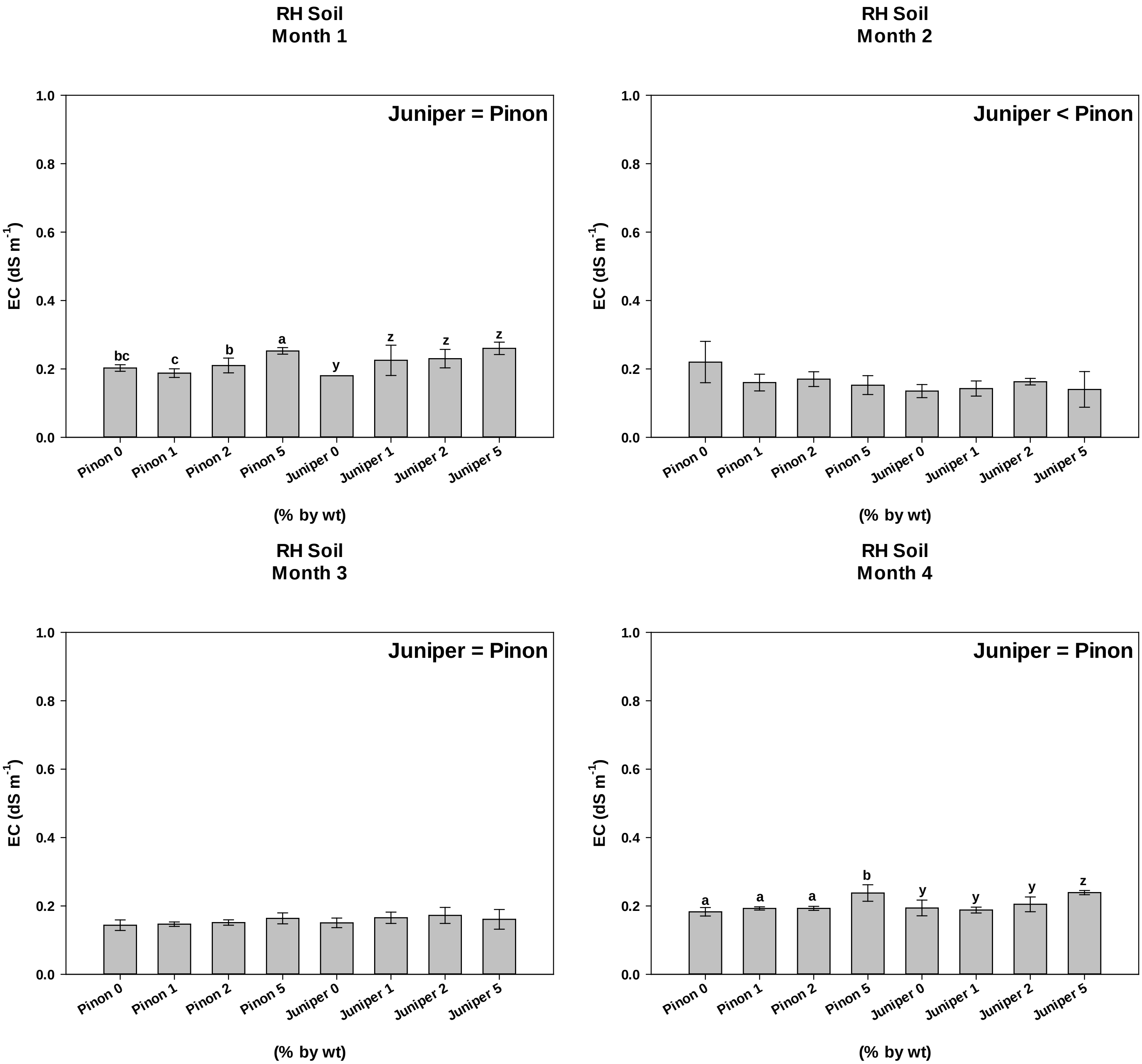


Figure 47. Soil NO_3-N

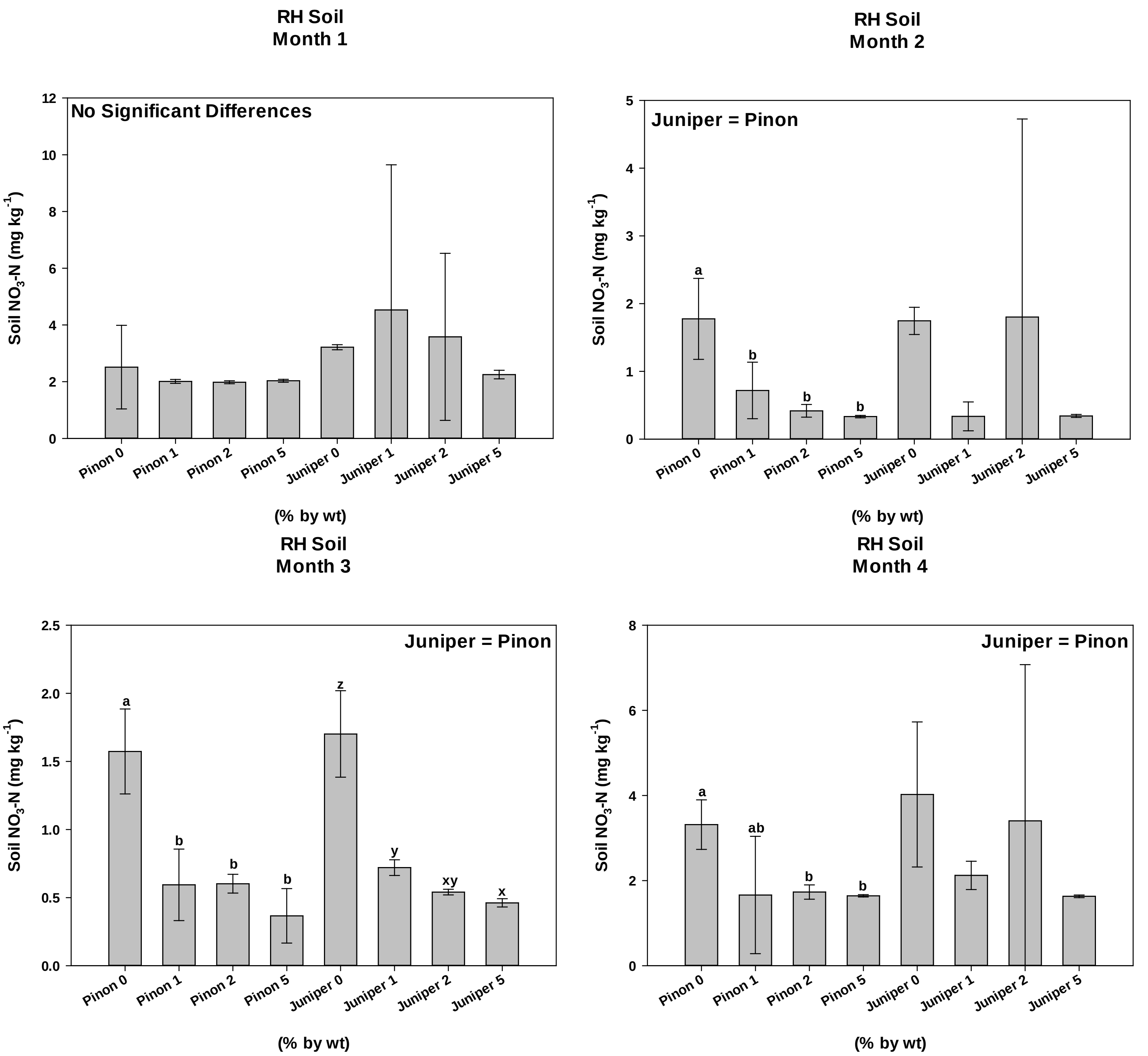


Figure 48. Soil Organic Carbon (C)

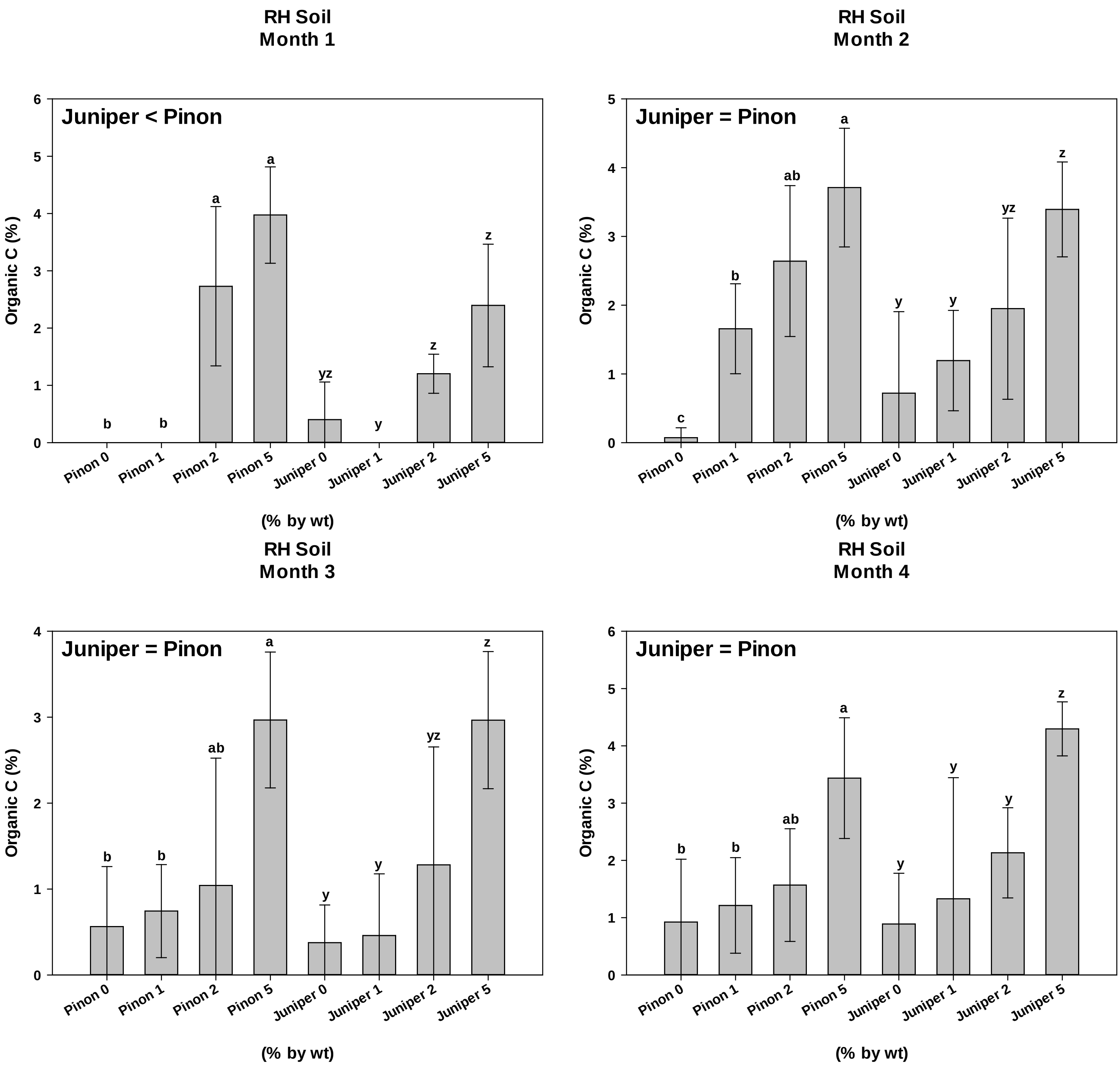


Figure 49. Olsen-Extractable (i.e. Plant-Available) Phosphorus (P)

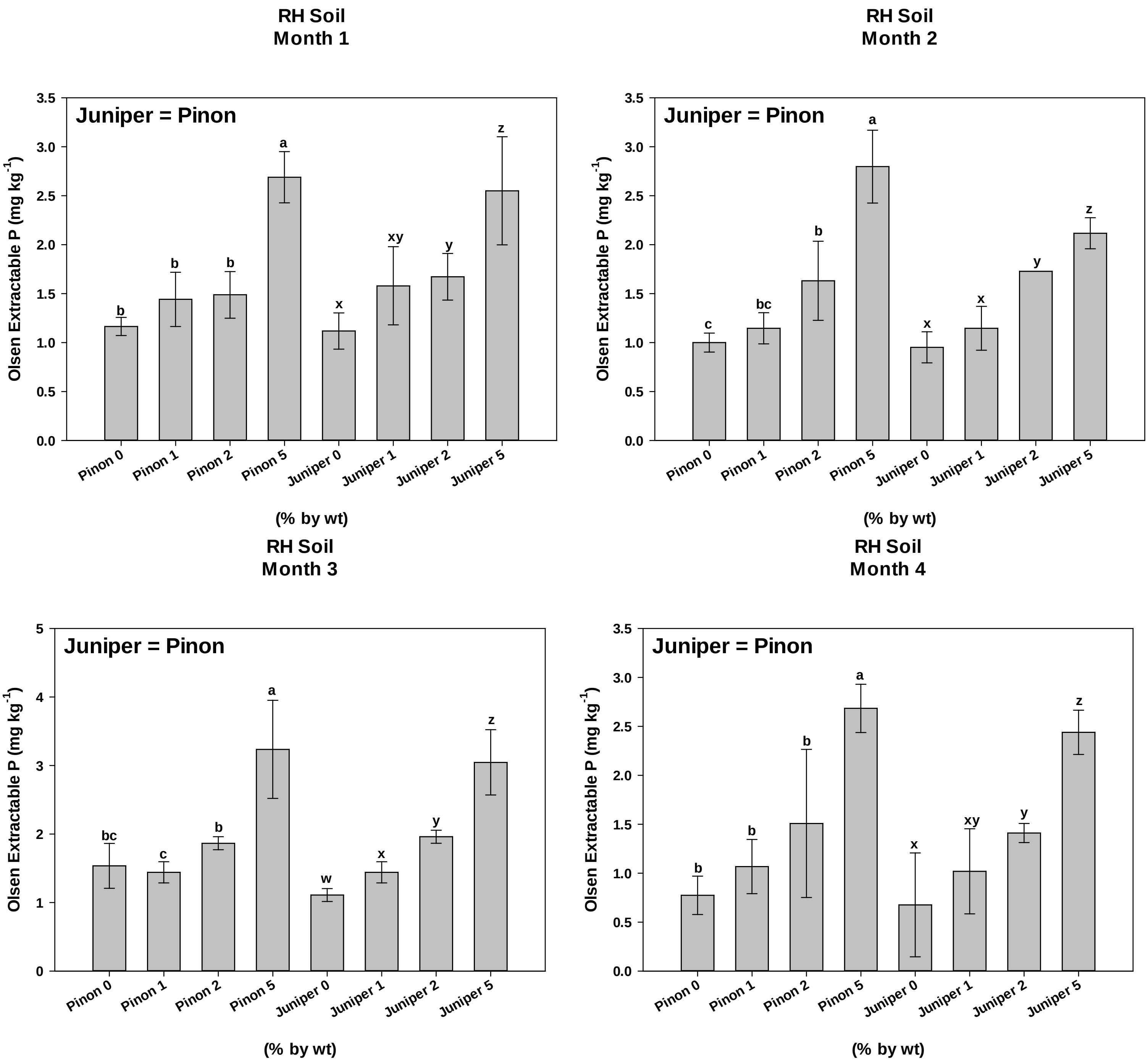


Figure 50. DTPA-Extractable (i.e. Plant-Available) Iron (Fe)

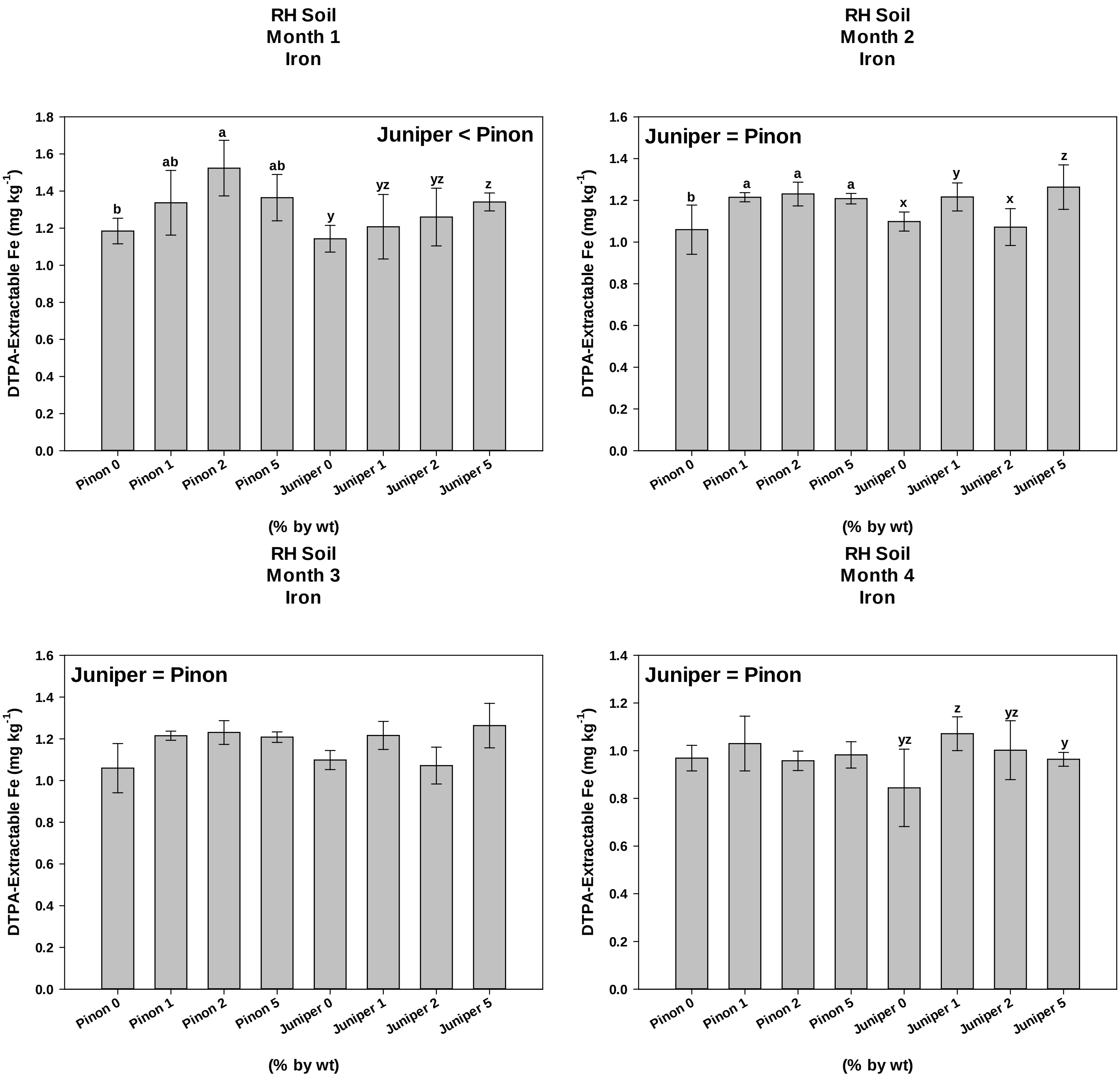


Figure 51. DTPA-Extractable (i.e. Plant-Available) Zinc (Zn)

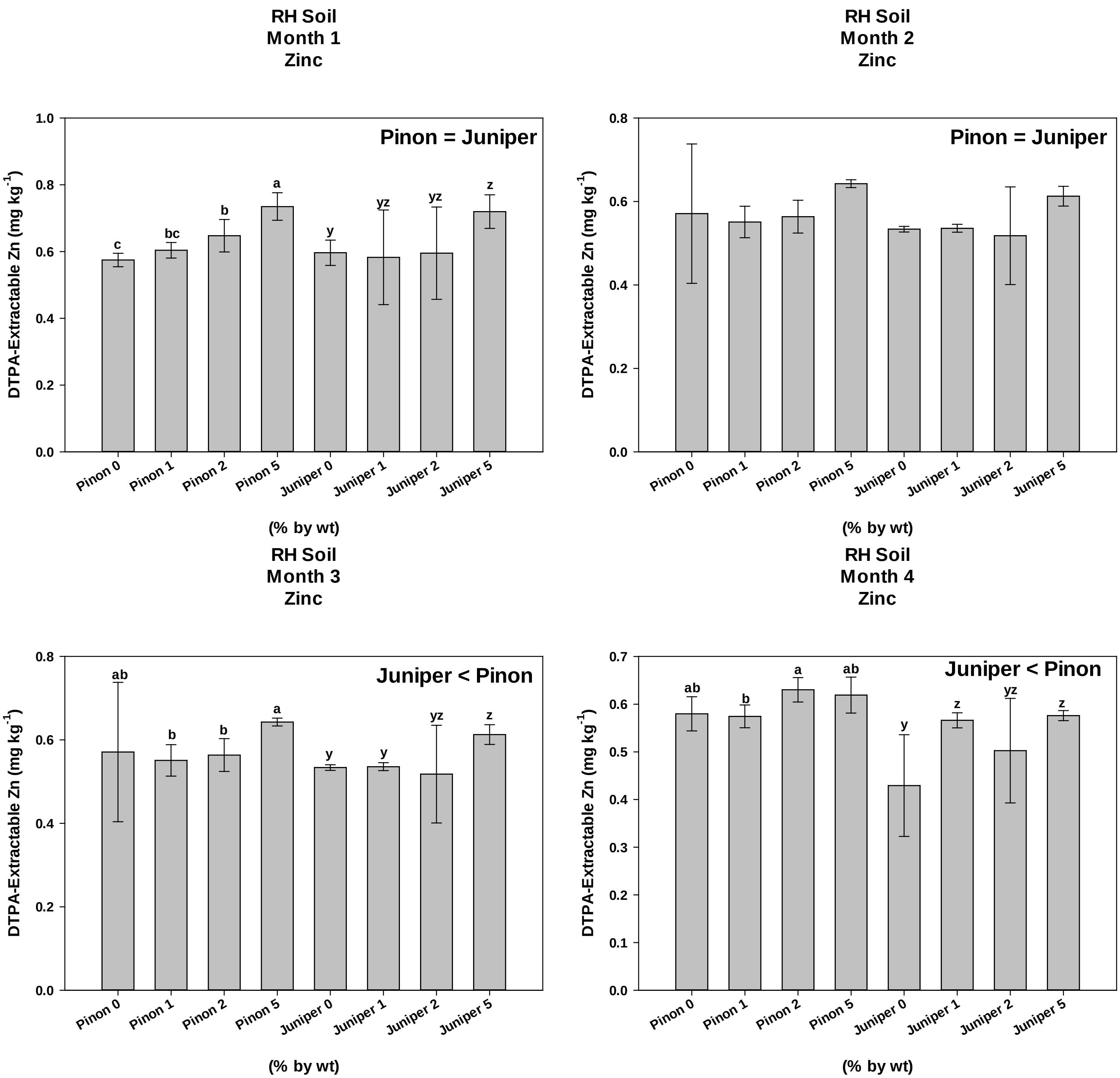


Figure 52. DTPA-Extractable (i.e. Plant-Available) Manganese (Mn)

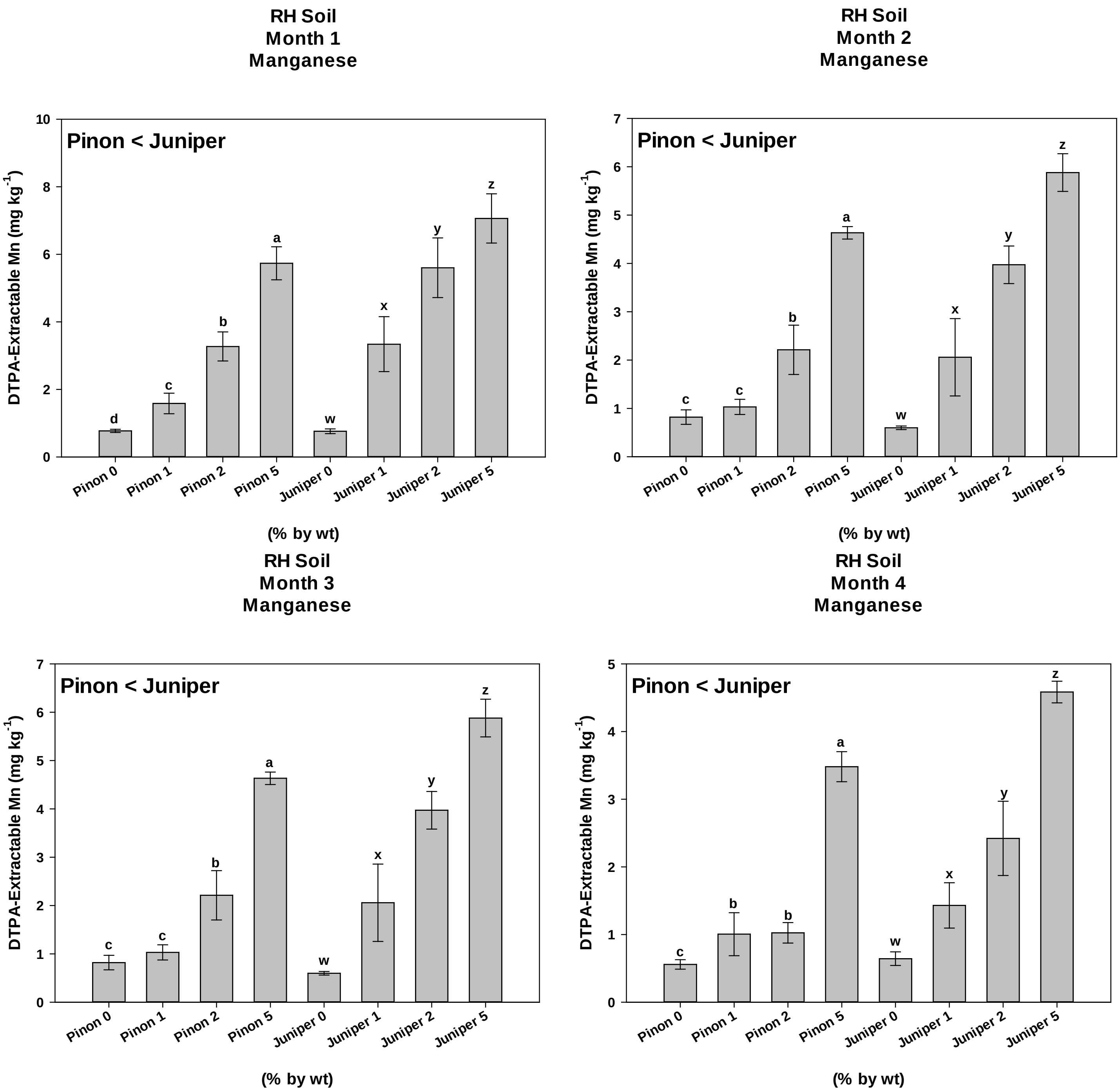


Figure 53. DTPA-Extractable (i.e. Plant-Available) Copper (Cu)

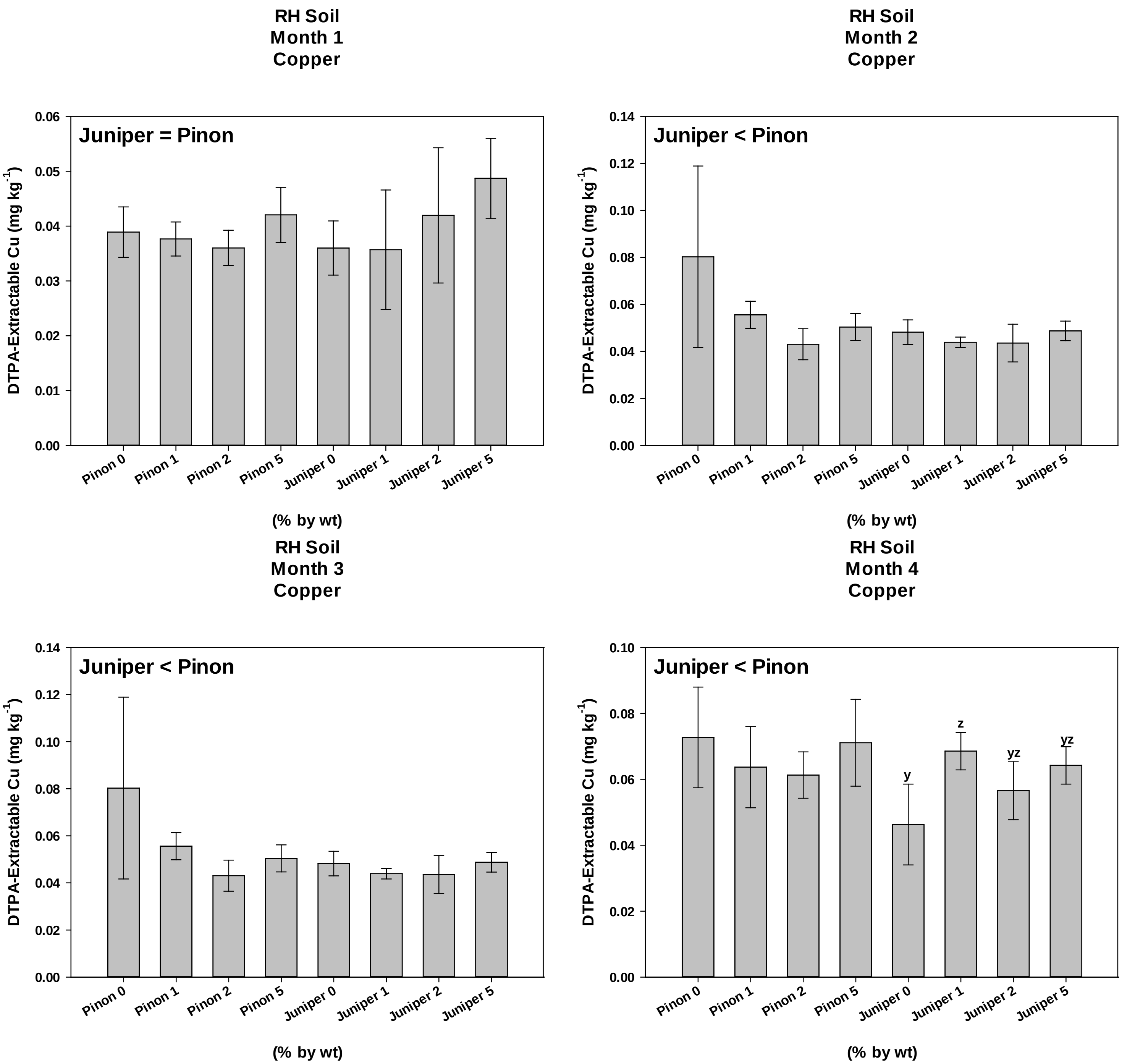


Figure 54. DTPA-Extractable (i.e. Plant-Available) Nickel (Ni)

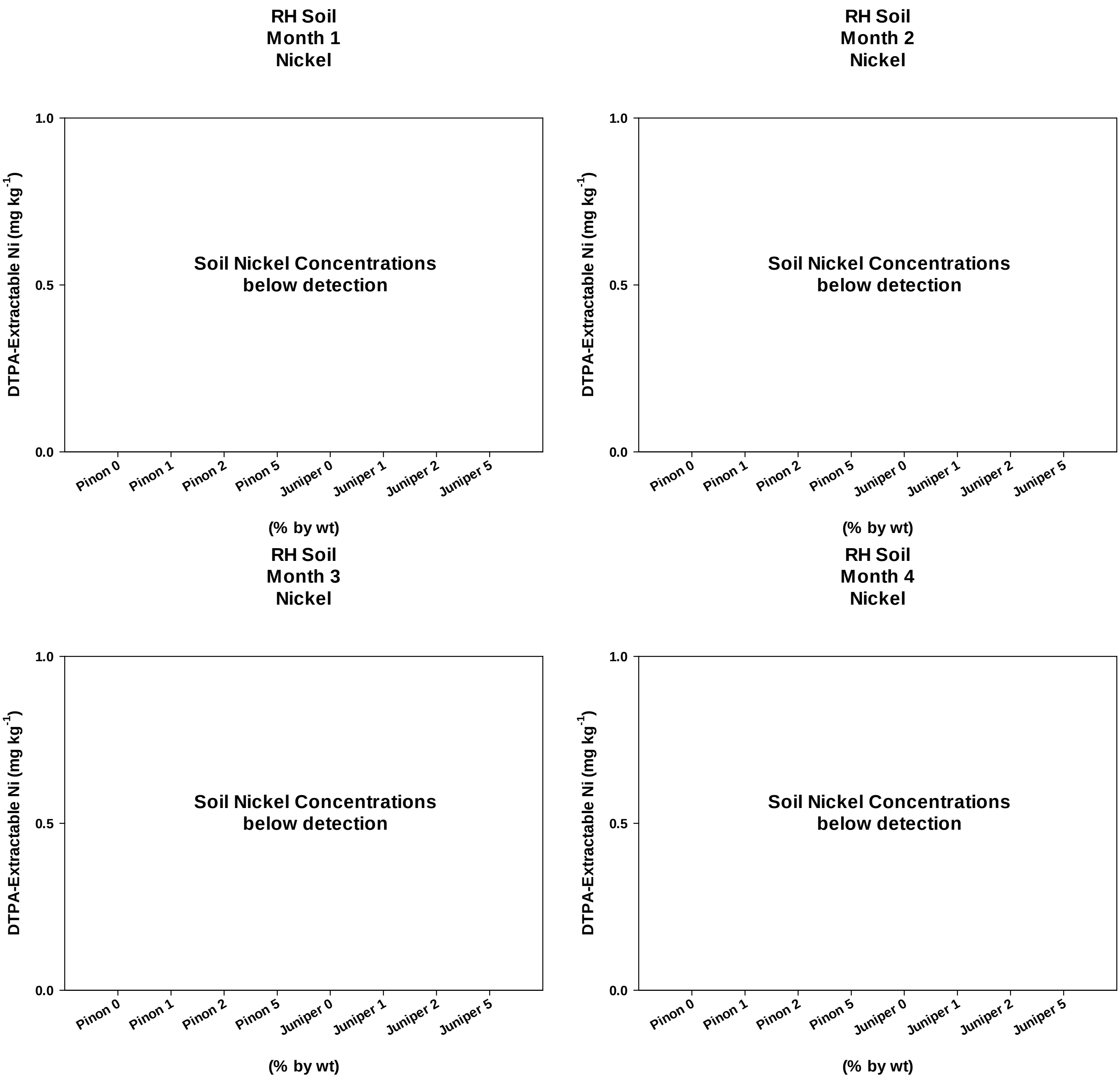


Figure 55. Soil Moisture

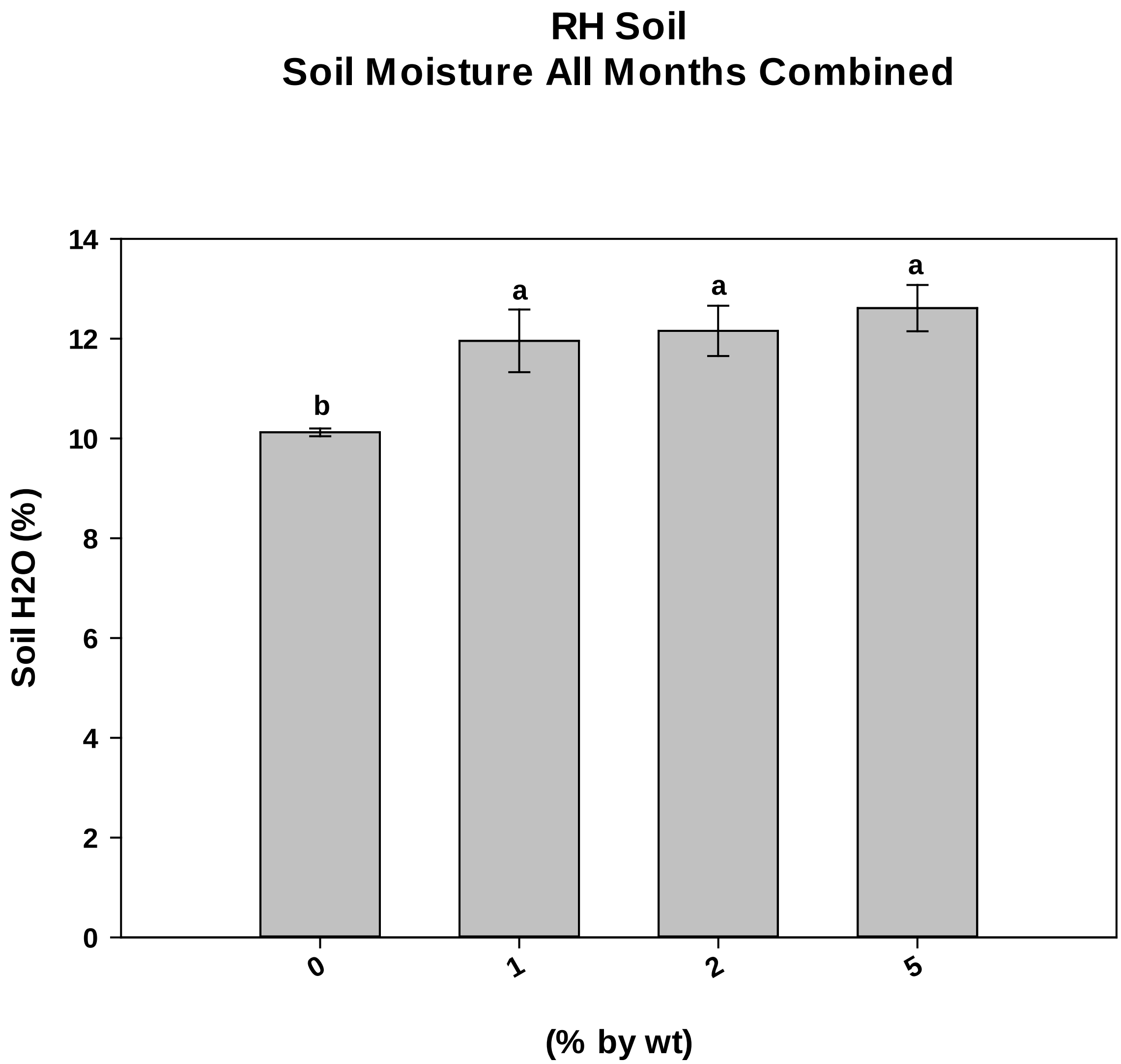


Figure 56. Alfalfa Germination

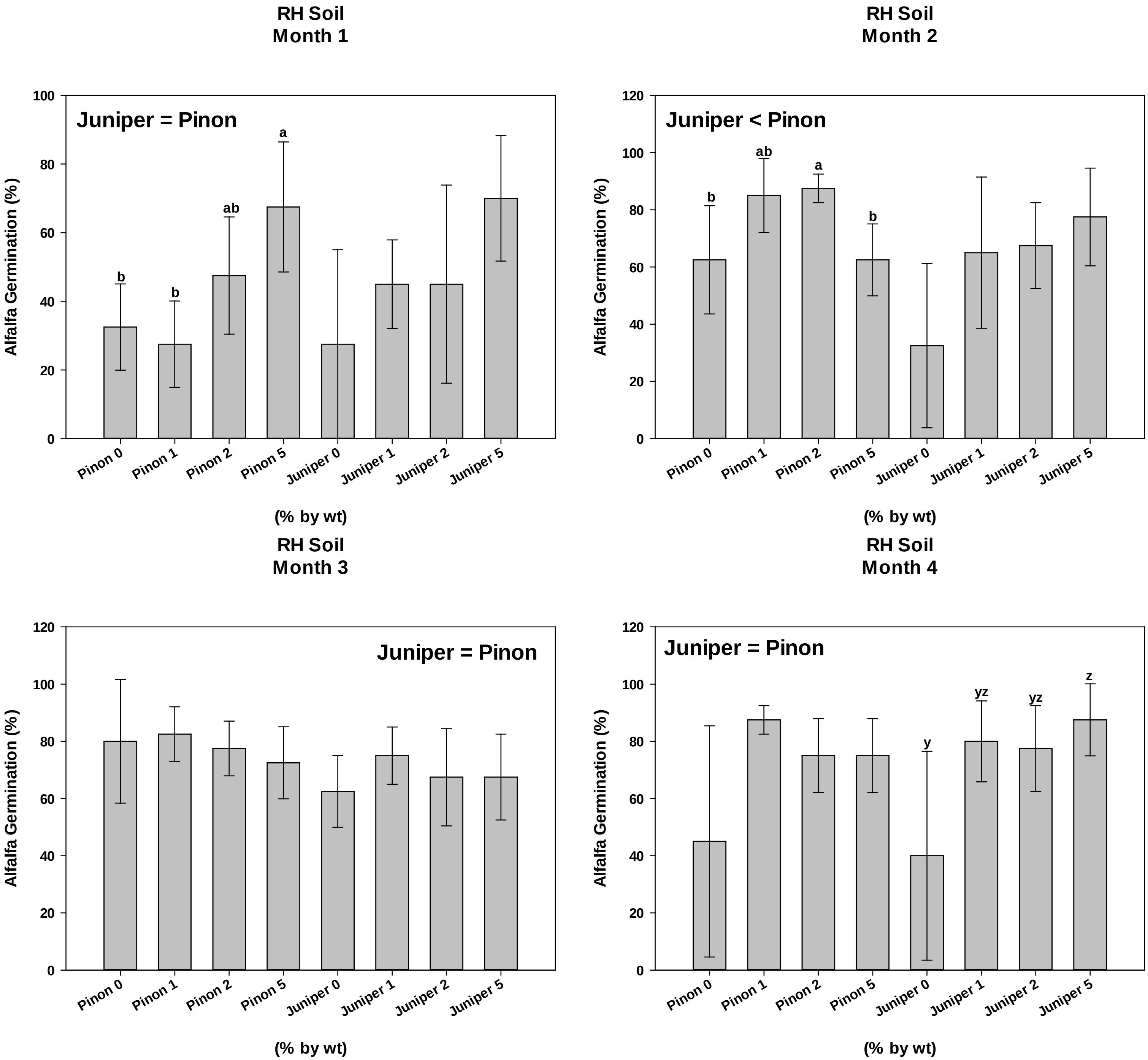


Figure 57. Alfalfa Germination All Months