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Ecosystem Health in Mineralized Terrane—Data from Podiform Chromite (Chinese Camp Mining District, California), Quartz Alunite (Castle Peak and Masonic Mining Districts, Nevada/California), and Mo/Cu Porphyry (Battle Mountain Mining District, Nevada) Deposits

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Marcia K. McNutt, Director

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
Area		
square meter (m^2)	10.76	square foot (ft^2)
Volume		
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, "North American Vertical Datum of 1988 (NAVD 88)"

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, "North American Datum of 1983 (NAD 83)"

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in decisiemens per meter at 25 degrees Celsius (dS/m at 25°C).

Ecosystem Health in Mineralized Terrane—Data from Podiform Chromite (Chinese Camp Mining District, California), Quartz Alunite (Castle Peak and Masonic Mining Districts, Nevada/California), and Mo/Cu Porphyry (Battle Mountain Mining District, Nevada) Deposits

By Steve W. Blecker[1], Lisa L. Stillings[1], Michael C. Amacher[2], James A. Ippolito[3], and Nicole M. DeCrappeo[4]

Introduction

The myriad definitions of soil/ecosystem quality or health are often driven by ecosystem and management concerns, and they typically focus on the ability of the soil to provide functions relating to biological productivity and/or environmental quality (Doran and Parkin, 1994; Karlen and others, 1997). A variety of attempts have been made to create indices that quantify the complexities of soil quality and provide a means of evaluating the impact of various natural and anthropogenic disturbances. Though not without their limitations (Sojka and Upchurch, 1999), indices can improve our understanding of the controls behind ecosystem processes and allow for the distillation of information to help link scientific and management communities. In terrestrial systems, indices were initially developed and modified for agroecosystems (Doran and Parkin, 1994); however, the number of studies implementing such indices in nonagricultural systems is growing (Bastida and others, 2008). Soil quality indices (SQIs) are typically composed of biological (and sometimes physical and chemical) parameters that attempt to reduce the complexity of a system into a metric of a soil's ability to carry out one or more functions (Papendick and Parr, 1992; Halvorson and others, 1996).

The indicators utilized in SQIs can be as varied as the studies themselves, reflecting the complexity of the soil and ecosystems in which they function. Regardless, effective soil quality indicators should correlate well with soil or ecosystem processes, integrate those properties and processes, and be relevant to management practices (Doran and Parkin, 1996; Dalal, 1998; Nortcliff, 2002). Commonly applied biological indicators include measures associated with soil microbial activity or function (for example, carbon and nitrogen mineralization, respiration, microbial biomass, enzyme activity; Winding and others, 2005). Cost, accessibility, ease of interpretation, and presence of existing data often dictate indicator selection given the number of available measures. We employed a large number of soil biological, chemical, and physical measures, along with measures of vegetation cover, density, and productivity, in order to test the utility and sensitivity of these measures within various mineralized terranes. We were also interested in examining these relations in the context of determining

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appropriate reference conditions with which to compare reclamation efforts.

The purpose of this report is to present the data used to develop indices of soil and ecosystem quality associated with mineralized terranes (areas enriched in metal-bearing minerals), specifically podiform chromite, quartz alunite, and Mo/Cu porphyry systems. Within each of these mineralized terranes, a nearby unmineralized counterpart was chosen for comparison. The data consist of soil biological, chemical, and physical parameters, along with vegetation measurements for each of the sites described below. Synthesis of these data and index development will be the subject of future publications.

Study Areas

Red Hills, Bureau of Land Management Area of Critical Concern (near Sonora, California)

The Chinese Camp mining district in the western Sierra Nevada of Tuolumne County, California, contains Upper Jurassic volcanic and sedimentary rocks that were intruded by ultramafic dunite, which has been partly or entirely serpentinized (Logan, 1949) and contains podiform chromite deposits (deposit model 8a in Cox and Singer, 1992). The podiform chromite formed within the dunite host as the dunite magma solidified and differentiated, and contemporaneous to subsequent alteration by seawater produced the serpentinite. Deposits of chromite, magnesite, and placer gold have been mined in this district sporadically through the 1940s (Logan, 1949). The Red Hills Area of Critical Environmental Concern (as designated by the BLM) is present within this mining district. This area contains a unique ecosystem of endemic vegetation and serpentine soils that are characterized by low Ca/Mg ratios and high Ni and Cr contents (Kruckeberg, 1984; Proctor, 1999). The vegetation and the red soil coloration made it easy to distinguish between the mineralized (serpentinized) and unmineralized areas (fig.1). In this study, the unmineralized site consisted of an open woodland/annual grass community derived from andesite bedrock, which is in stark contrast to the adjacent buckbrush chaparral that grows on the serpentinite-derived soils (table 1.) Unlike the other deposit types that were studied, the dunite, due to its origin, does not have an unmineralized phase. The andesite rocks that surround the dunite have a somewhat different origin and chemical composition as the dunite. As a result, the andesite is not a truly unmineralized analog of the dunite, but it is spatially related and is the only unmineralized and unaltered igneous lithology in the district. Mine dumps from defunct chromite and placer gold mines were also sampled.

Figure 1. Red Hills (podiform chromite) study area location map, Toulumne County, California. The red soil coloration visible in the imagery is due to limited vegetative cover and high soil-iron content.

Castle Peak (near Reno, Nevada) and Masonic Mining district (near Bridgeport, California)

The Castle Peak mining district in Washoe and Storey Counties, Nevada (Tingley, 1998) contains large areas of Miocene volcanic rocks that were altered to quartz, alunite, and clays during hydrothermal alteration that occurred at 9 to 16 Ma (deposit model 25e in Cox and Singer, 1992). Precious-metal and mercury deposits formed and occur in or adjacent to areas of alteration (Vikre, 1998). Sites of hydrothermal alteration are characterized by open woodland as compared to unaltered sites characterized by sagebrush shrubland (table 1). Samples were collected in areas with visually obvious quartz-alunite alteration minerals, nonaltered andesites and dacites, and waste-rock and tailings piles at abandoned Hg and ferricrete mines (fig. 2).

In order to assess the similarity/differences in observations between sites with similar deposit types and climate, we also collected samples at the Masonic mining district in Mineral County, Nevada, and in Mono County, California. This mining district also contains large areas of Miocene andesites and dacites that were subject to periods of hydrothermal quartz-alunite alteration between 7.2 and 8.4 Ma (Silberman, and others, 1972; Chesterman and others, 1986; deposit model 25e in Cox and Singer, 1992). As in the Castle Peak mining district, the hydrothermally altered areas are characterized by open woodland, with sagebrush shrubland communities in adjacent areas of unaltered andesite and dacite. Samples were collected in ecosystems above altered and nonaltered rocks, as well as in nearby waste-rock and tailings piles associated with precious-metal mining (fig. 2).

Figure 2. Study area location maps. A, Castle Peak, Washoe and Storey Counties, Nevada; B, Mineral County, Nevada, and Mono County California. The quartz-alunite alteration, which is visible through the limited vegetation, appears as the lighter yellow-colored areas resulting from hydrothermal leaching.

Buckingham (near Battle Mountain, Nevada)

The Buckingham deposit is a low-fluorine, calc-alkaline stockwork molybdenum-copper system (deposit model 21b in Cox and Singer, 1992) in the Battle Mountain mining district in north-central Nevada. Mineralization occurred during seven major phases of molybdenum-bearing magmatism. The resulting intrusive center consists of two stocks and several outlying intrusive masses, along with regions of Cu-, Ag-, and W-bearing veins and mineral deposits (Loucks and Johnson, 1992). The surrounding nonmineralized geology is dominated by interbedded arenites, shale and greenstone of the Paleozoic Harmony Formation (Theodore and others, 1992). As the sagebrush communities on both the mineralized and nonmineralized rocks (table 1) do not differ visually, we utilized extensive mapping from Theodore and others (1992) to identify appropriate sampling areas and also sampled from nearby waste-rock and tailings piles (fig. 3).

Figure 3. Buckingham (Mo/Cu porphyry) study area location map, north-central, Nevada. The mineralized area is depicted by the red oval within the overall study area.

Table 1. Site locations and general characteristics for selected mining districts in Nevada and California.

[MAP, Mean annual precipitation; MAT, Mean annual air temperature; mm, millimeter; °C, degrees Celsius]

Site (latitude, longitude) Elevation	Mineralization type / Unmineralized country rock	Soil classification[1]	Vegetation community	Dominant species	MAP in mm	MAT in °C
Red Hills (RH) – Sonora, CA (37.85° N, 120.4°W) 530 m	**Podiform chromite**	Lithic Xerochrept	Buckbrush chaparral	*Ceanothus cuneatus, Pinus sabiniana, Eriogonum tripodum, Melica californica, Elymus multisetus*	820	14.9
	Andesite	Lithic Haploxeralf	Blue oak woodland	*Quercus douglasii, Pinus sabiniana, Bromus sp., Avena fatua, Amsinckia menziesii, Erodium sp.*		
Castle Peak (CP) – Reno, NV (39.48° N, 119.7° W) 1,350 m	**Epithermal quartz-alunite Au**	Xeric Torriorthent	Pine woodland	*Pinus jeffreyii, Pinus monophylla, Pinus ponderosa, Eriogonum robustum*	185	10.4
	Andesite, Dacite	Xerollic Haplargid	Sagebrush/ pinion-juniper	*Artemisia tridentata, Achnatherum thurberianum, Poa secunda, Elymus elymoides, Pinus monophylla, Juniperous osteosperma*		
Masonic (MA) - Bridgeport, CA (38.40° N, 119.1° W) 2,125 m	**Epithermal quartz-alunite Au**	Xeric Torriorthent	Pine woodland	*Pinus jeffreyii, Pinus monophylla, Pinus ponderosa, Eriogonum robustum*	210	5.0
	Andesite, Dacite	Lithic Xerollic Haplargid	Sagebrush/ pinion-juniper	*Artemisia arbuscula, Achnatherum thurberianum, Pinus monophylla, Juniperous osteosperma*		
Buckingham (BK) – Battle Mt. NV (40.57° N, 117.1° W) 1,380 m	**Porphyry Cu-Mo, low F**	Xerollic Haplargid	Sagebrush shrubland	*Artemisia nova, Artemisia tridentata, Pseudoroegneria spicata, Achnatherum thurberianum, Achnatherum hymenoides*	210	9.5
	Arenites, Shale, Greenstone	Xerollic Haplargid	Sagebrush shrubland	*Artemisia nova, Artemisia tridentata, Pseudoroegneria spicata, Achnatherum thurberianum, Achnatherum hymenoides*		

[1]Soil Survey Staff (2006)

Sampling and Analyses

Study Design/Field Sampling

The study design is represented schematically in figure 4 and described below. Within each of the four study areas (three deposit types plus one duplicate), three random locations were selected within each of the three study-design levels [undisturbed/mineralized, undisturbed/nonmineralized, disturbed/mineralized (waste-rock and tailings piles)]. Each location within a given level was situated on a similar aspect (150° to 210°), elevation, and slope within the same subwatershed. At each of the locations, three 30-m transects (spaced 120-m apart) were established. One soil sample (collected at 0-15 cm depth, after gently removing any O horizon or litter material) was taken at a random location along each transect for a total of 9 samples per 'treatment' at each of the four sites. In order to minimize small-scale spatial variability and effect a more equivalent comparison among the treatments, samples were collected outside of the canopy of any trees or shrubs. For the Buckingham site only, an additional study-design level was added to examine soil variability under and between the shrub canopy within the undisturbed/mineralized and undisturbed/nonmineralized design levels. The "under and between canopy" samples were collected at each of the three transects using the same sampling procedure.

The same 30-m transects were used for vegetation measurements. A line-point intercept with 0.6-m intervals was used to determine percentage of canopy cover and percentage of bare ground (n=150 per level). A 4-m belt transect was used to determine densities of trees (categorized by species) and shrubs [categorized as sagebrush (*Artemisia sp*.), rabbitbrush (*Crysothamnus sp.*), or other]. Above-ground net primary productivity (ANPP) was estimated by harvesting all living plant material within 0.5 by 0.5 m quadrats at three random locations along each transect (n=27 per level). Sites were sampled one time in the spring (2008) near peak spring soil moisture/microbial activity (Red Hills, early April; Castle Peak and Buckingham, early and late May respectively; Masonic, mid-June).
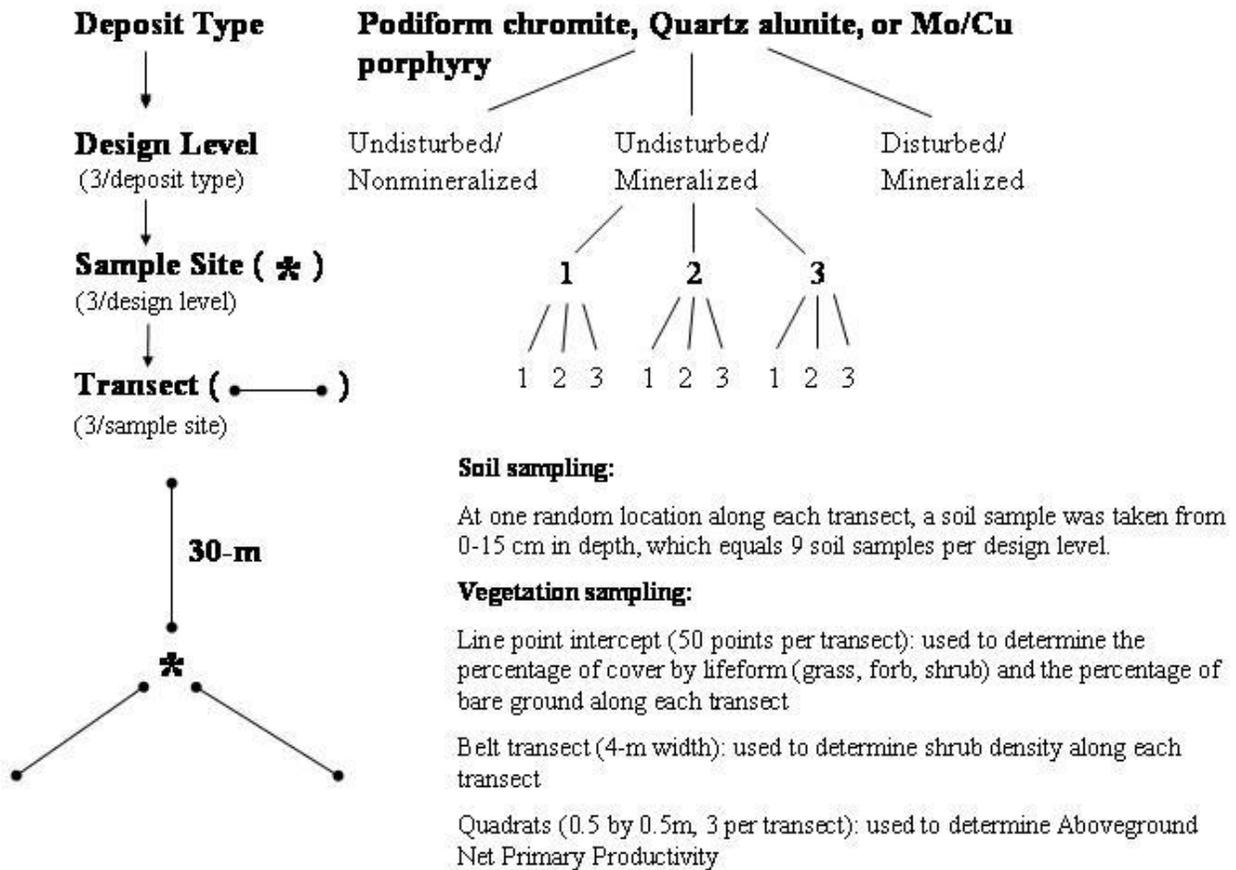
Deposit Type → **Podiform chromite, Quartz alunite, or Mo/Cu porphyry**

Design Level
(3/deposit type)

| Undisturbed/ Nonmineralized | Undisturbed/ Mineralized | Disturbed/ Mineralized |

Sample Site (✳)
(3/design level)

1   2   3

1 2 3   1 2 3   1 2 3

Transect (•——•)
(3/sample site)

30-m

✳

Soil sampling:

At one random location along each transect, a soil sample was taken from 0-15 cm in depth, which equals 9 soil samples per design level.

Vegetation sampling:

Line point intercept (50 points per transect): used to determine the percentage of cover by lifeform (grass, forb, shrub) and the percentage of bare ground along each transect

Belt transect (4-m width): used to determine shrub density along each transect

Quadrats (0.5 by 0.5m, 3 per transect): used to determine Aboveground Net Primary Productivity

Figure 4. Study-design schematic.

Analytical Methods

Analytical methods are outlined in tables 2 and 3. Additional detail for the soil microbial methods follows. All enzyme assays in this study are measurements of potential activity using short-term incubations at controlled temperature and pH, and were analyzed spectrophotometrically against a standard curve of known substrate concentrations. C and N soil-mineralization potential was performed in closed vessels for 10-d at 25°C as outlined in table 2. Community-level physiological profiling (CLPP) provides an estimate of bacterial community functional diversity using Biolog EcoPlates (Biolog Inc., Hayward, California, USA). Data presented are all from day 4 (96-hr) spectrophotometric readings to allow for maximum well response variance without exceeding the linear absorbance range (Garland, 1996). All Ecoplate data were corrected using the blank cell, and then separately divided by the respective plate's Average well color development (AWCD), in order to normalize against potential differences in bacterial inoculum density. To provide an estimate of microbial biomass and community structure, we used phospholipid fatty-acid (PLFA) analysis. Certain lipid "signatures" within the cell membranes of living microbes can be used to identify a portion of the microbial community: gram + and gram - bacteria, fungi, actinomycetes, and protozoa (Sinsabaugh et al. 1999). Extracted lipids from

freeze-dried soil were resuspended in a hexane and MTBE solution and analyzed on a gas chromatograph with a flame ionization detector (GC/FID). Microbial biomass C was determined as the sum of the phospholipid fatty acids extracted from all microbes.

Table 2. Measures of ecosystem function.

Parameter	Variable	Methods
Vegetation	Community composition	Line point intercept, belt transect (Pellant and others, 2005)
	Aboveground net primary productivity (ANPP)	Harvest by quadrat (Pellant and others, 2005)
Soil – biotic (microbial indicators)	Enzyme activity (lipase, protease, esterase): General[1]	Fluorescein diacetate (FDA) hydrolysis to fluorescein (Green and others, 2006)
	Enzyme activity (arylsulfatase): Sulfur-cycle[2]	Potassium p-nitrophenyl sulfate hydrolysis to p-nitrophenol (Dick and others, 1996)
	Enzyme activity (acid and alkaline phosphatase; pH 6.5 and 11 respectively): Phosphorous-cycle[2]	Disodium p-nitrophenyl phosphate hydrolysis to p-nitrophenol (Dick and others, 1996)
	C, N mineralization potential[1,3]	10-d static incubation with 1M NaOH trap; CO_2 determined by titration with 1M HCl; inorganic N (NO_3 and NH_4) determined by 2M KCl extraction and flow injection analysis (Robertson and others, 1999)
	Soil microbial community structure and biomass C[4]	Phospholipid fatty-acid analysis (PLFA) (Hill and others 2000)
	Soil microbial functional diversity[1]	Community-level physiological profiling (CLPP) using Biolog EcoPlates™ (Sinsabaugh and others, 1999)

[1]Samples were stored at 4°C, passed through a 2-mm sieve, and analyzed within 2 weeks of the collection date.
[2]Samples were air-dried, then passed through a 2-mm sieve.
[3]Samples were brought to 60 percent water-filled pore space just prior to analysis.
[4]Samples were stored at 4°C; immediately placed in -20°C storage upon return from the field, freeze-dried within 2 weeks, and analyzed within 3 months.

Table 3. Metals concentrations and relevant chemical and physical parameters.

Parameter		Variable	Method
Vegetation		Total C/N[1]	Dry combustion; Flash EA1112 NC analyzer
		Metal and nutrient content[1]	Dry ash with acid digest followed by inductive coupled plasma mass spectrometry (ICP-MS) analysis (Taggart and others, 2002)
Soil - abiotic	physical properties	Particle size distribution[3]	Hydrometer (Elliot and others, 1999)
		Bulk density	Soil core (Elliot and others, 1999)
		Volumetric moisture content	Gravimetric (oven-dry for 48 hr at 110°C) with bulk density correction
	chemical properties	pH[2]	1:2 (soil:de-ionized water), (Thomas, 1996)
		Electrical conductivity (EC)[3]	Saturated paste extract (Rhoades, 1996)
		Total C/N/S[3]	Dry combustion; LECO RC-412 C and LECO TruSpec C/N/S analyzers
		Metal and nutrient content[3]	Water-soluble P by ICP-AES on a saturated paste extract, Diethylene triamine pentaacetic acid (DTPA) extractable metals by ICP-MS[4] (Amacher, 1996), Total metals by ICP-AES (Taggart and others, 2002)

[1]Plant samples were washed in distilled water, oven-dried at 55°C for 72 hours, and ground to pass a 20-mesh sieve.
[2]Samples were stored at 4°C, and passed through a 2-mm sieve.
[3]Samples were air-dried, and passed through a 2-mm sieve. Selected samples were analyzed for total soil Hg using cold vapor atomic adsorption spectroscopy (Taggart and others, 2002).
[4]DTPA extractable metals are generally associated with the bioavailable metals fraction (Amacher, 1996).

Results

The entire data set is presented in tabular form by study site as Excel worksheets. The quartz-alunite sites (Castle Peak and Masonic) have been combined into one table. Where applicable, censored values (data below the detection limit) were replaced with a value of 1/2 the lower limit of detection (see tabular data for more detail). Selected data from each study site are presented as box plots (see figs. 5-30). The line within a given box represents the median. The lower and upper boundaries of the box represent the 25th and 75th percentiles, respectively. Error bars above and below each box represent the 90th and 10th percentiles, respectively. All values listed as a percentage are by weight.

Acknowledgments

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Appendix

All of the appendix tables can be accessed using the following link:
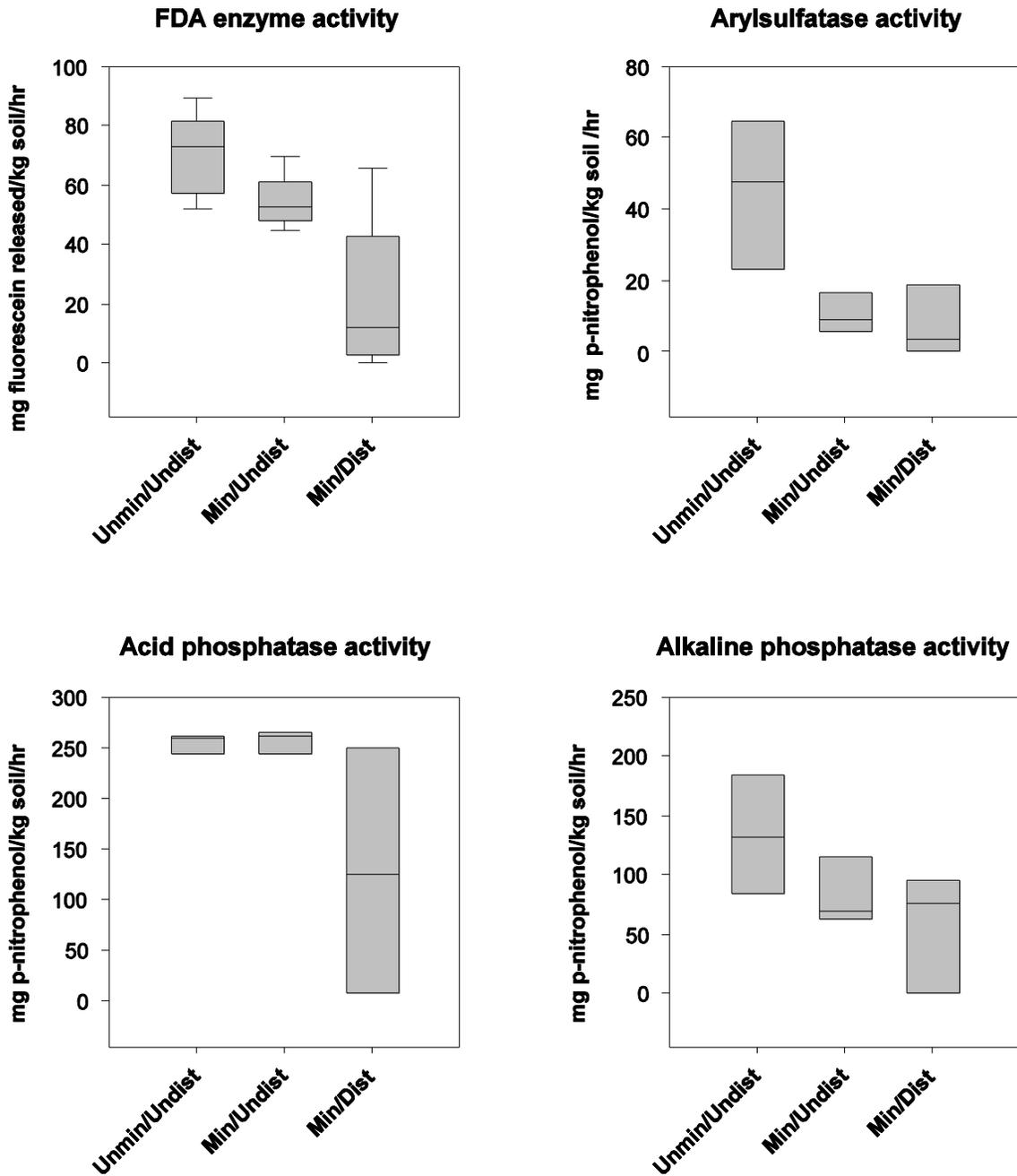*http://pubs.usgs.gov/of/2010/1040/tables/*

Figure 5. Red Hills study area, Tuolumne County, Calif.: Soil microbial data (Enzyme activity) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist = mineralized/disturbed (waste-rock and tailings piles); FDA, Fluorescein diacetate.
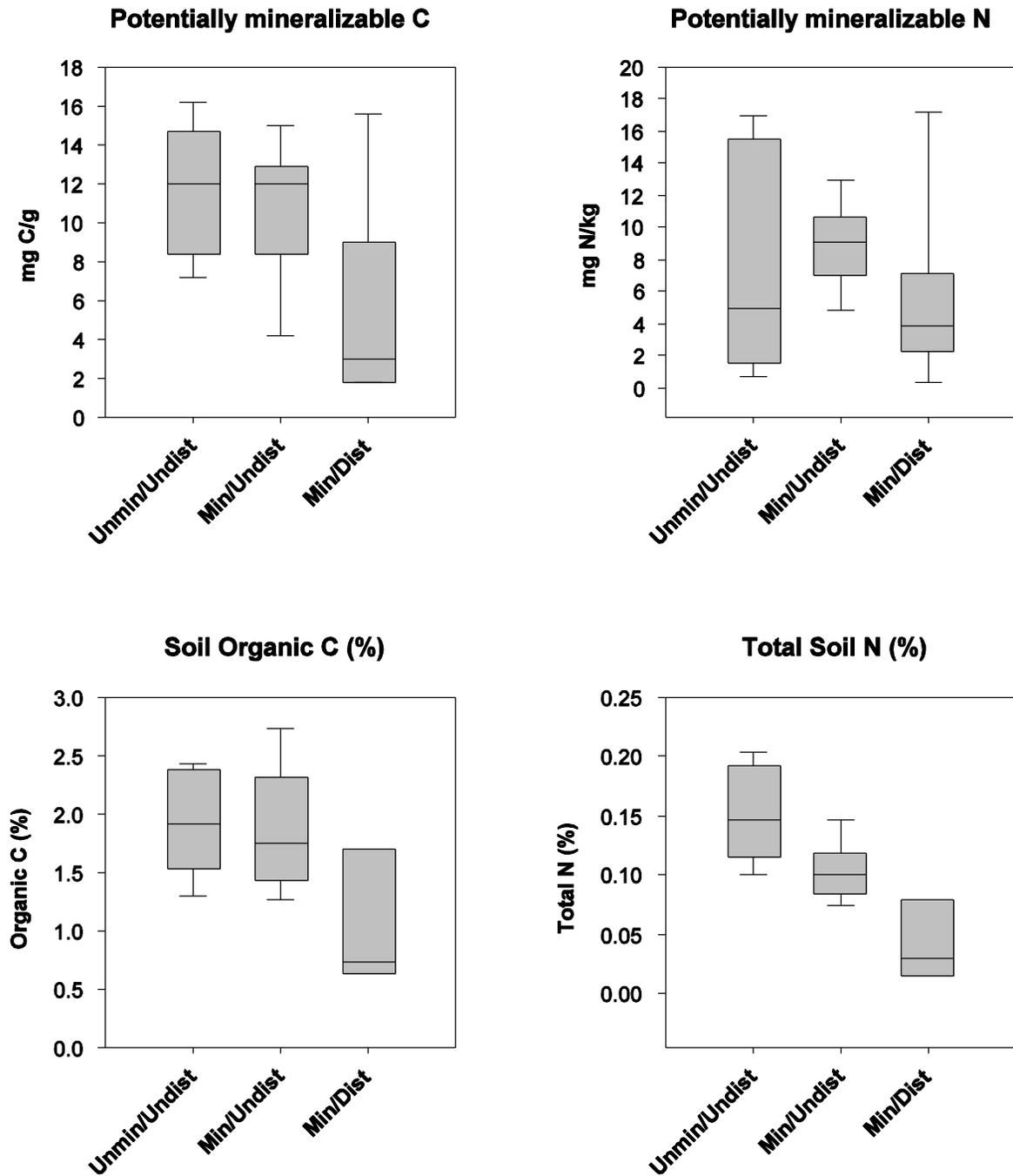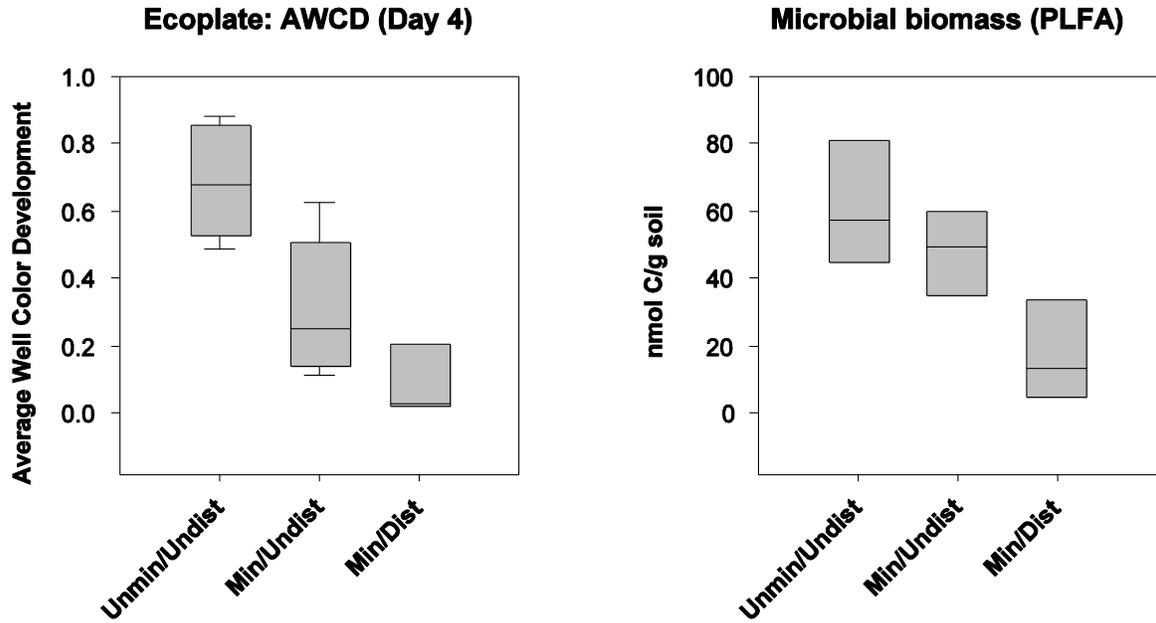
Figure 6. Red Hills study area, Tuolumne County, Calif.: Soil microbial data (Mineralizable C and N, Organic C, and Total N) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist = mineralized/disturbed (waste-rock and tailings piles).

Figure 7. Red Hills study area, Tuolumne County, Calif.: Soil microbial data (Ecoplate AWCD, Microbial biomass (PLFA)) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles), AWCD, Average well color development; PLFA, Phospholipid fatty acids.
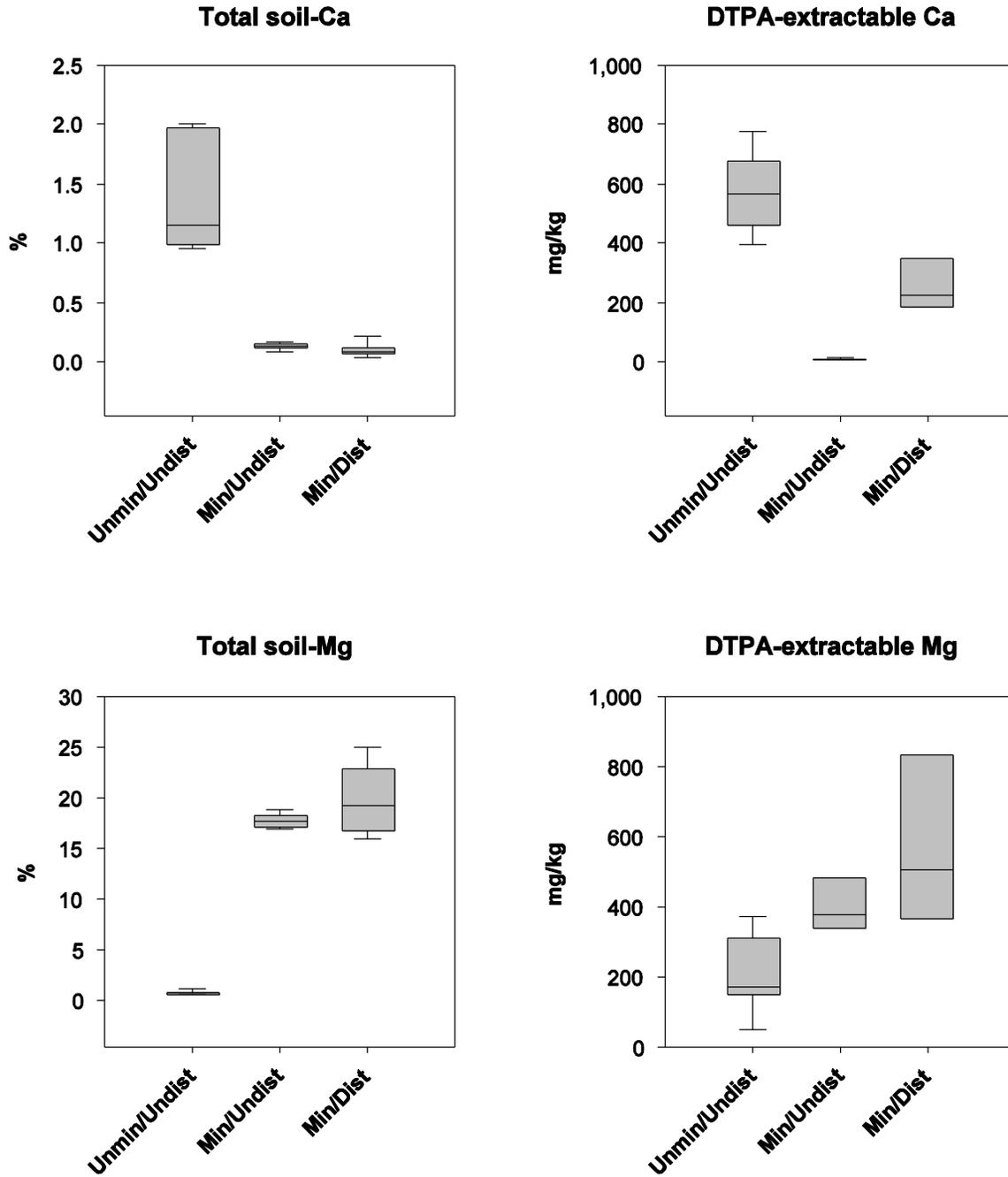
Soil pH

Electrical conductivity (EC)

Water-Filled Pore Space (%)

Bulk Density

Figure 8. Red Hills study area, Tuolumne County, Calif.: Selected soil physical and chemical data (Soil pH, Electrical conductivity, Water-filled pore space (WFPS), and Bulk density) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); dS = decisiemens.
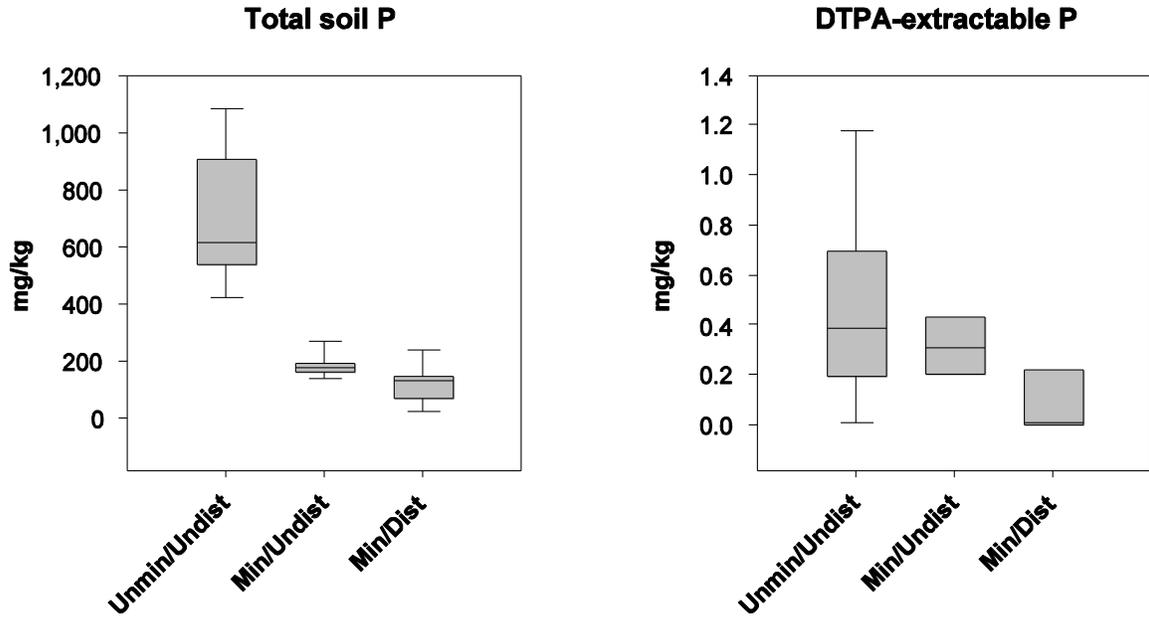
Figure 9. Red Hills study area, Tuolumne County, Calif.: Selected soil macronutrient data (Total and DTPA-extractable Ca and Mg) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles).
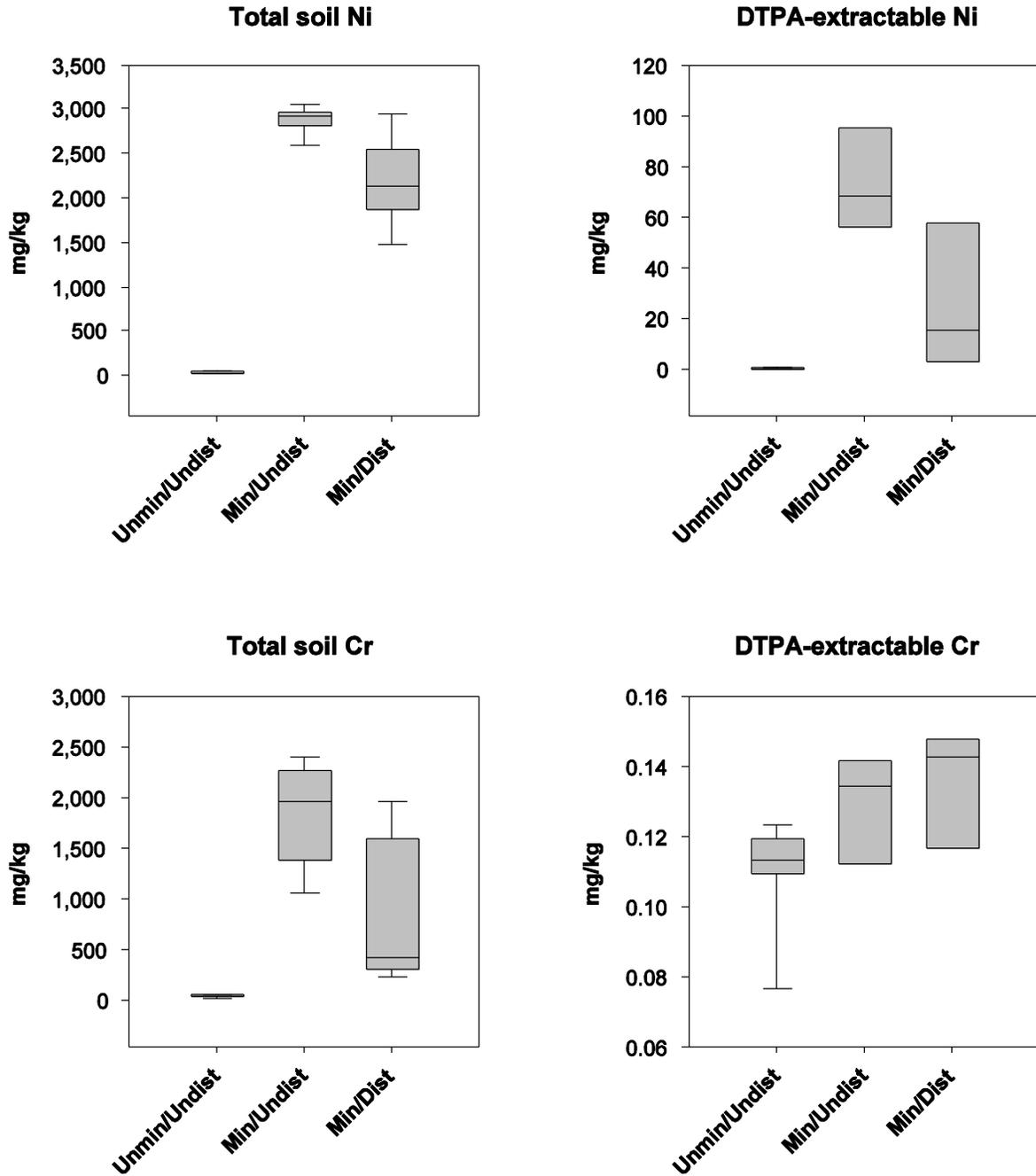
Figure 10. Red Hills study area, Tuolumne County, Calif.: Selected soil macronutrient data (Total and DTPA-extractable P) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles).
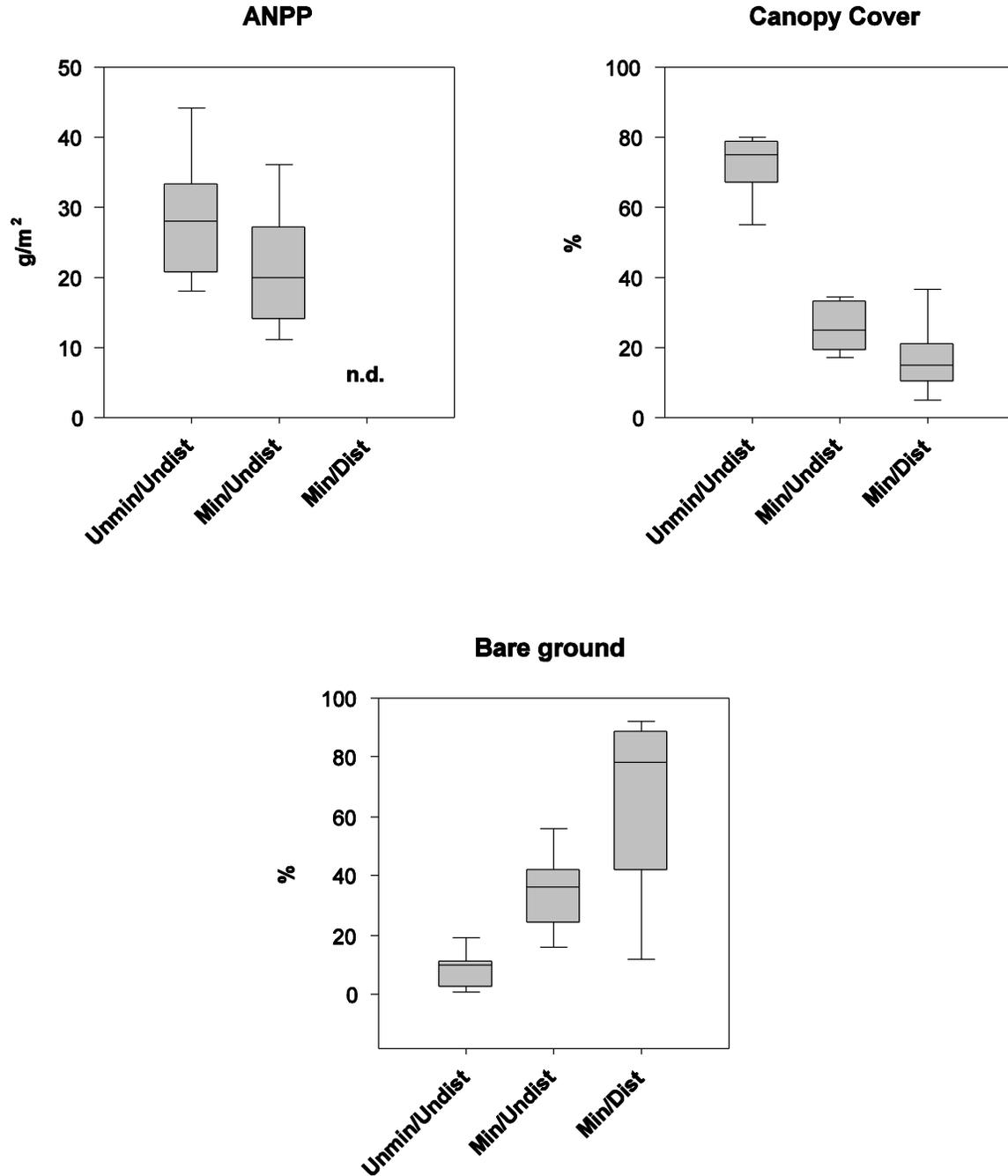
Figure 11. Red Hills study area, Tuolumne County, Calif.: Selected soil trace metals (Total and DTPA-extractable Ni and Cr) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles).

ANPP

Canopy Cover

Bare ground

Figure 12. Red Hills study area, Tuolumne County, Calif.: Selected vegetation data (Aboveground net primary productivity (ANPP), Canopy cover, Bare ground) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (serpentinite soils); Min/Undist, mineralized/undisturbed (andesite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); n.d., not determined.
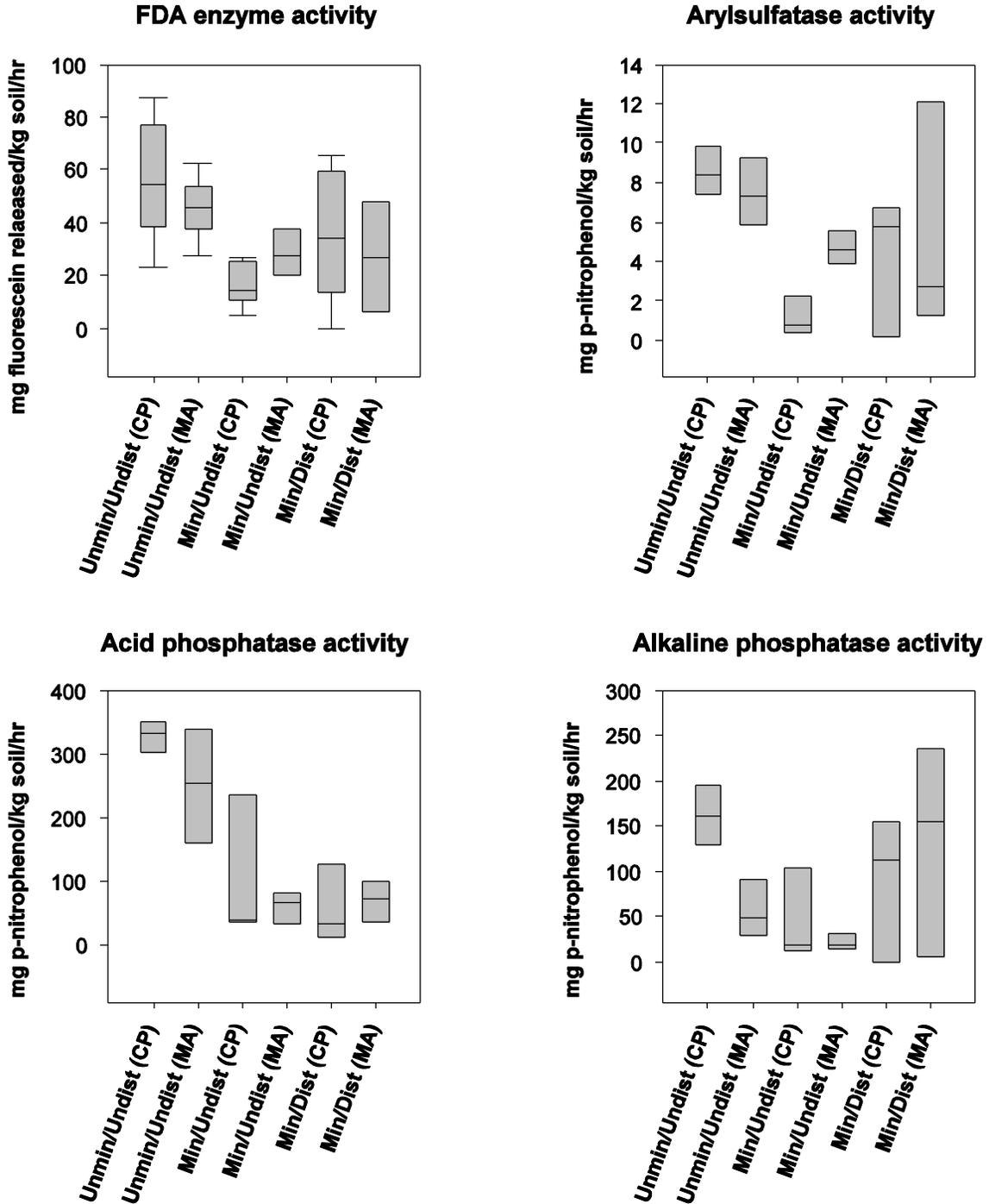
Figure 13. Quartz-alunite study sites: Soil microbial data (Enzyme activity) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles), CP, Castle Peak; MA, Masonic; FDA, Fluorescein diacetate.
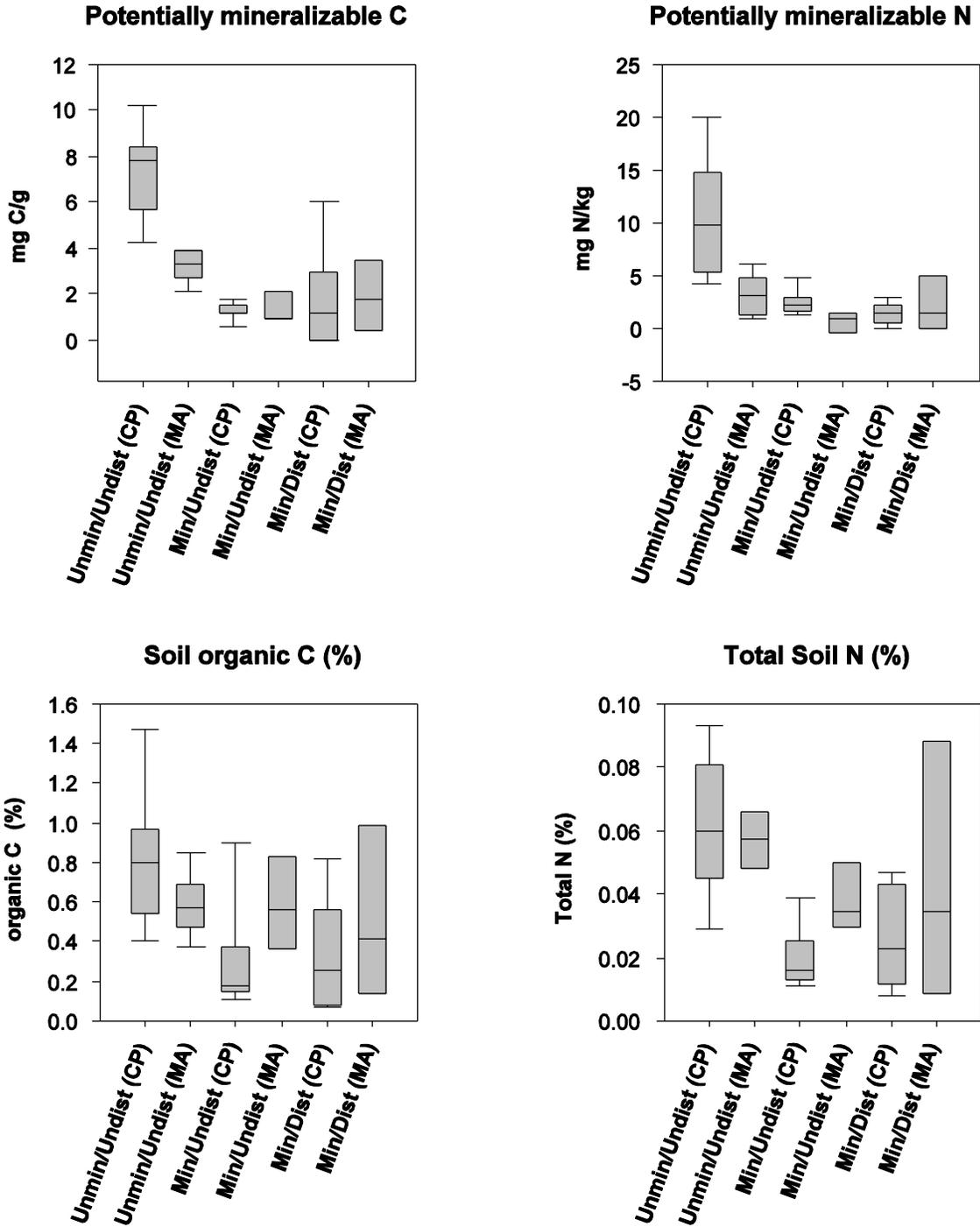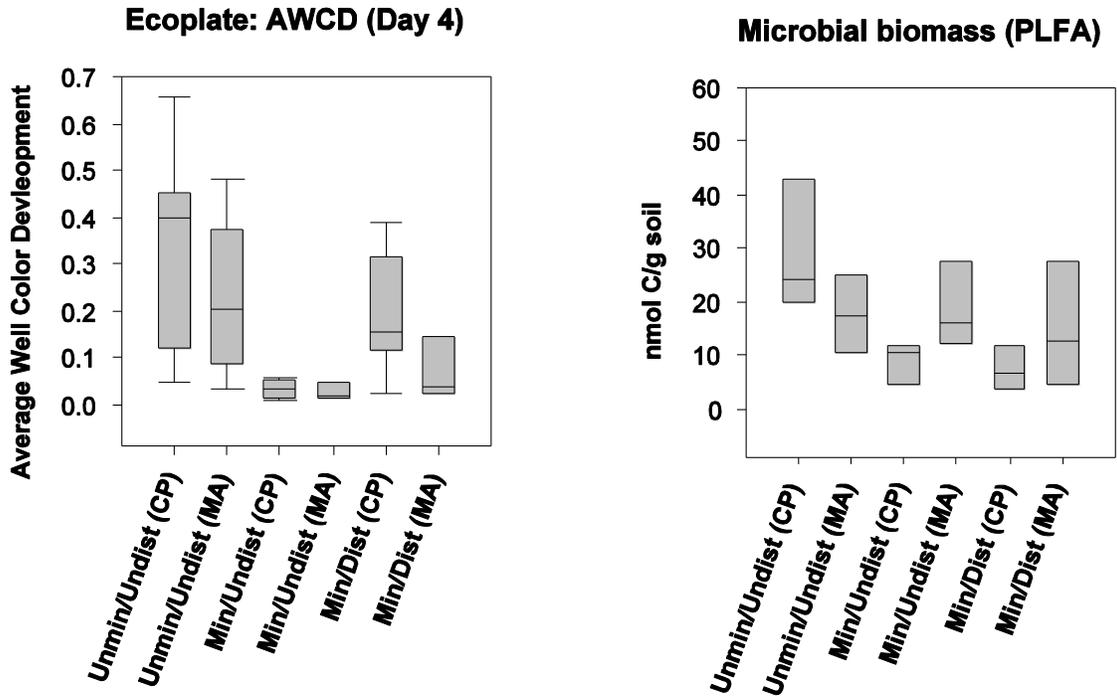
Figure 14. Quartz-alunite study sites: Soil microbial data (Mineralizeable C and N, Organic C, and Total N) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic.

Figure 15. Quartz-alunite study sites: Soil microbial data (Ecoplate AWCD, Microbial biomass (PLFA)) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic; AWCD, average well color development; PLFA, Phospholipid fatty acids.
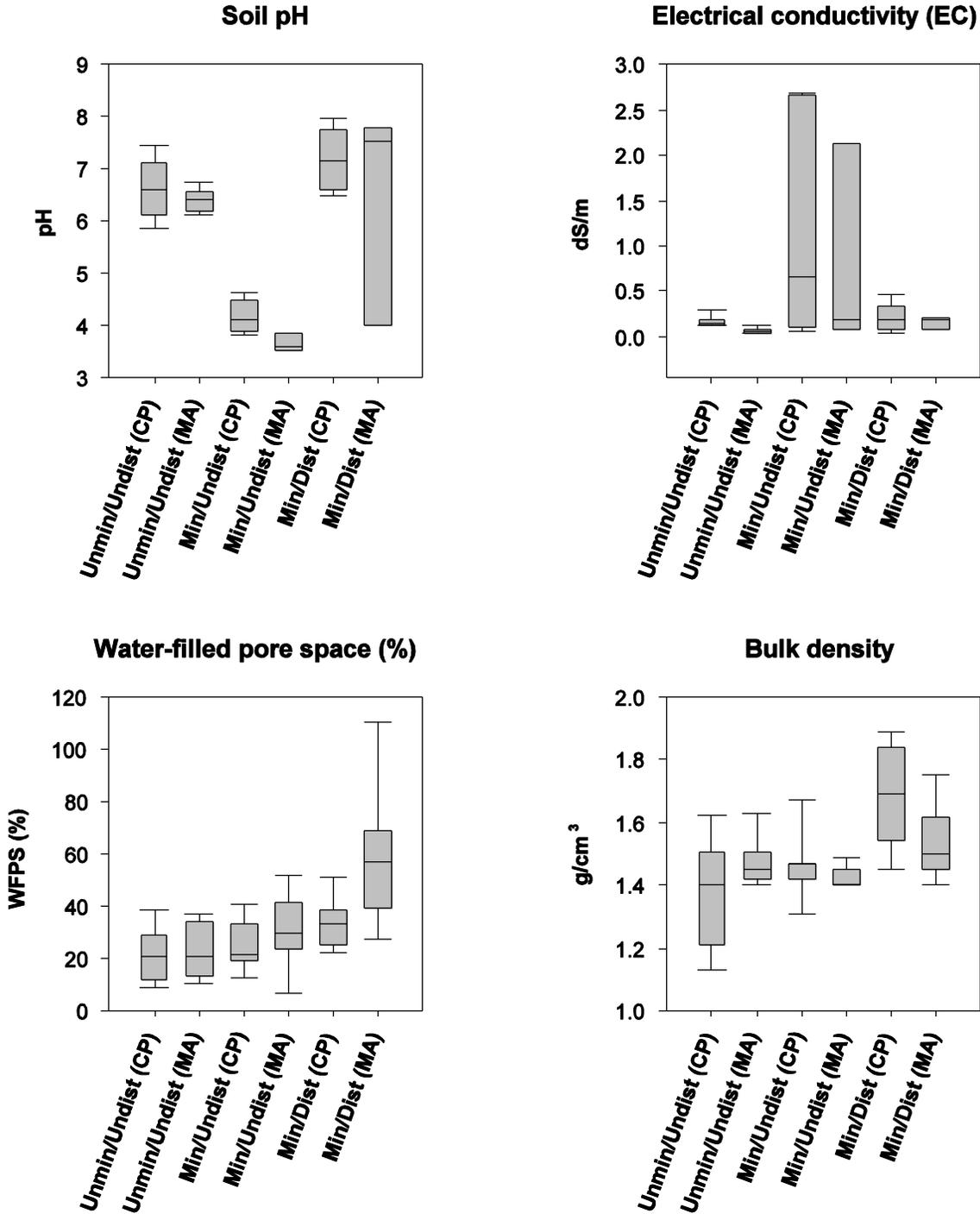
Figure 16. Quartz-alunite study sites: Selected soil chemical and physical data (Soil pH, Electrical conductivity, Water-filled pore space (WFPS), Bulk density) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic; dS = decisiemens.
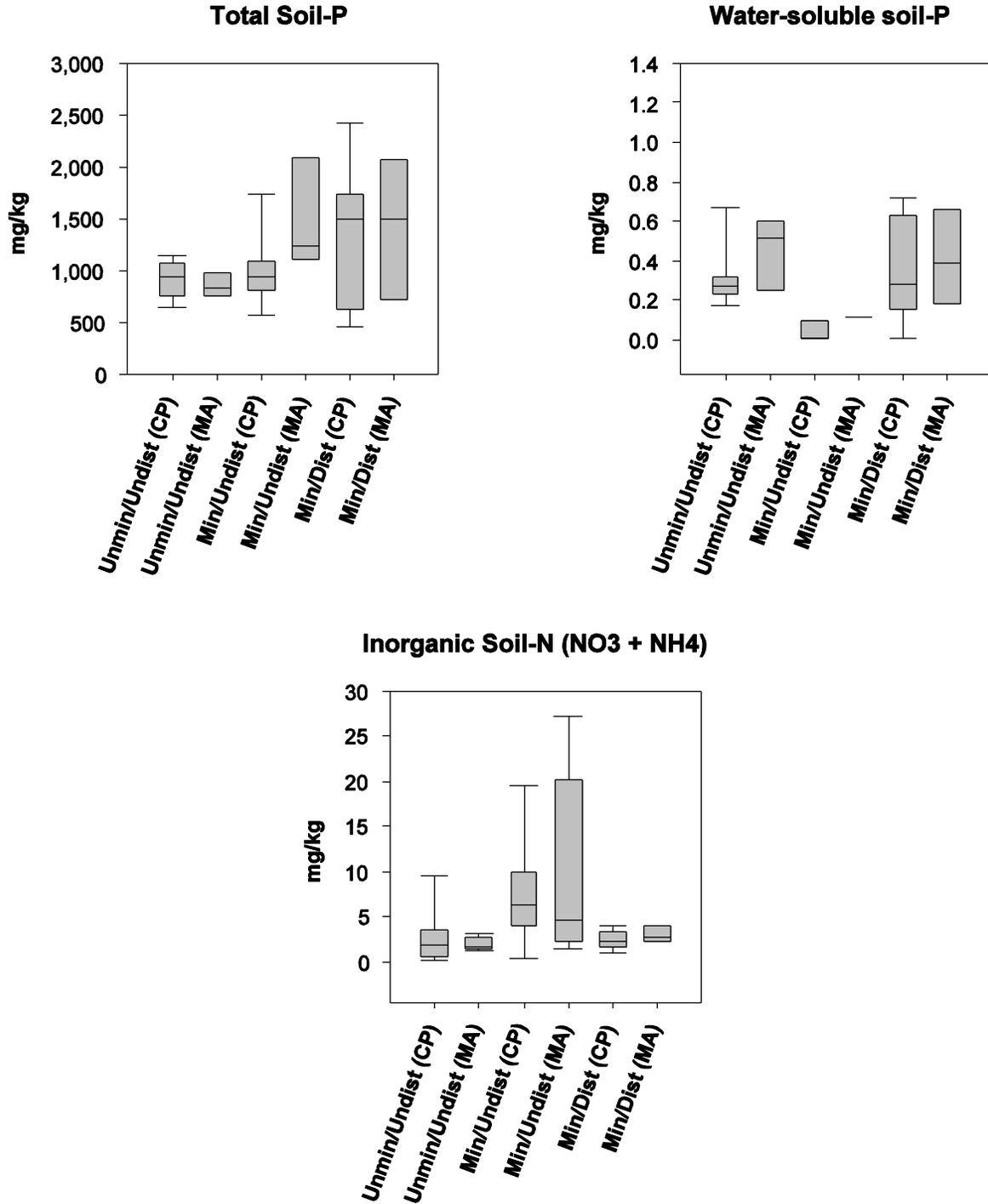
Figure 17. Quartz-alunite study sites: Selected soil macronutrient data (Total and Water-soluble P, and Inorganic N) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); NO3, nitrate; NH4, ammonium; CP, Castle Peak; MA, Masonic.
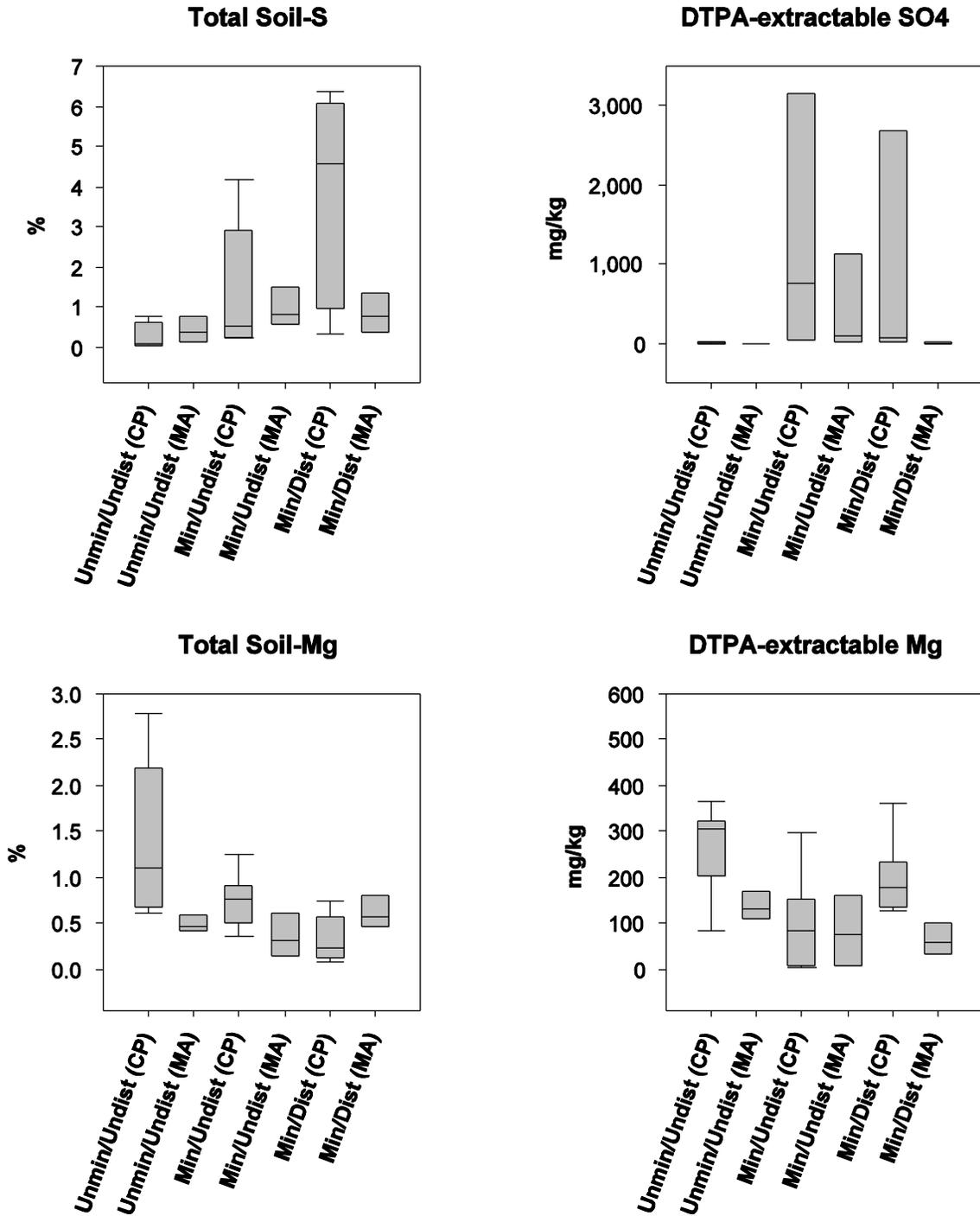
Figure 18. Quartz alunite study sites: Selected soil macronutrient data (Total and DTPA-extractable S and Mg) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist, mineralized/disturbed (waste-rock and tailings piles); SO4, sulfate; CP, Castle Peak; MA, Masonic.
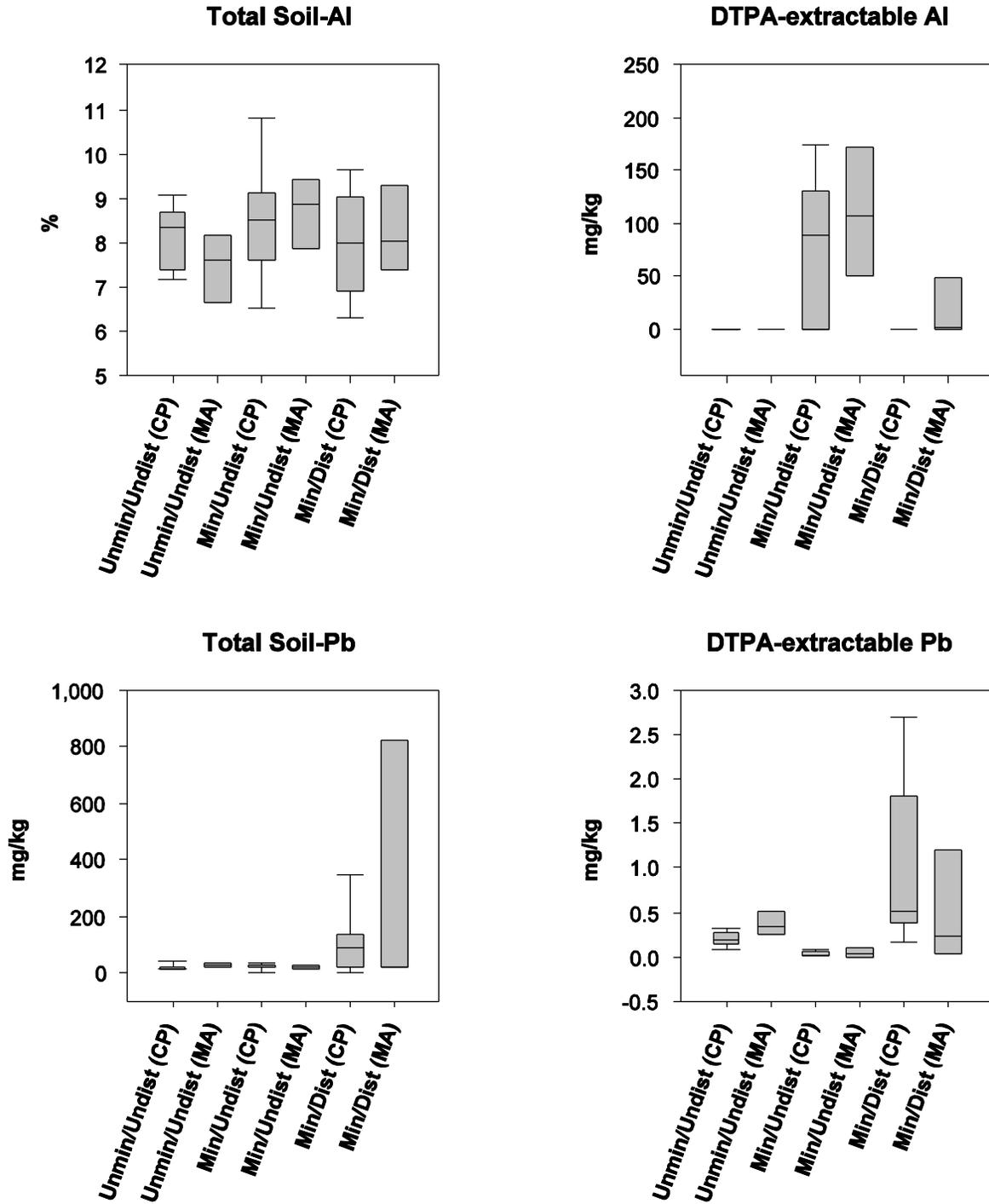
Figure 19. Quartz-alunite study sites: Selected soil metal data (Total and DTPA-extractable Al and Pb) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist = mineralized/undisturbed (quartz-alunite soils); Min/Dist = mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic.

Total soil-Mn

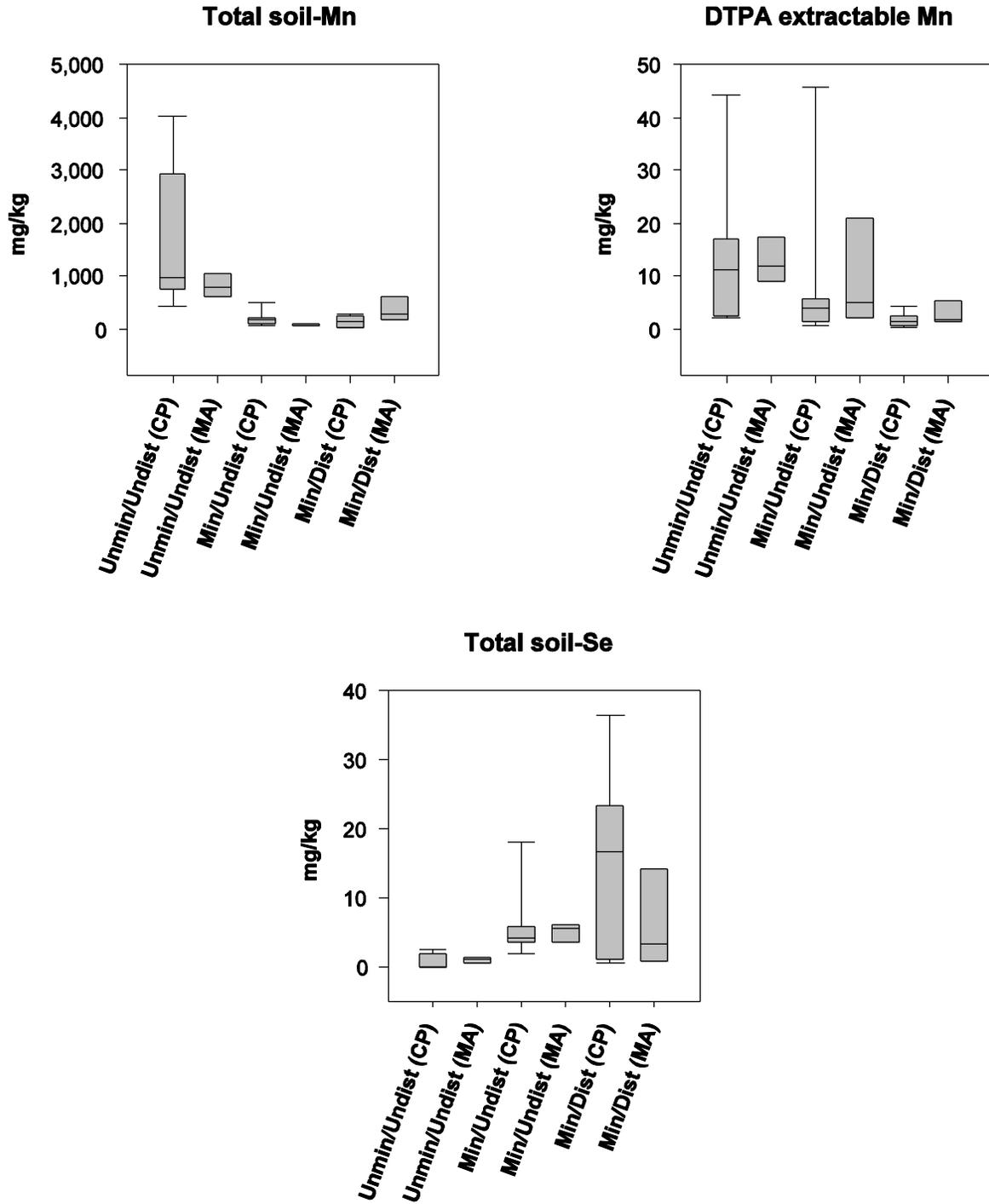**DTPA extractable Mn**

Total soil-Se

Figure 20. Quartz-alunite study sites: Selected soil metal data (Total and DTPA-extractable Mn and Total Se) across the study-design levels. Unmin/Undist = unmineralized/undisturbed (andesite soils); Min/Undist = mineralized/undisturbed (quartz-alunite soils); Min/Dist = mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic.
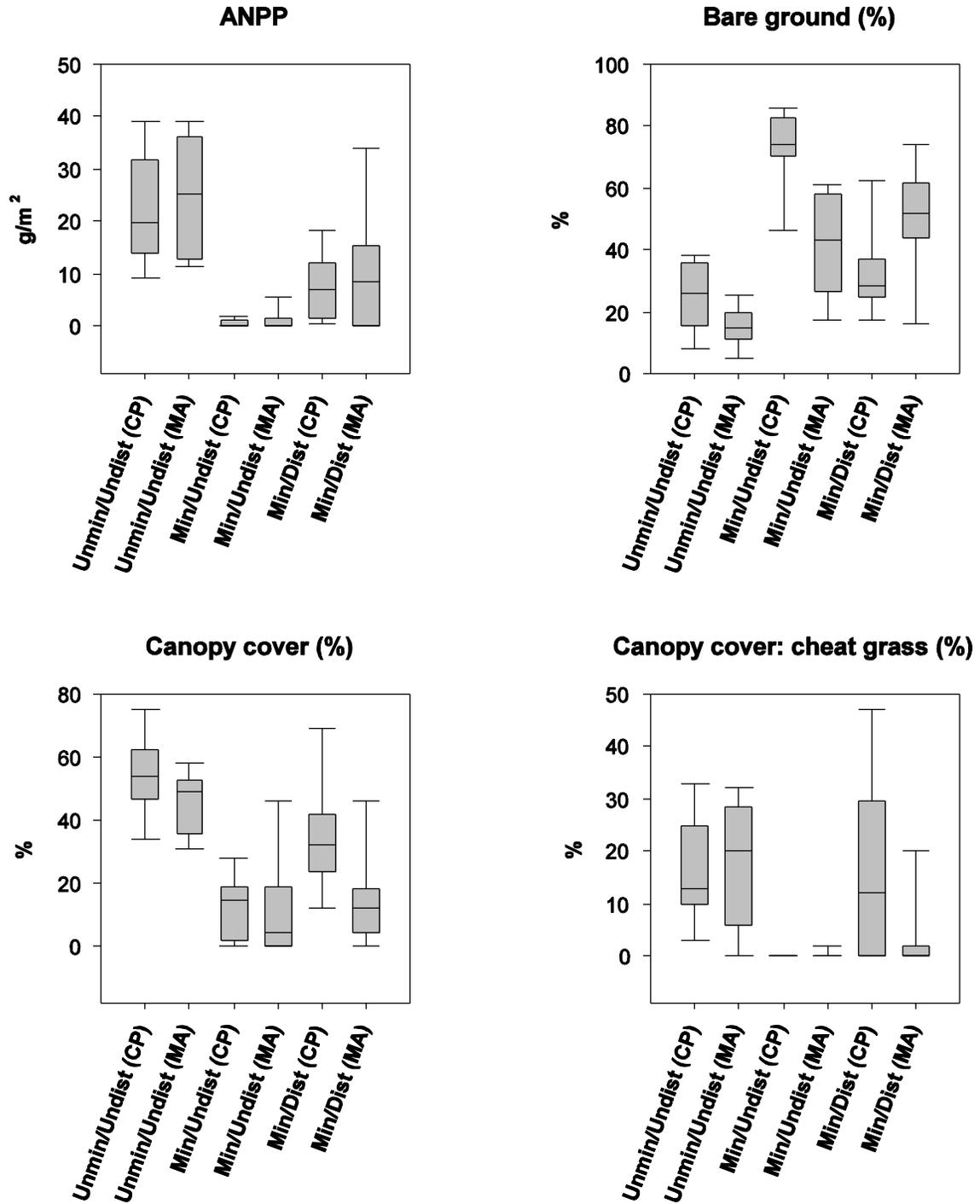
Figure 21. Quartz-alunite study sites: Selected vegetation data (Aboveground net primary productivity (ANPP), Bare ground, Canopy cover, Canopy cover comprised of cheat grass) across the study-design levels. Unmin/Undist, unmineralized/undisturbed (andesite soils); Min/Undist, mineralized/undisturbed (quartz-alunite soils); Min/Dist = mineralized/disturbed (waste-rock and tailings piles); CP, Castle Peak; MA, Masonic.
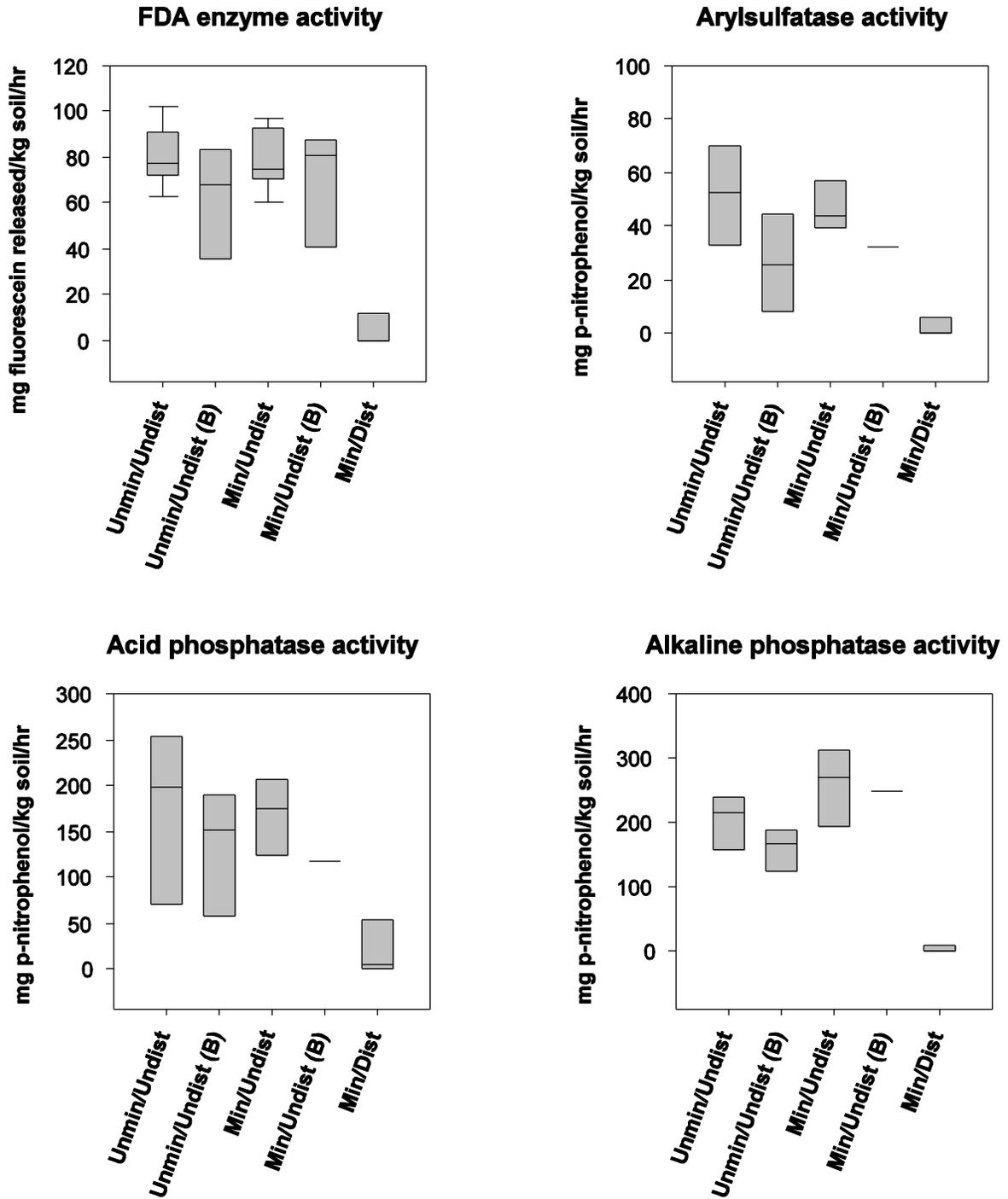
Figure 22. Buckingham study area, north-central, Nevada: Soil microbial data (Enzyme activity) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies); FDA, Fluorescein diacetate.
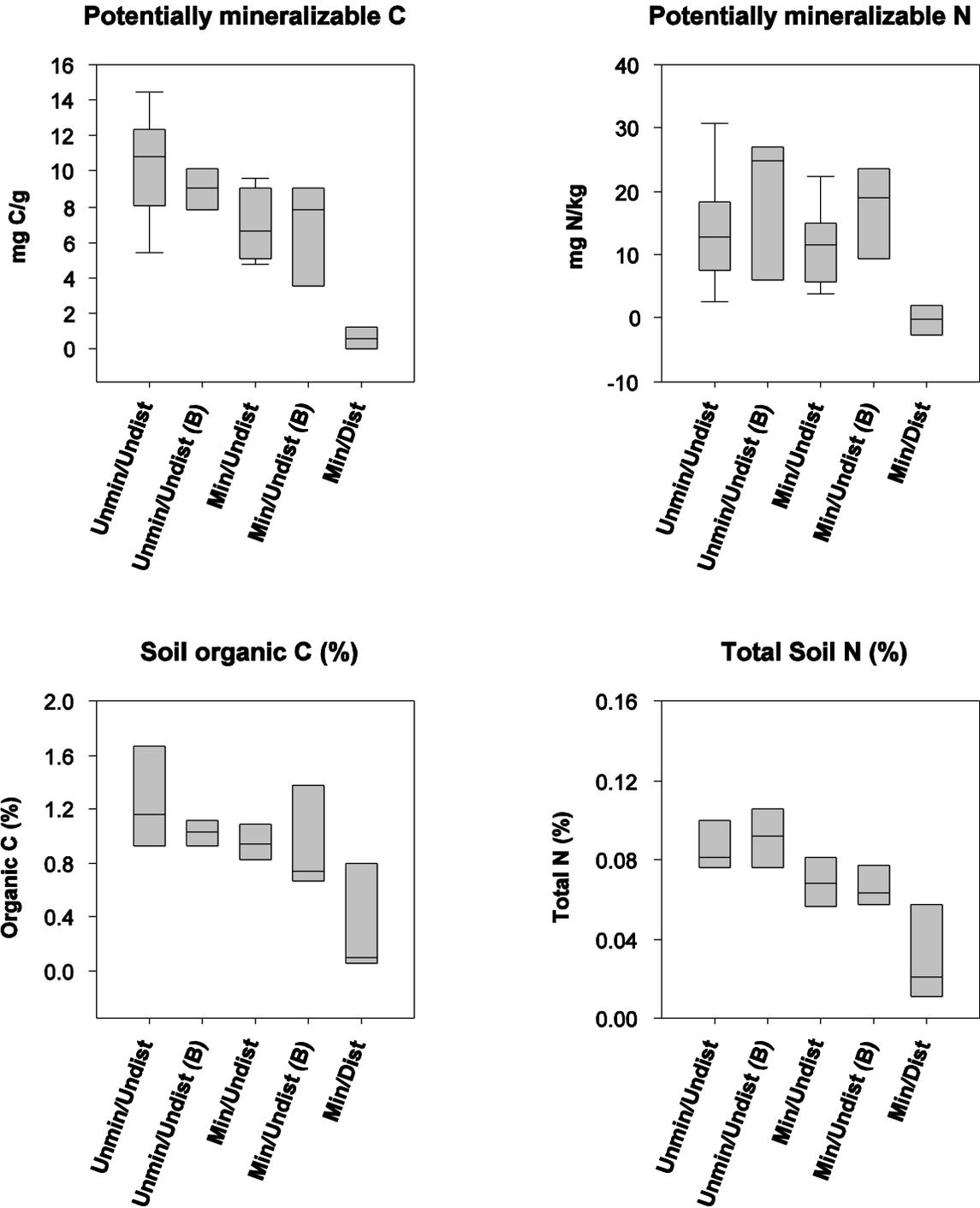
Figure 23. Buckingham study area, north-central, Nevada: Soil microbial data (Mineralizeable C and N, Organic C, Total N) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies).
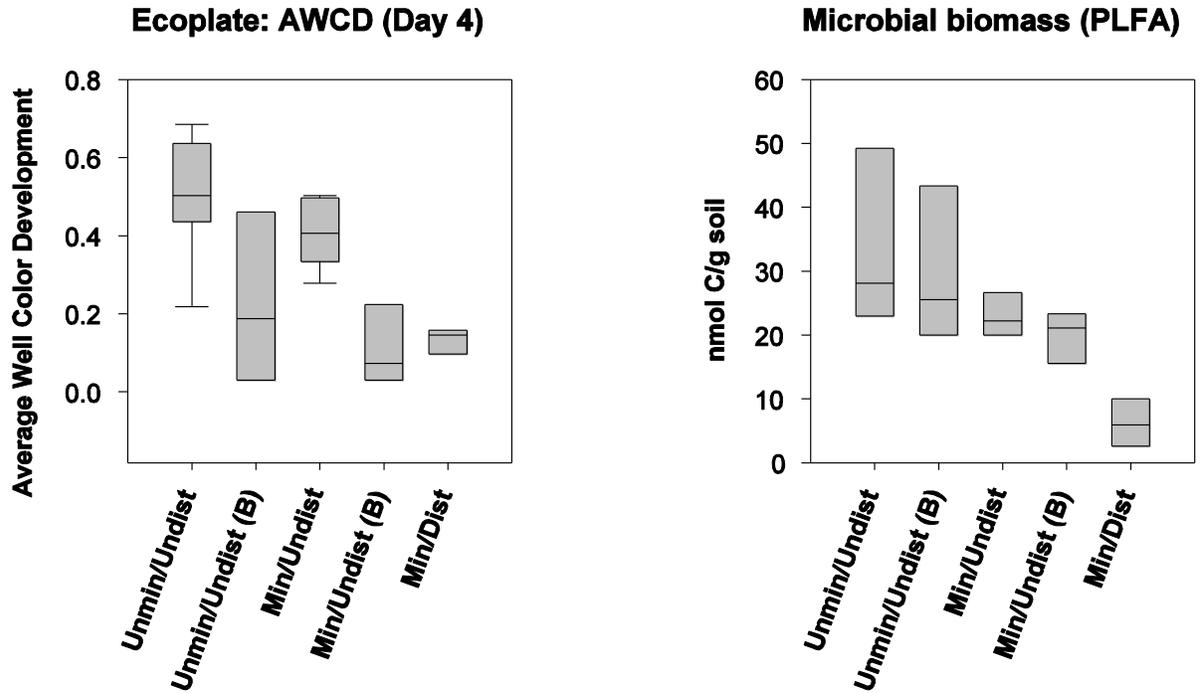
Figure 24. Buckingham study area, north-central, Nevada: Soil microbial data (Ecoplate AWCD, Microbial biomass (PLFA)) across the study-design levels. Unmin/undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles). (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies); AWCD, Average well color development; PLFA, Phospholipid fatty acids.
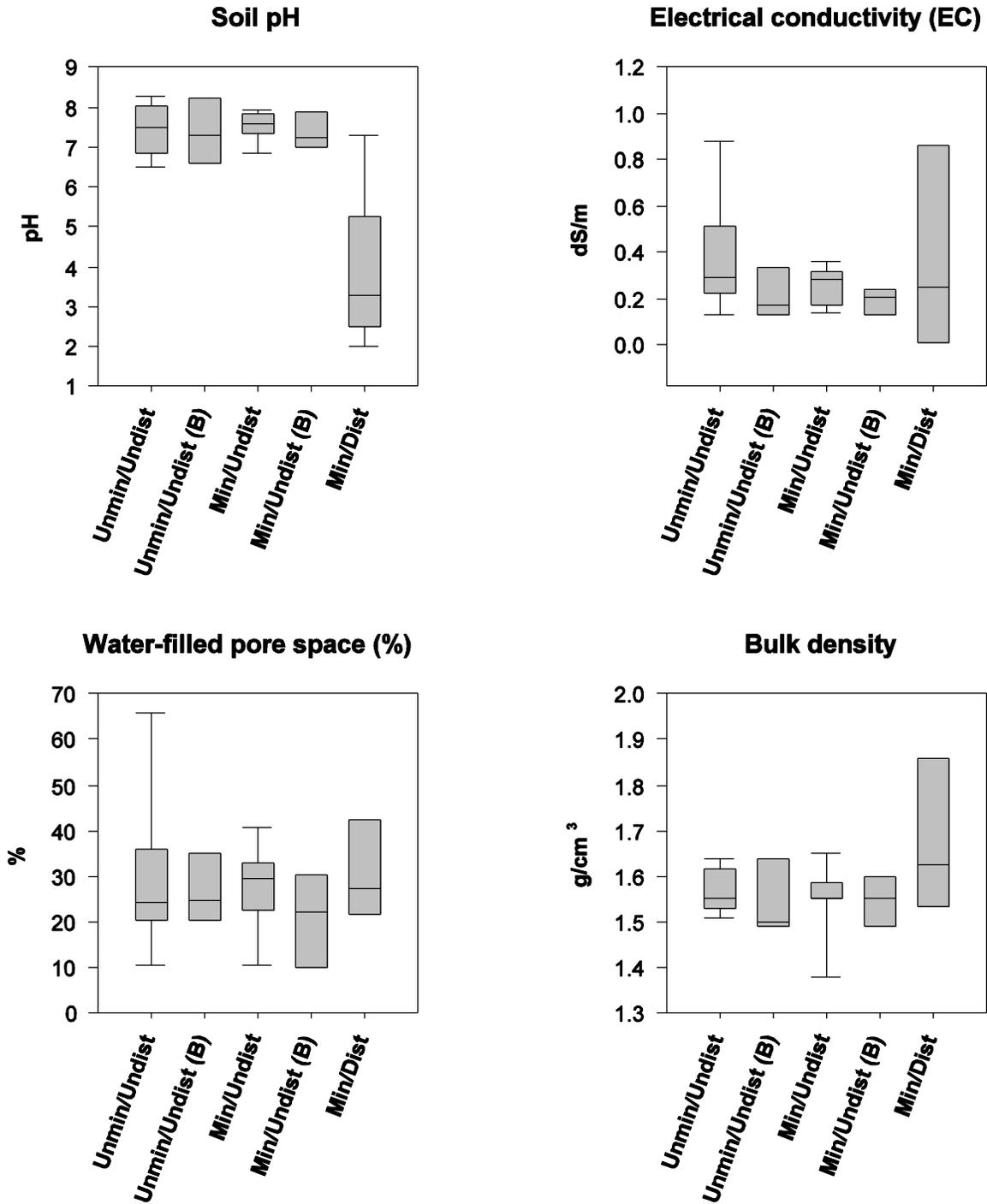
Figure 25. Buckingham study area, north-central, Nevada: Selected soil chemical and physical data (Soil pH, Electrical conductivity, Water-filled pore space (WFPS), Bulk density) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies); dS = decisiemens.
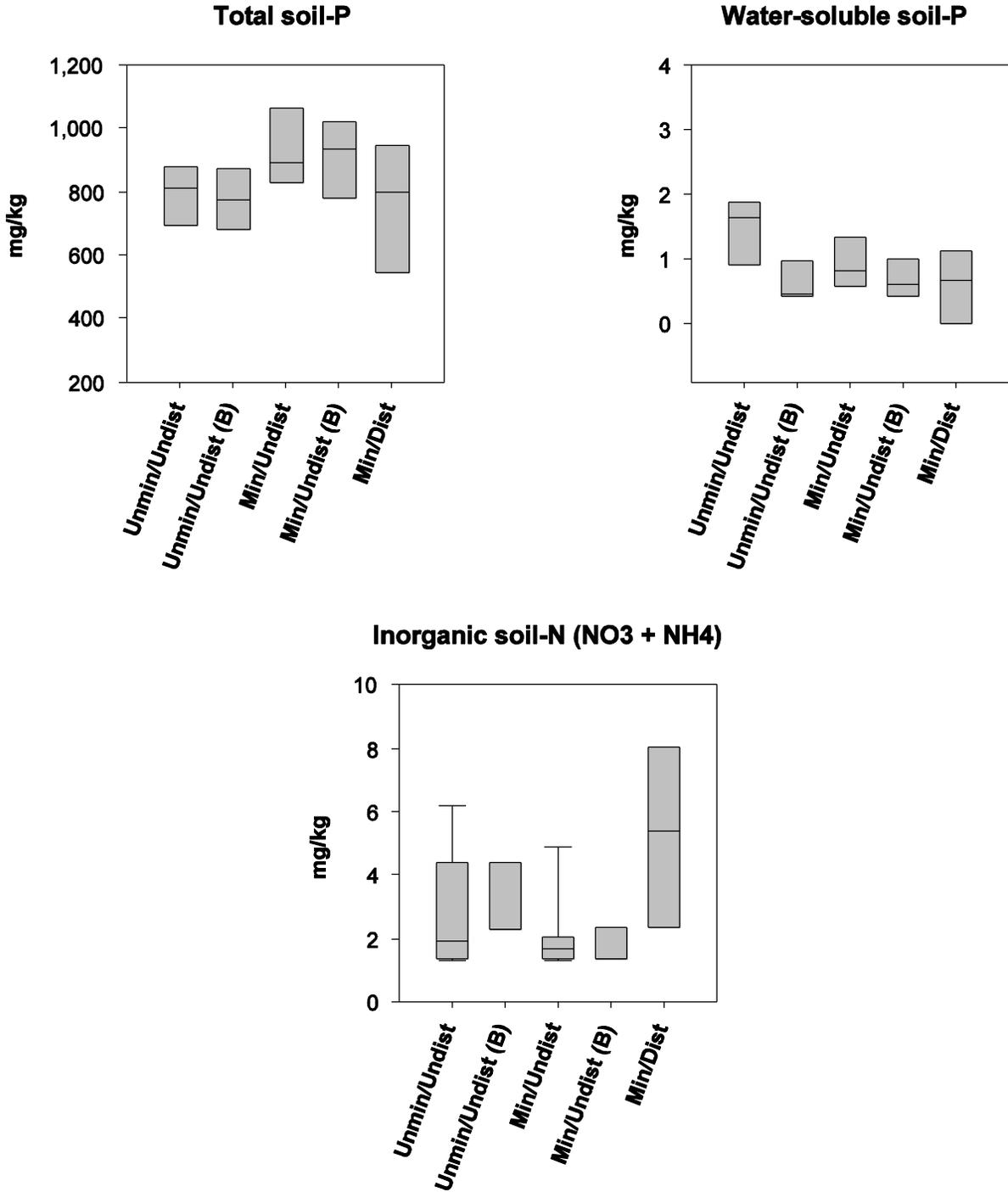
Figure 26. Buckingham study area, north-central, Nevada: Selected soil macronutrient data (Total and Water-soluble P, Inorganic N) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies); NO3, nitrate; NH4, ammonium.

Total soil-S

DTPA-extractable SO4

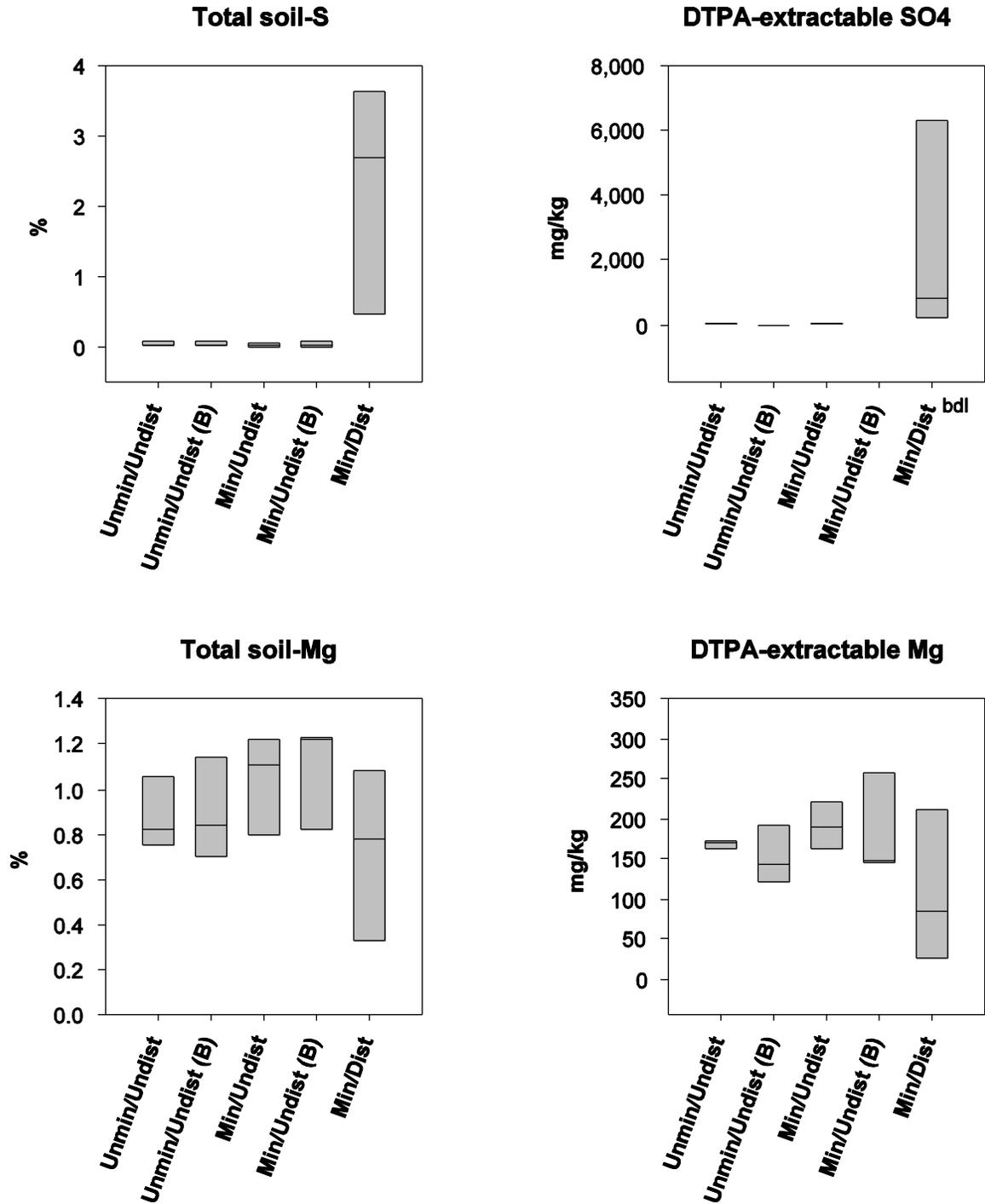**Total soil-Mg**

DTPA-extractable Mg

Figure 27. Buckingham study area, north-central, Nevada: Selected soil macronutrient data (Total and DTPA-extractable S and Mg) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies); bdl, below detection limit; SO4, sulfate.

Total soil-Cu

DTPA-extractable Cu

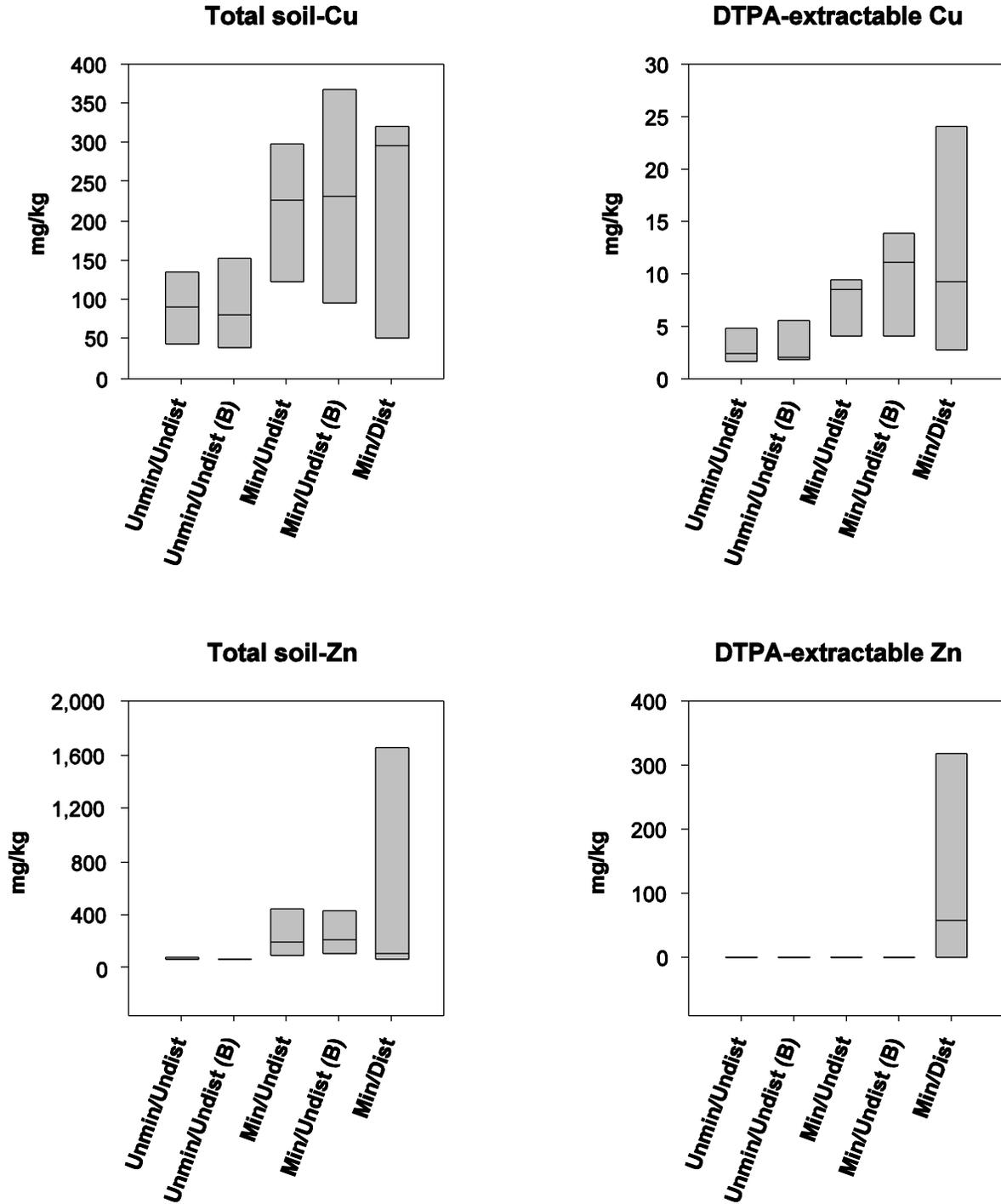## Total soil-Zn

DTPA-extractable Zn

Figure 28. Buckingham study area, north-central, Nevada: Selected soil metal data (Total and DTPA-extractable Cu and Zn) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies).
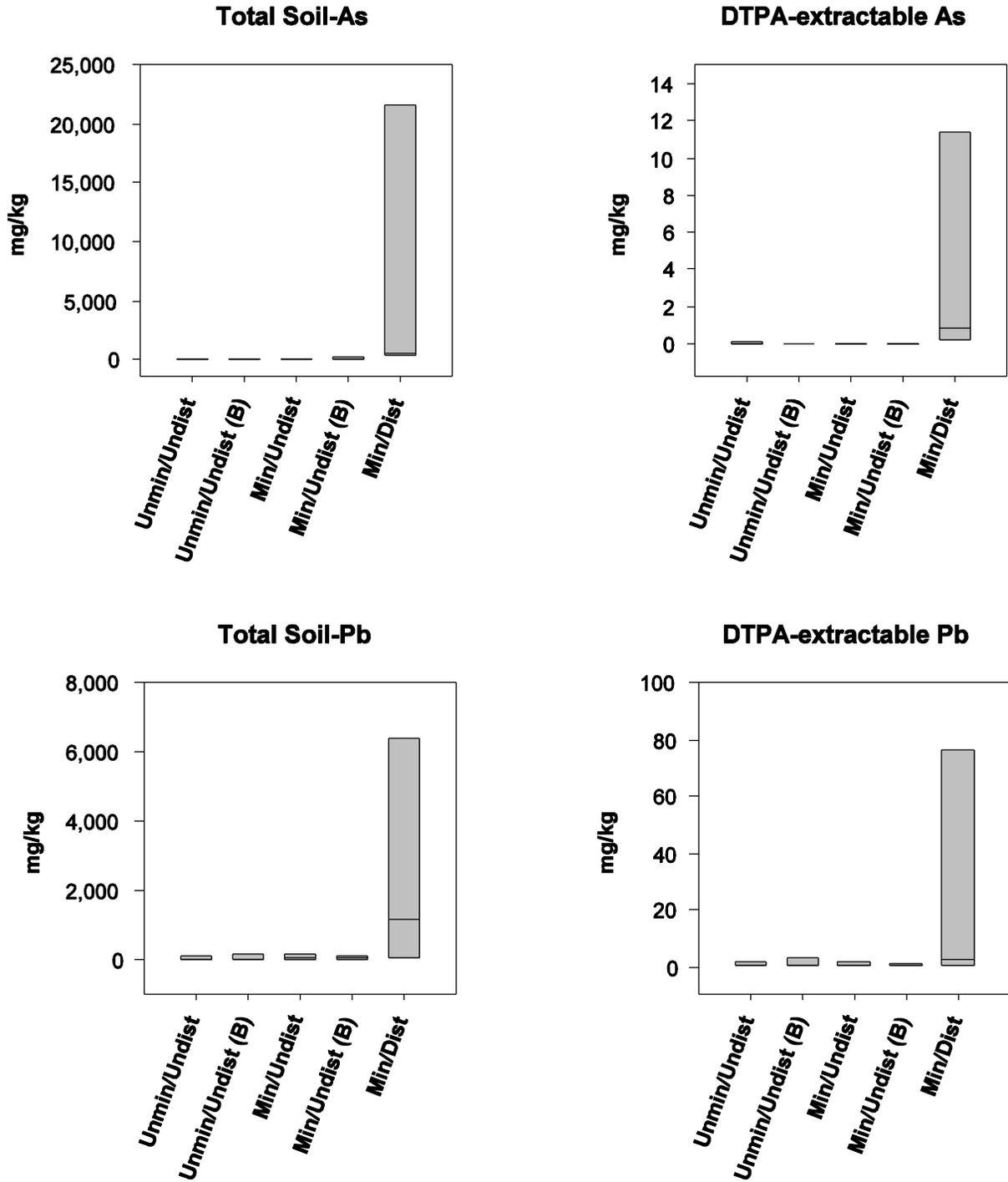
Figure 29. Buckingham study area, north-central, Nevada: Selected soil metal data (Total and DTPA-extractable As and Pb) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles); (B), samples taken between shrub canopies (Min/Dist samples were also taken between shrub canopies).
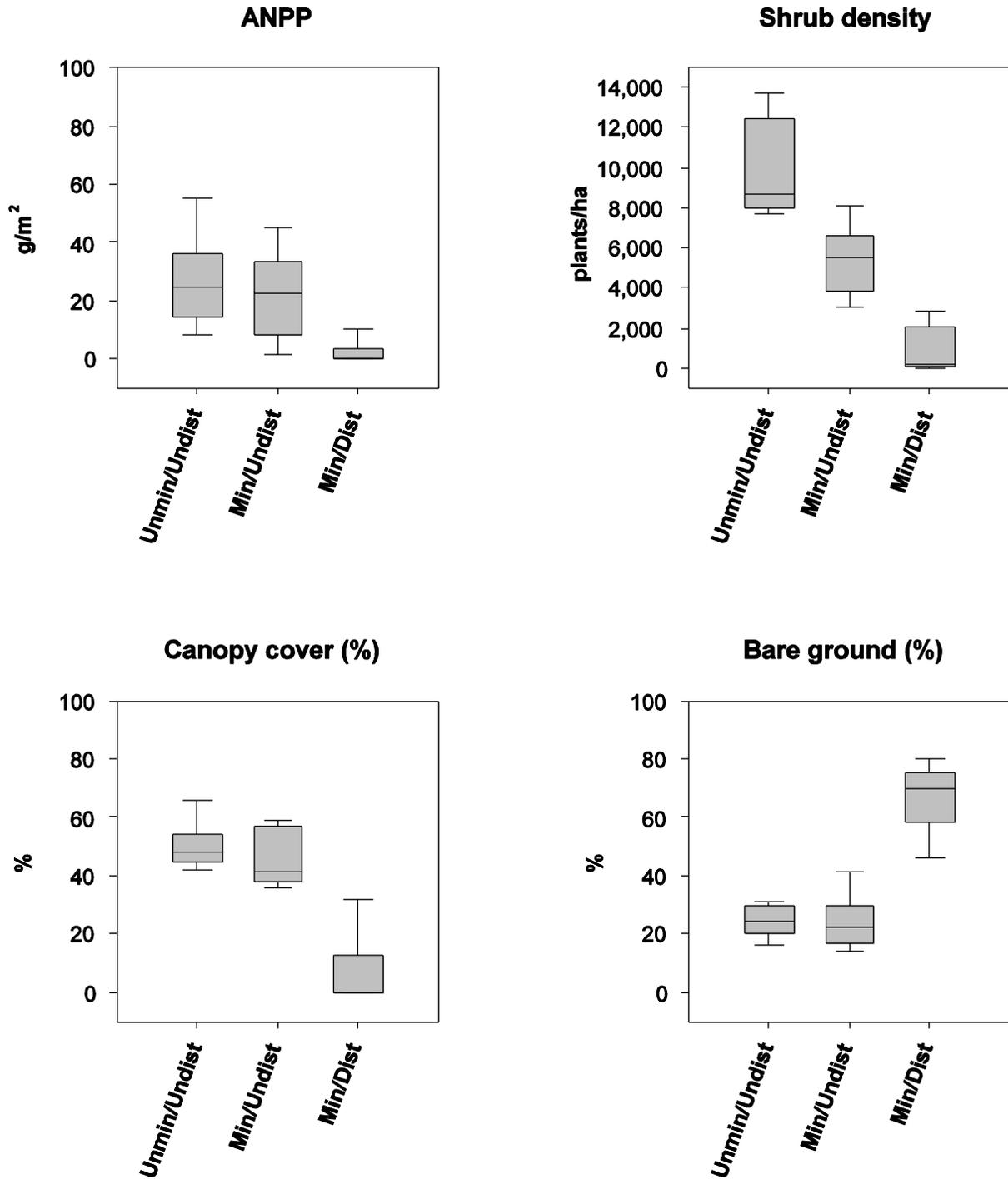
Figure 30. Buckingham study area, north-central, Nevada: Selected vegetation data (Aboveground net primary productivity (ANPP), Shrub density, Canopy cover, Bare ground) across the study-design levels. Unmin/Undist, unmineralized/undisturbed soils; Min/Undist, mineralized/undisturbed soils; Min/Dist, mineralized/disturbed (waste-rock and tailings piles).