Release of Nutrients in Mine Soils of Different Ages

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West Virginia largest coal producer in the Appalachian region

90 active surface mines in 2013

Over 30 million Mg coal

Sources: Bise, 2013; U.S EIA, 2015

WV Forests

78% Eastern deciduous forests

Wood production

Ecosystem functions

Wildlife habitat

Source: Burger, 1999

Appalachian Regional Reforestation Initiative (ARRI)

5 Steps of the Forestry Reclamation Approach

1. Create suitable rooting medium
2. Do not compact
3. Use tree compatible ground cover
4. Plant at least two types of trees
5. Use proper planting techniques

Source: Burger et al., 2005

Create suitable medium

Salvaging topsoil not always possible

Topsoil substitute allowed if ≥ native Appalachian soil

Sandstones > siltstones or shales

Sources: Burger et al., 2005; Daniels and Amos, 1985

Brown vs. Gray Sandstone

Brown is better

- **Lower pH**
- **Lower EC**
- **> Fines**

Sources: Angel et al, 2006; Burger et al., 2005; Conrad et al., 2008; Haering et al., 2004; Skousen et al., 2011; Daniels and Amos, 1984; Rodrigue and Burger, 2004

Overburden for Reclamation

Weathered (Brown)

- **Closer to the surface**
- **Loss of soluble carbonates and iron oxidation**

Unweathered (Gray)

- **Deeper down geological column**
- **More resistant to weathering**

In WV typically composed of:

- **Mica**
- **Kaolinite**
- **Quartz**
- **Feldspar**

Weathering releases nutrients making them bioavailable

Sources: Daniels and Amos, 1985; Haering et al., 2004; Miller et al., 2012; Roberts et al., 1988

Nutrients in Soil

Soil Phases

- **Soil solution**
- **Sorbed to soil phases**
- **Part of soil structure**

How do nutrients in brown and gray sandstone differ between soil phases?

Source: Brown et al., 1999

BCR Optimized Sequential Extraction

Used to determine speciation of elements

Four step procedure to determine the following phases:

- **Acid extractable (acetic acid)**
- **Reducible (hydroxylamine hydrochloride)**
- **Oxidizable (ammonium acetate)**
- **Residual (aqua regia)**

Sources: Pueyo et al., 2008; Rao et al., 2008; Sutherland, 2010; Sutherland and Tack, 2003,

Objectives

Determine if available nutrients in brown and gray sandstones increase over time at the same rate;

Determine if available nutrients in brown and gray sandstone reach the same levels of forested soils over time;

Determine if soil physical and chemical properties in brown and gray sandstone change over time; and;

Determine if soil physical and chemical properties in brown and gray sandstone are comparable to forest soil conditions over time.

Hypotheses

Gray sandstone will initially have lower available nutrients than brown sandstone

Over time, gray sandstone will have more available nutrients than brown sandstone as it is weathered

Forest soil will have the highest amount of available nutrients

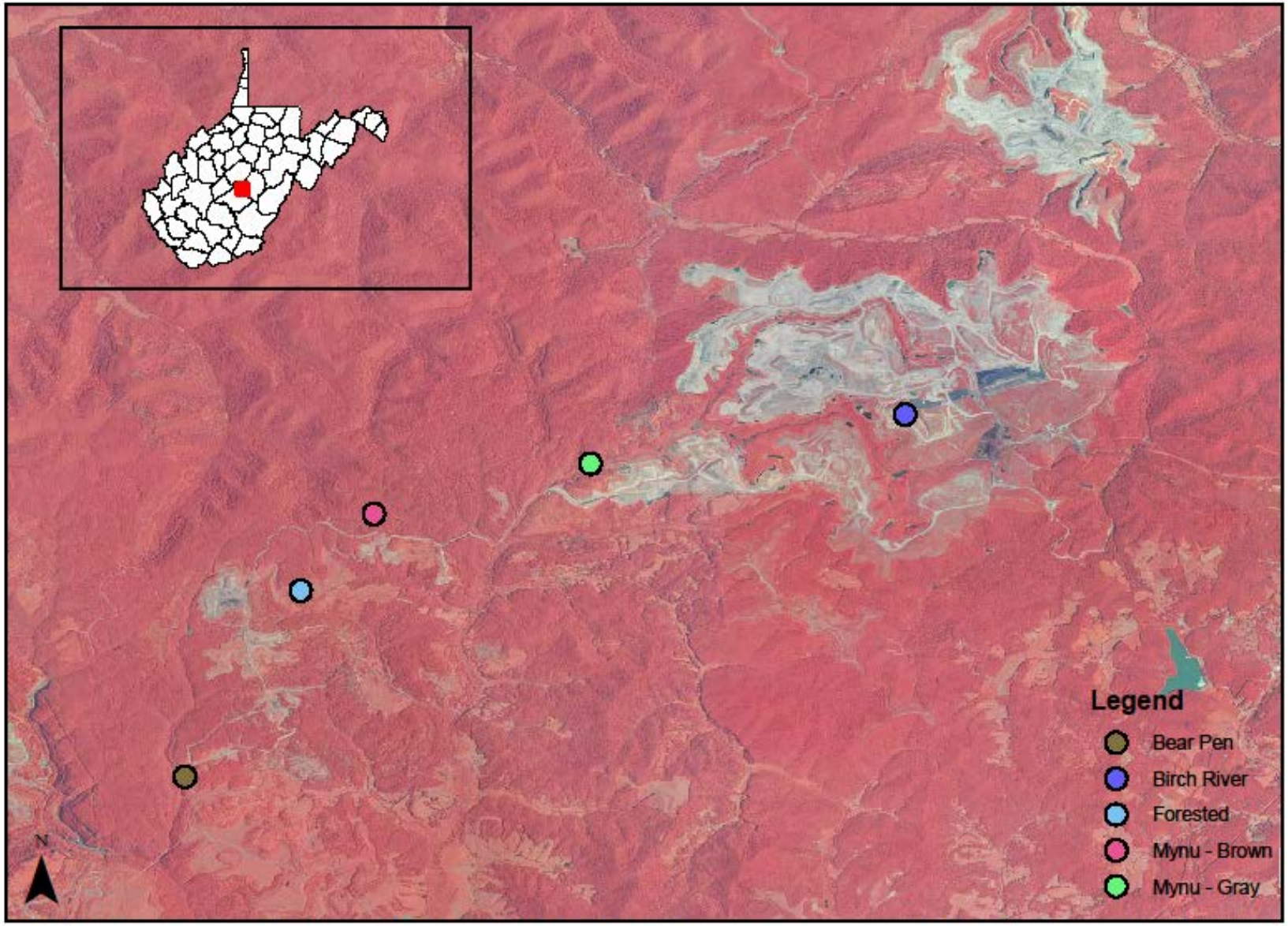
Site

Brown and Gray Sandstones

- **45 years since reclamation**
- **20 years since reclamation**
- **9 years since reclamation**

Undisturbed Soils

Site	Sandstone	Site description
Mynu Area	Gray	Less than 2% slope Vegetation: silver maple, birch, tulip poplar, goldenrod, oak seedlings, ash
	Brown	2 to 5% slope Vegetation: black birch, hemlock, sugar maple, red maple, tulip poplar, ferns, American beech, red oak, sourwood
Bear Pen	Gray	2 to 5% slope Vegetation: Black locust, multiflora rose, grasses, Autumn olive
	Brown	Vegetation: Black birch, ferns, grasses, mosses, goldenrod, lespedeza,
Reforestation Plots	Gray	Less than 2% slope Vegetation: red oak, white pine, black locust; low herbaceous cover
	Brown	Less than 2% slope Vegetation: red oak, black locust, white pine, white oak, Rubus, mosses
Forested	NA	20% Slope, SW Aspect Vegetation: Recently clearcut, Rubus, greenbrier, Solidago, deer tongue, red maple seedlings,



Map 4-1. Locations of soil samples collected for BCR analysis.

Map Created by: Kara Dallaire
Image Source: WV GIS Tech Center

Methods

Use BCR Sequential Extraction to analyze for:

- **P, K, Ca, Mg, Mn, Cu, Zn, Al, Fe**

pH

Electrical Conductivity

Organic Matter Content

Particle Size Distributions

Percent Fines

3 samples from each site

Statistical Analysis

First three BCR steps added together = “Available”

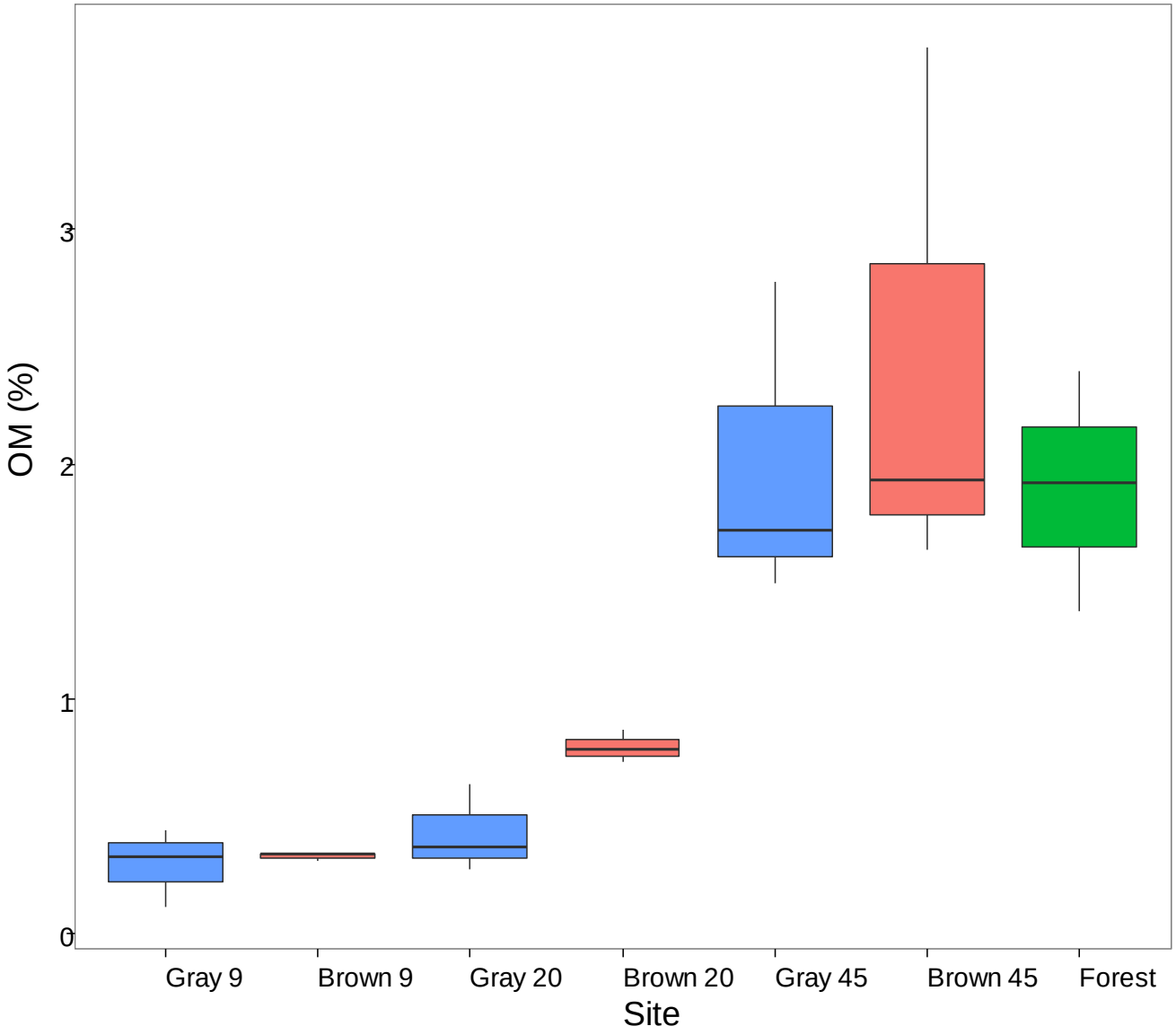
Initially, linear regression modelling was conducted to determine any correlation between age and available nutrients

ANOVA to determine if significant differences between all three ages of brown and gray sandstone and forest soil

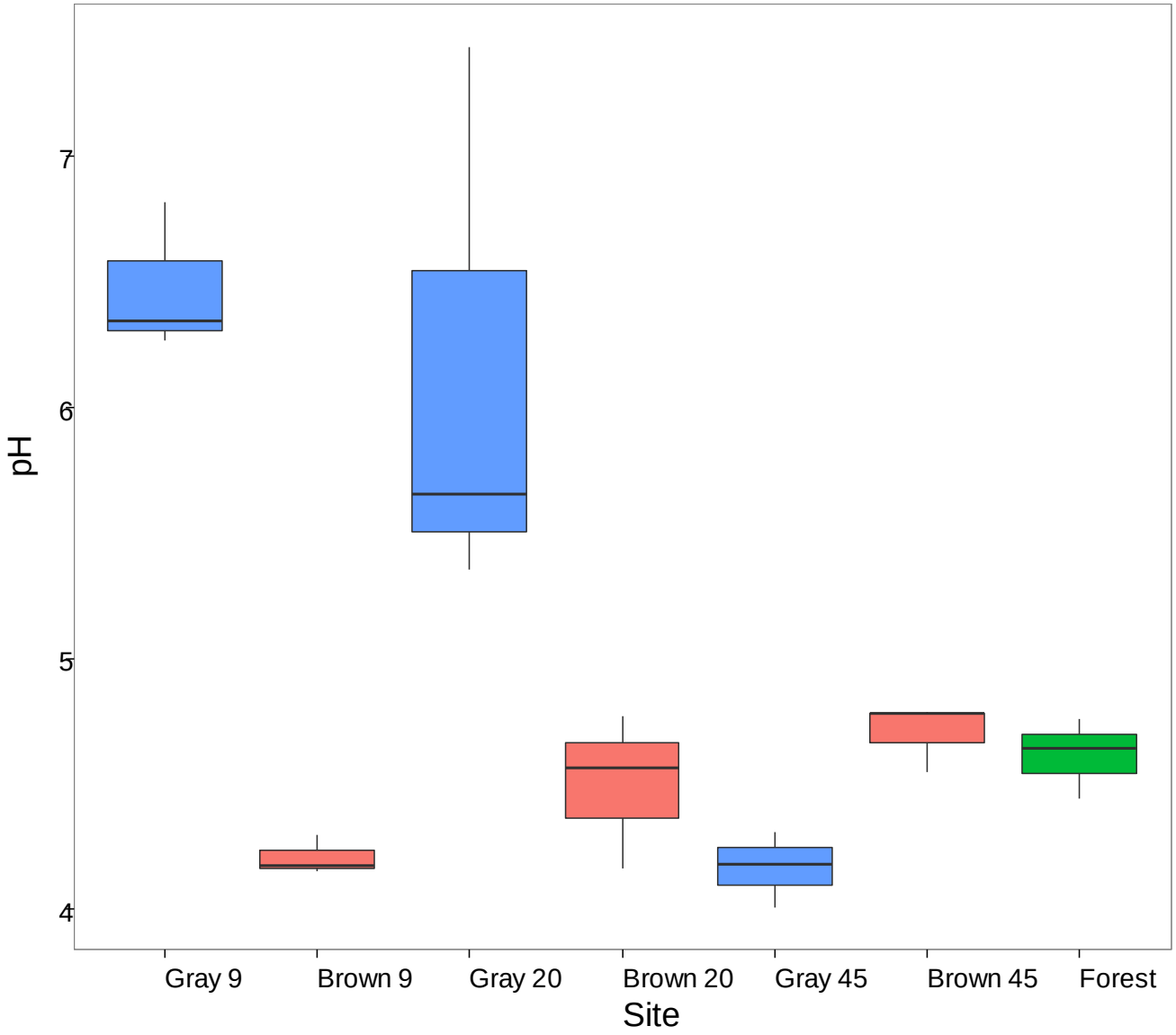
Results

Property	DF	Sum of Squares	F Value	P> F
OM	6	15	8.19	<0.001
pH	6	16	12.21	<0.001
EC	6	0.01	9.45	<0.001
Fines	6	4588	6.21	0.002
Sand	6	4581	3.68	0.02
Silt	6	1104	1.06	0.43
Clay	6	1306	16.78	<0.001

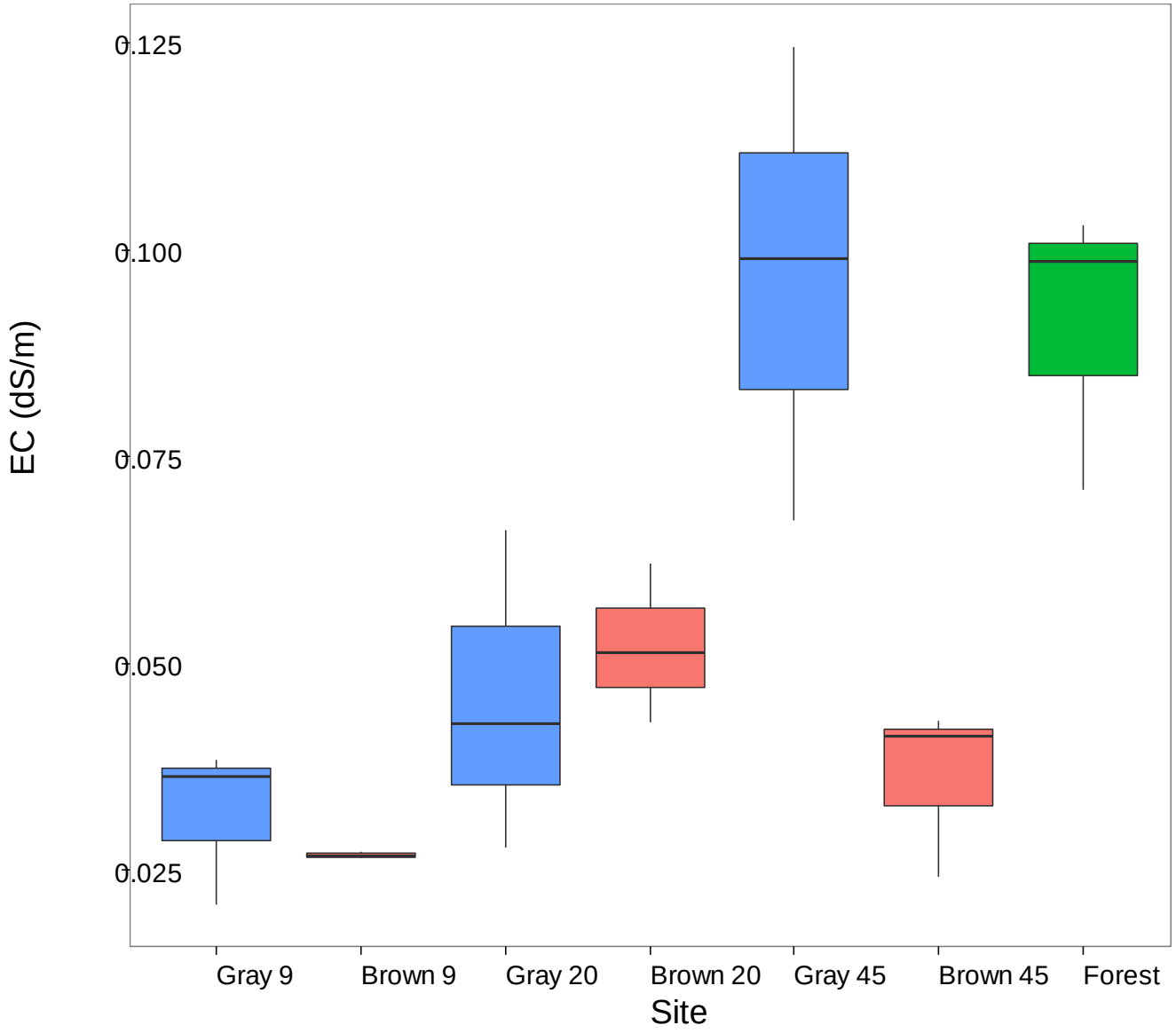
Results


OM (%)
3
2
1
0
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Results


pH
7
6
5
4
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

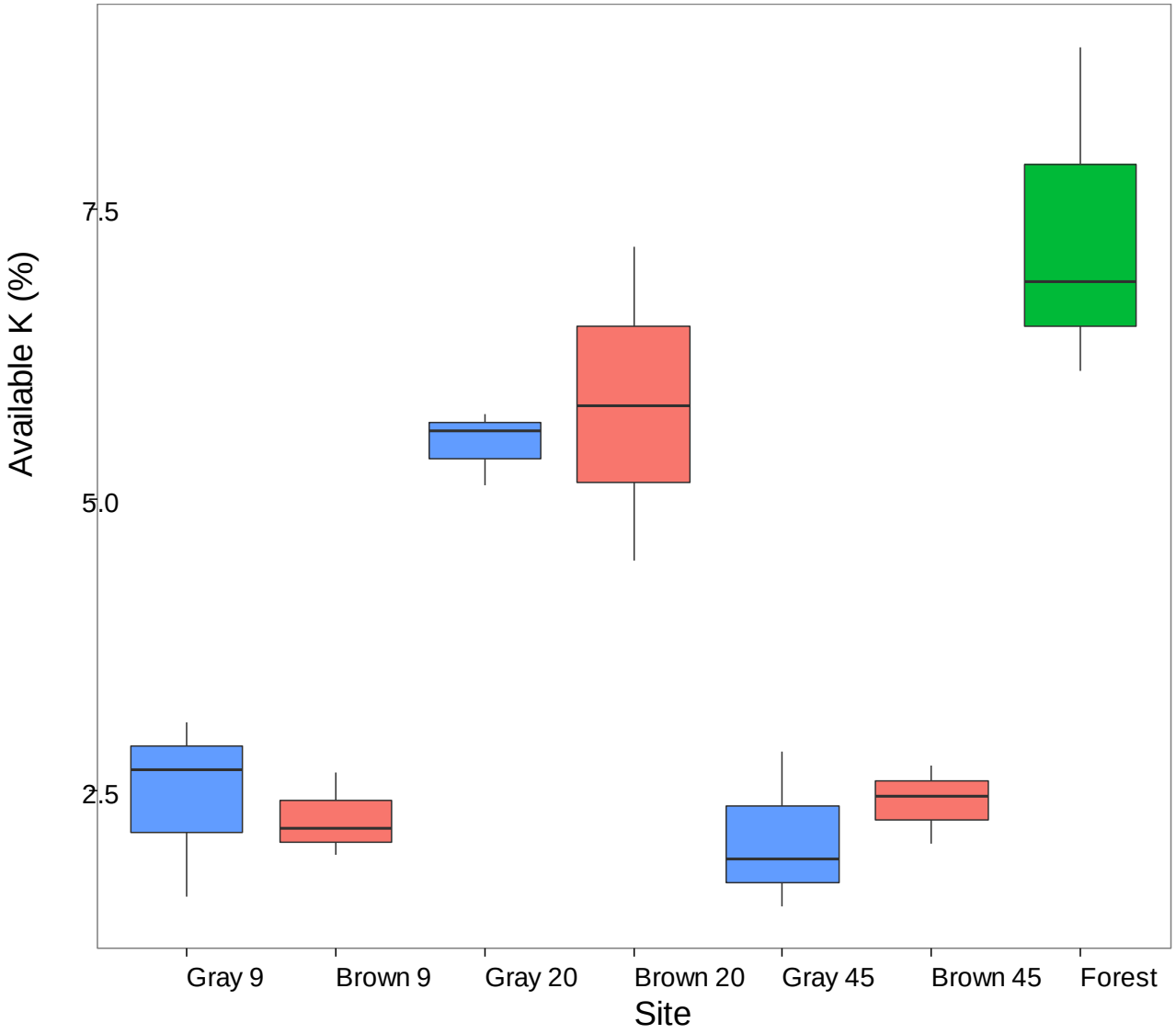
Results


0.125
0.100
0.075
0.050
0.025
EC (dS/m)
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

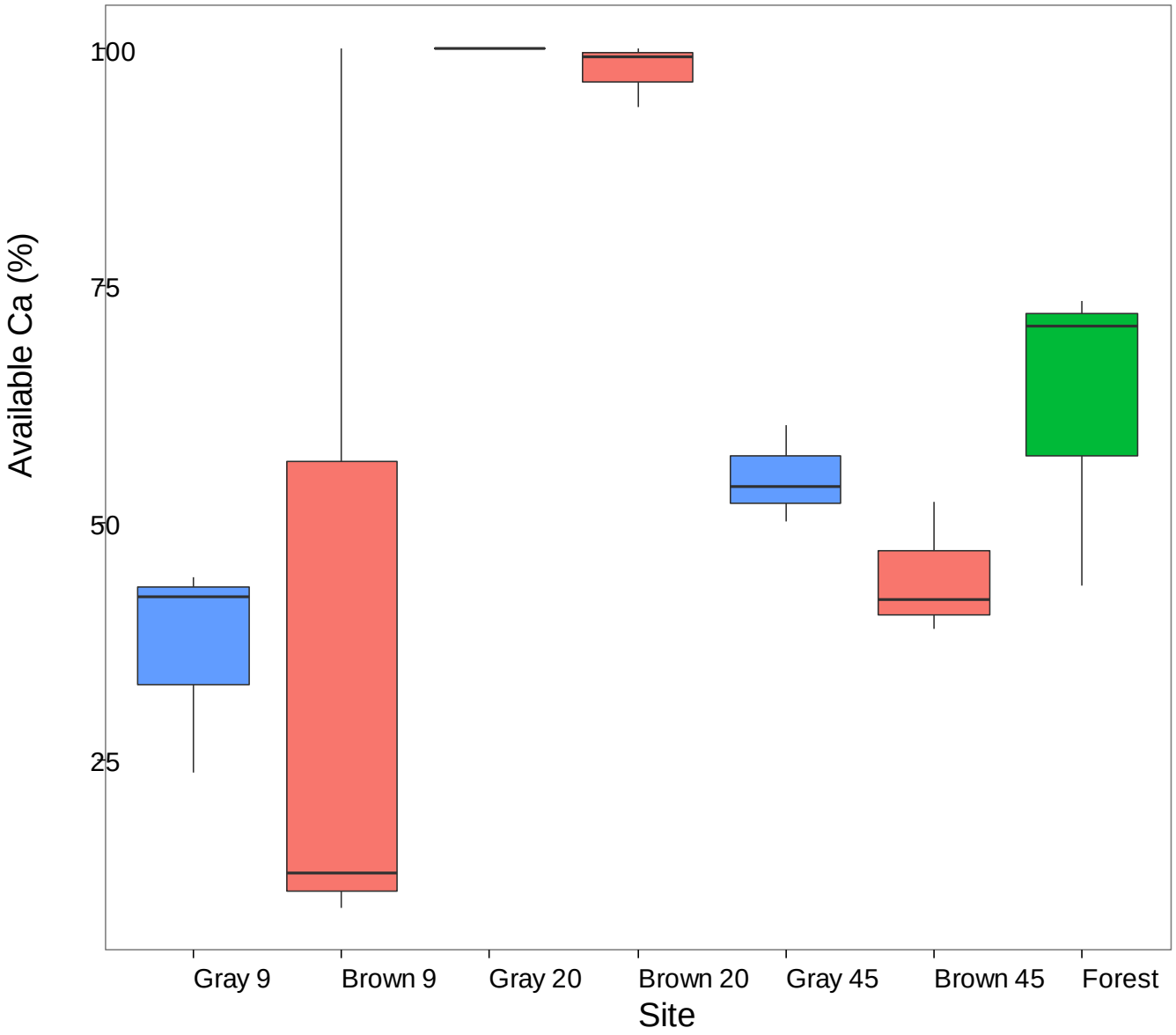
Results

Element	DF	Sum of Squares	F Value	P > F
P	6	3769	27.33	<0.001
K	6	84	18.52	<0.001
Ca	6	12533	4.62	0.008
Mg	6	6663	102	<0.001
Mn	6	5357	3.92	0.017
Cu	6	15802	29.9	<0.001
Zn	6	2654	3.59	0.023
Al	6	4450	46.77	<0.001
Fe	6	1201	18.34	<0.001

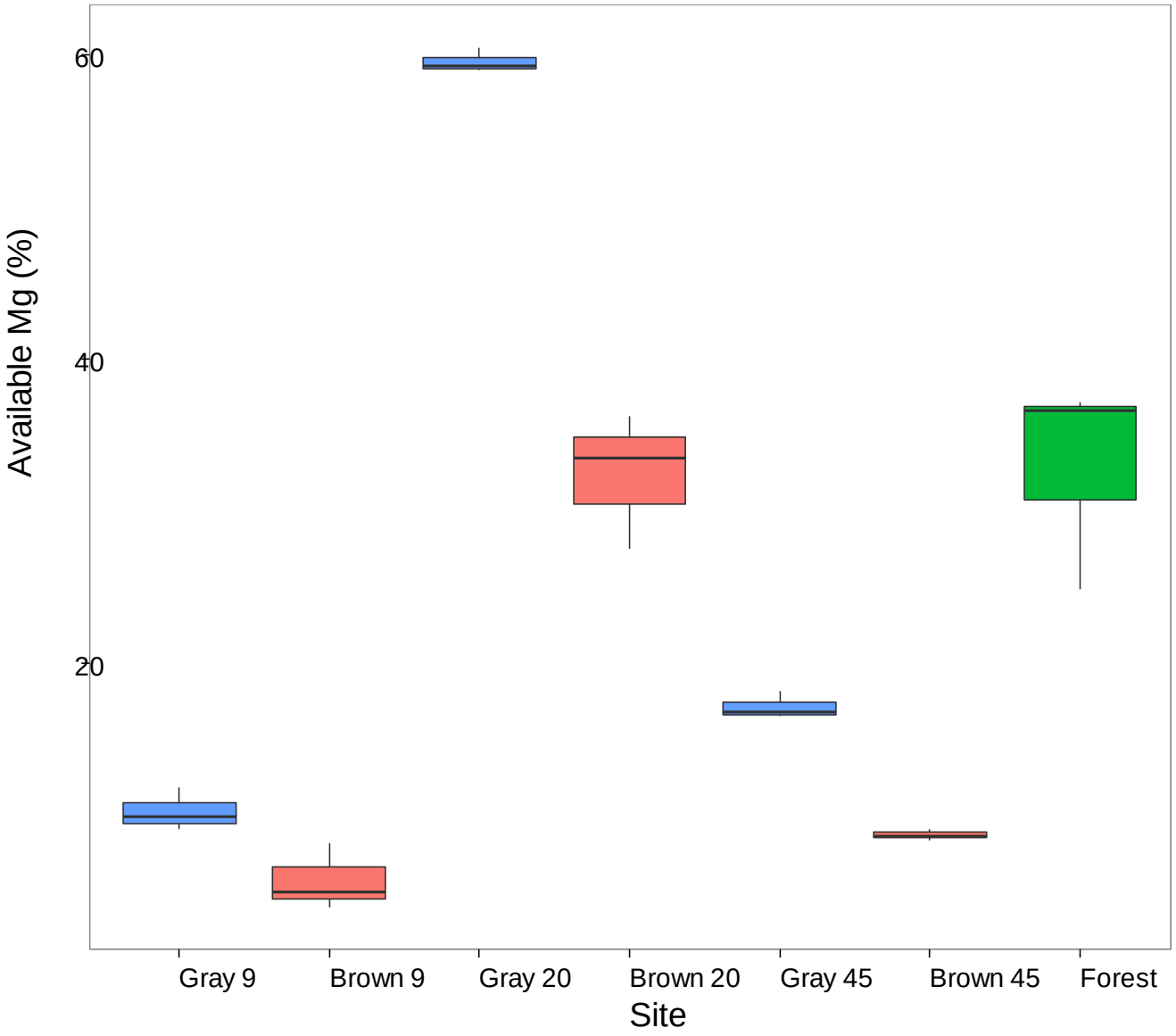
Study 4 - Results



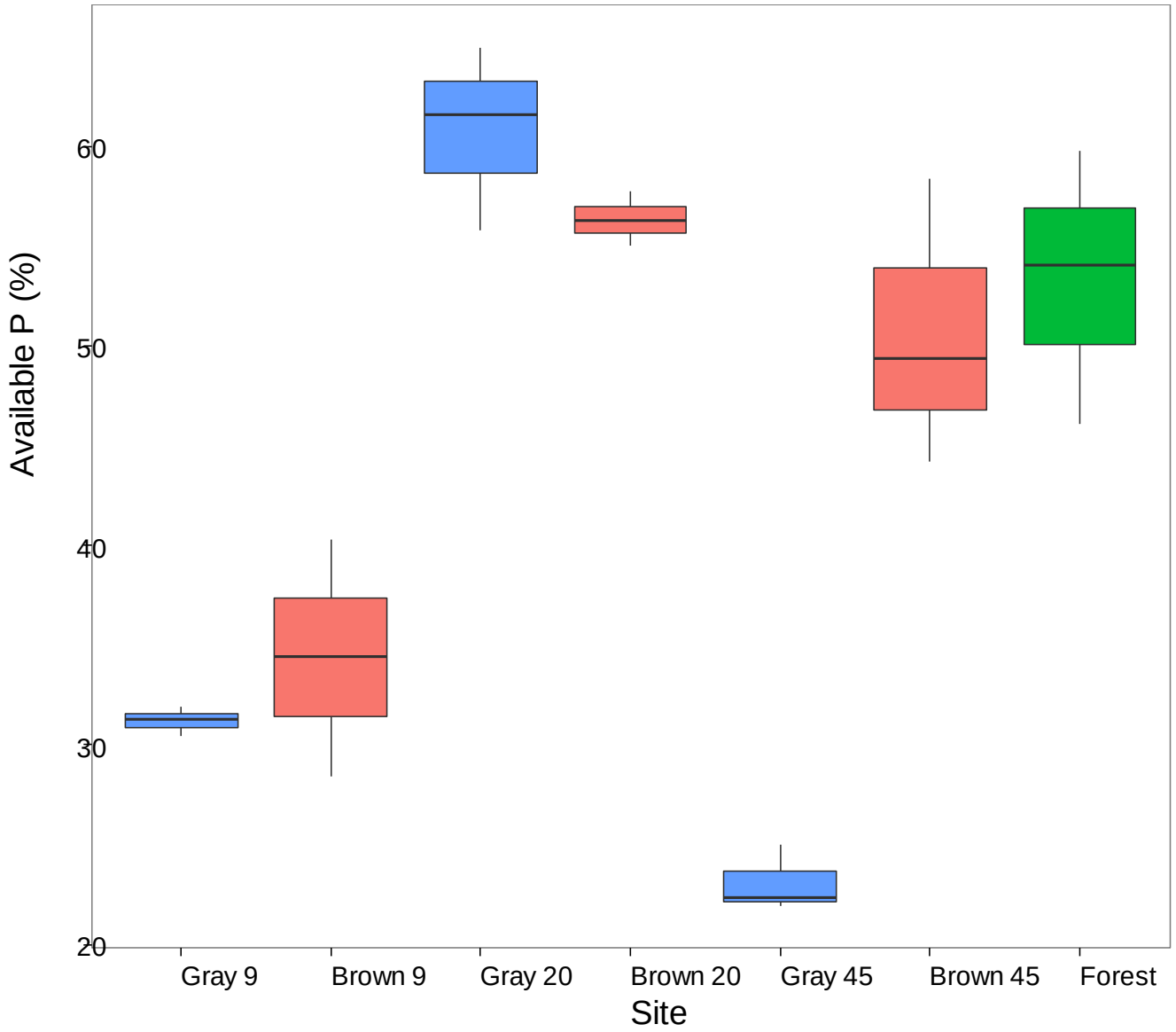
Results


Available Ca (%)
100
75
50
25
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Results


Available Mg (%)
60
40
20
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Results


Available P (%)
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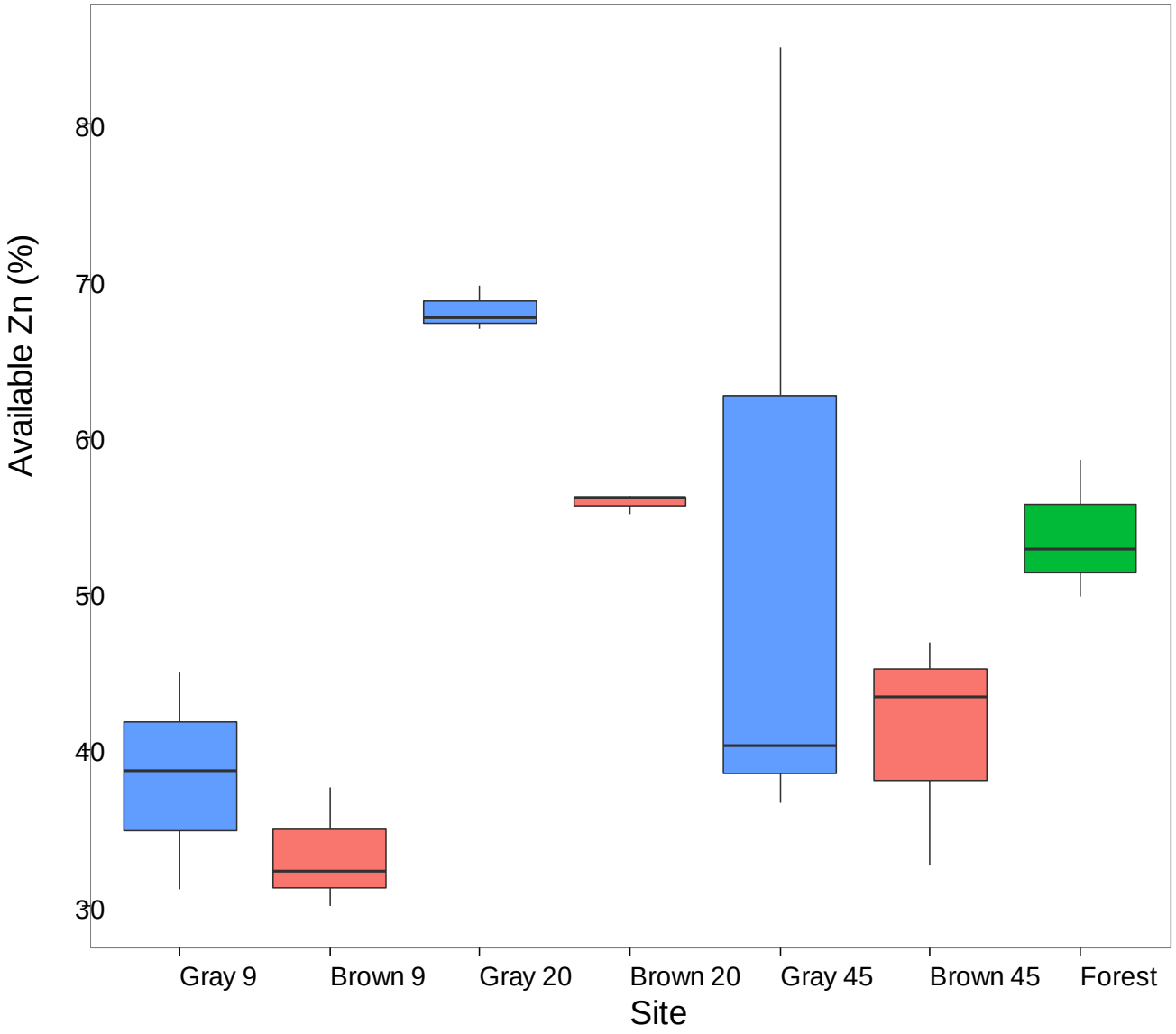
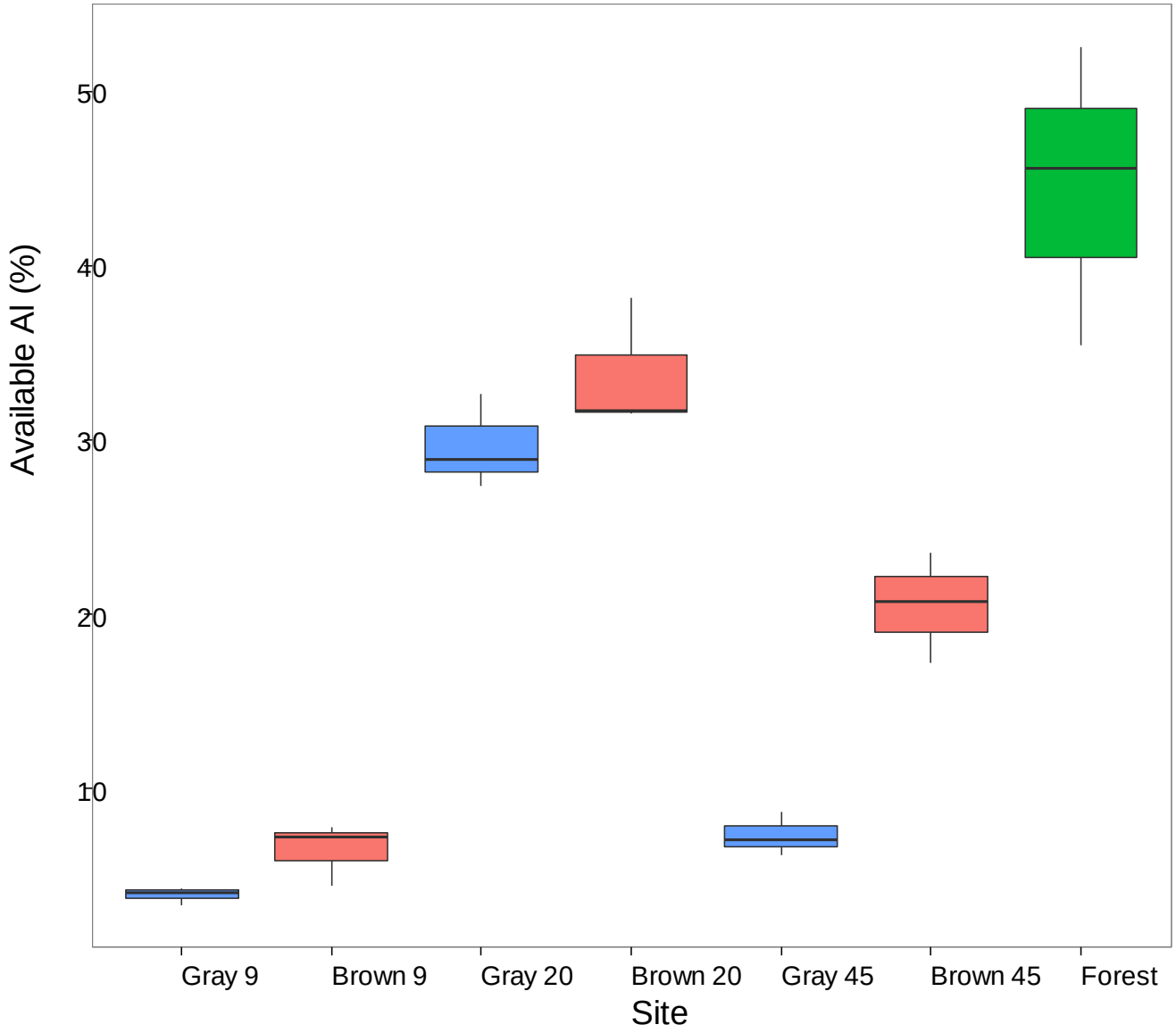
50
40
30
20
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Results


Available Zn (%)
80
70
60
50
40
30
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Results


Available Al (%)
50
40
30
20
10
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

Summary

By Age 45:

- **OM and pH similar to forest**

EC within acceptable range for tree growth

Increase of nutrients from age 9 to 20?

- **Weathering increases nutrients initially**
- **Less plant uptake**

Decrease from age 20 to 45?

- **Nutrient storage higher in above ground biomass or organic layers**
- **Immobilization as secondary minerals**

Questions?

Angel, P., C. Barton, R. Warner, C.Agouridis, T. Taylor, and S. Hall. 2008. Forest establishment and water quality characteristics as influenced by spoil type on a loose-graded surface mine in eastern Kentucky. p. 28-65. *In:* Barnhisel, R. (ed), Proceedings, 2008 American Society of Mining and Reclamation. June 4-8, 2008. Richmond, VA.

Angel, P.N., D.H. Graves, C. Barton, R.C. Warner, P.W. Conrad, R.J. Sweigard, and C. Agouridis. 2006. Surface mine reforestation research: evaluation of tree response to low compaction reclamation techniques. p. 45-58. *In:* Barnhisel, R. (ed.), Proceedings, 2006 American Society of Mining and Reclamation. March 26-30, 2006, St. Louis, MO.

Bise, J.B. 2013. Coal industry statistics. p. 1-23. *In* C.J. Bise (ed.) Modern American coal mining methods and applications. Society for Mining, Metallurgy, and Exploration, Inc. Englewood, CO.

Burger, J.A. 1999. Academic research perspective on experiences, trends, constraints and needs related to reforestation of mined lands. p. 63-74. In: Proceedings, Enhancements of Reforestation at Surface Coal Mines: Technical Interactive Forum, March 23-24, 1999. Fort Mitchell, KY.

Burger, J., D. Graves, P. Angel, V. Davis, and C. Zipper. 2005. The forestry reclamation approach. Forest Reclamation Advisory No. 2. p. 4. Available at http://arri.osmre.gov/Publications/Publications.shtm#FRAs. Accessed 8 January 2015.

Carmean, W.H. 1975. Forest quality evaluation in the United Sates. Advances in Agronomy. 27: 209-269.

Carmean, W.H. 1977. Site classification for northern forest species. p. 205-239. *In:* Intensive Culture of Northern Forest Types Symposium Proceedings. USDA Forest Service General Technical Report NE-29.

Carmean, W.H., J.T. Hahn, and R.D. Jacobs. 1989. Site index curves for forest species in the eastern United States. USDA Forest Service, North Central Forest Experiment Station. Gen. Tech. Rep. NC-128. St. Paul, MN.

Conrad, P.W., R.J. Sweigard, V. Badaker, D.H. Graves, and C.D. Barton. 2008. The impact of surface applied mulches on selected physical properties of reclaimed mountaintop removal sits. Inter. J. Mining, Reclamation and Environment. 22:222-236.

Daniels, W.L. and D.F. Amos. 1985. Generating productive topsoil substitutes from hard rock overburden in the southern Appalachians. Env. Geochem. & Health. 7:8-15.

Emerson, P., J. Skousen, P. Ziemkiewicz. 2009. Survival and growth of hardwoods in brown versus gray sandstone on a surface mine in West Virginia. J. Environ. Qual. 38:1821-1829.

Haering, K.C., W.L. Daniels, and J.M. Galbraith. 2004. Appalachian mine soil morphology and properties: effects of weathering and mining method. Soil Sci. Soc. Am. J. 68:1315-1325.

Rodrigue, J.A. and J.A. Burger. 2004. Forest Soil productivity of mined land in the Midwestern and Eastern coalfield regions. Soil Sci. Soc. Am. J. 68:833–844.

Sena, K., C. Barton, S. Hall, P. Angel, C. Agouridis. 2014. Influence of spoil type on afforestation success and natural vegetation recolonization on a surface coal mine in Appalachia, United States. Restoration Ecology. Available at http://onlinelibrary.wiley.com/doi/10.1111/rec.12164/pdf. Accessed 08 February 2015.

Skousen, J. Showalter, J.M., J.A. Burger, and C.E. Zipper. 2010. Hardwood seedling growth on different mine spoil types with and without amendment. J. Environ. Qual. 39: 483-491.

Skousen, J., , C. Zipper, J. Burger, C. Barton, and P. Angel. 2011. Selecting materials for mine soil construction when establishing forests on Appalachian mine sites. Forest Reclamation Advisory No. 8. p. 6. Available at http://arri.osmre.gov/FRA/Advisories/FRA_No.8%20Soil%20Materials.pdf. Accessed 08 February 2015.

Smith, H.C. 1983. Growth of Appalachian hardwoods kept free to grow from 2 to 12 years after clearcutting. USDA Forest Service, Northeastern Forest Experiment Station. Res. Paper. NE-528. Broomall, PA.

Thomas, C., and J. Skousen. 2011. Hardwood tree performance on amended brown and gray mine spoils after four years. p. 665-675. *In:* Barnhisel, R. (ed.), Proceedings, 2011 American Society of Mining and Reclamation, June 12-16, 2011. Bismark, ND.

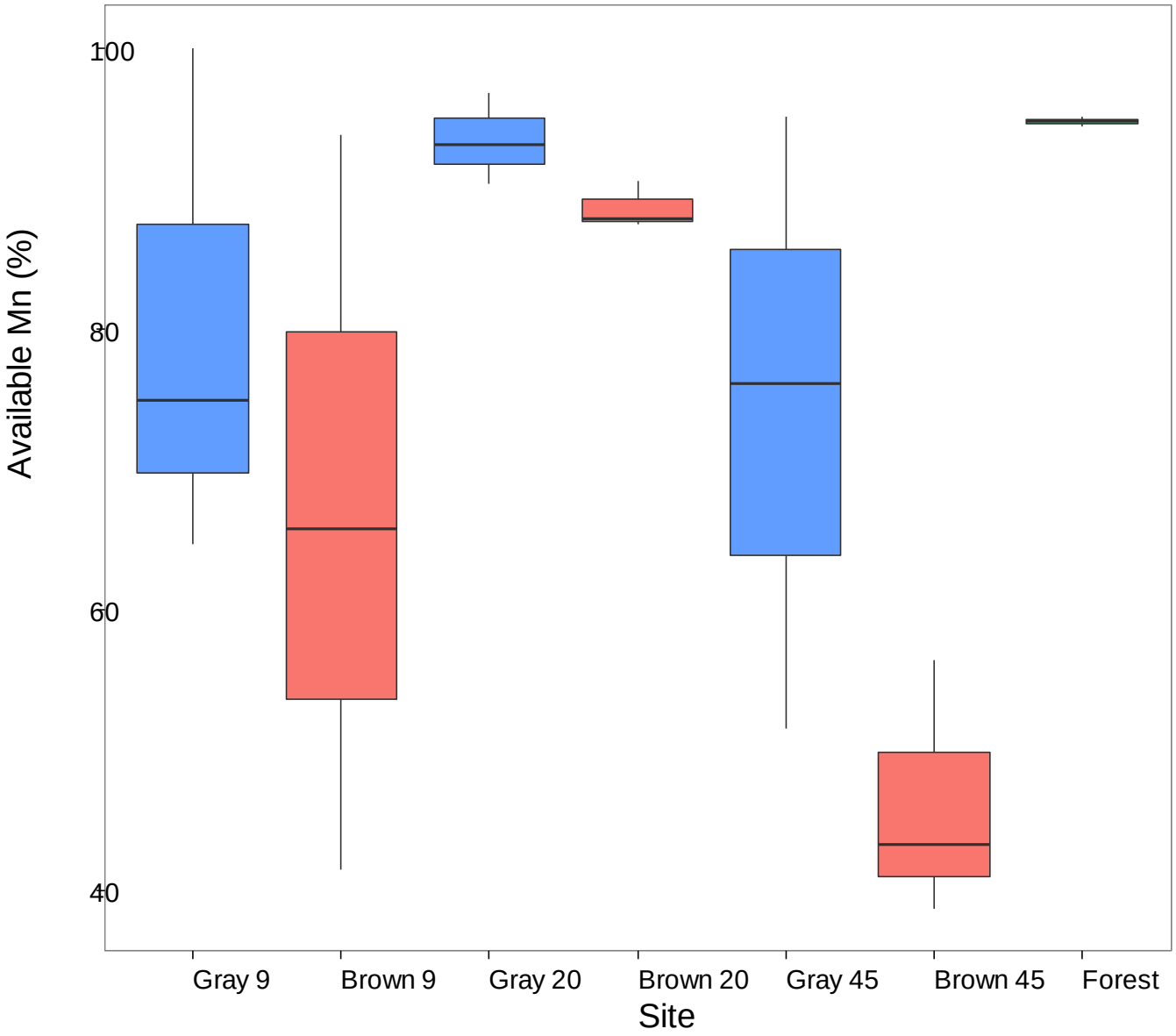
Trimble, G.R. 1973. Response to crop-tree release by 7-year old stems of yellow-poplar and black cherry. USDA Forest Service, Northeastern Forest Experiment Station. Res. Paper. NE-253. Upper Darby, PA.

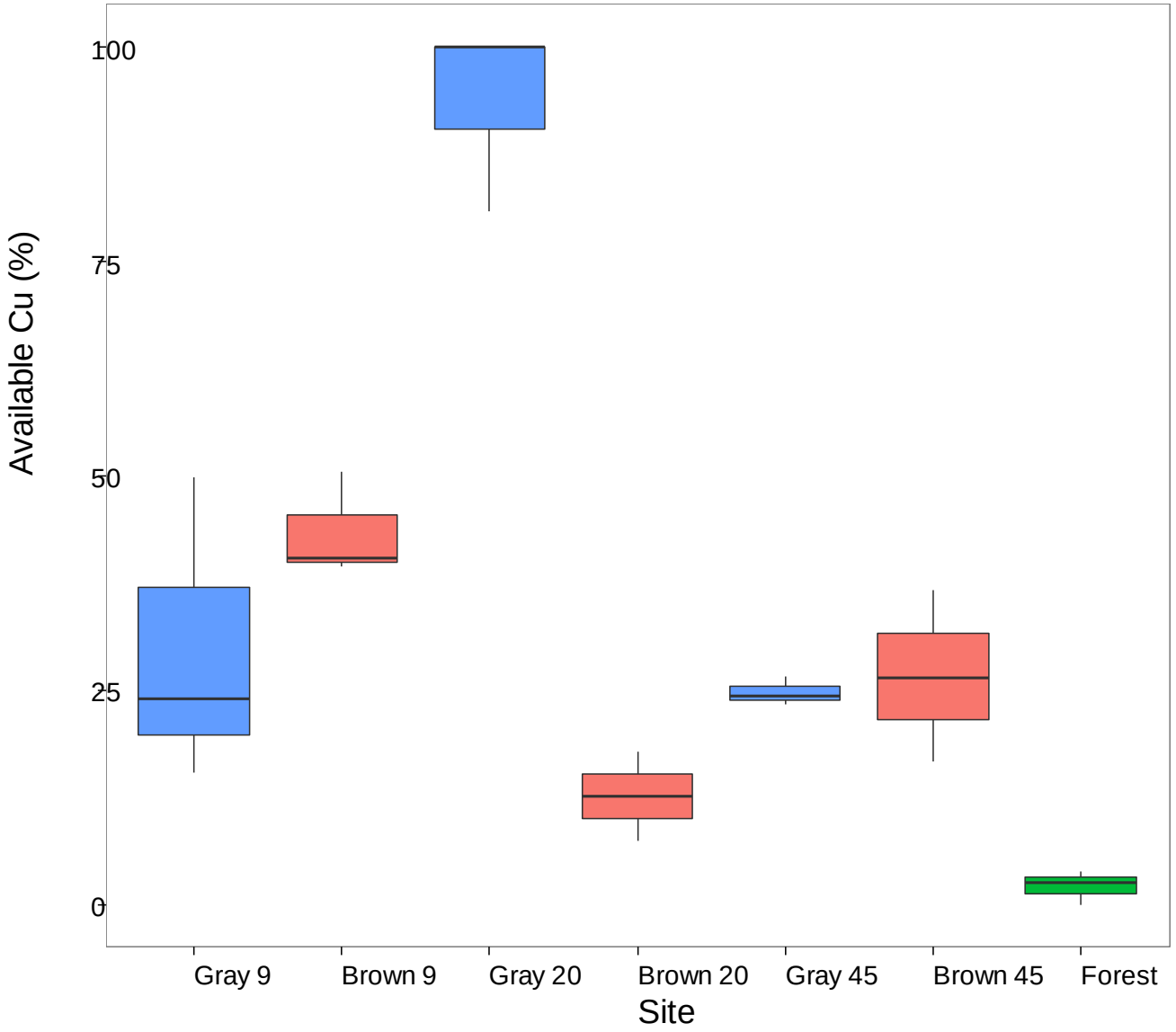
U.S. Energy Information Administration (EIA). 2013. Annual coal report 2012. Available at http://www.eia.gov/coal/annual/pdf/acr.pdf. Accessed 19 January 2015.

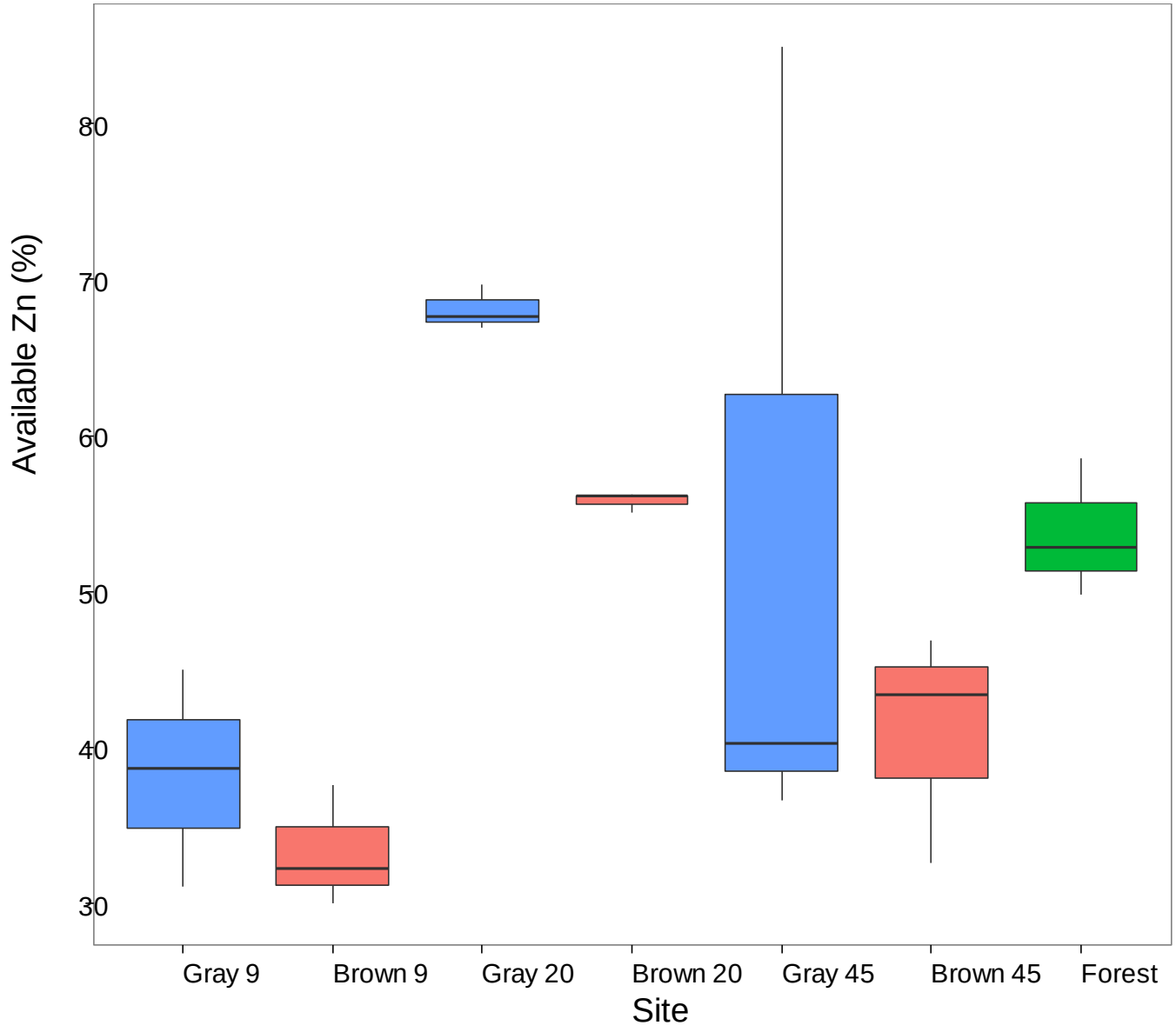
USDA. 2014b. Web Soil Survey. Available online athttp://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. Accessed 01 February 2015.

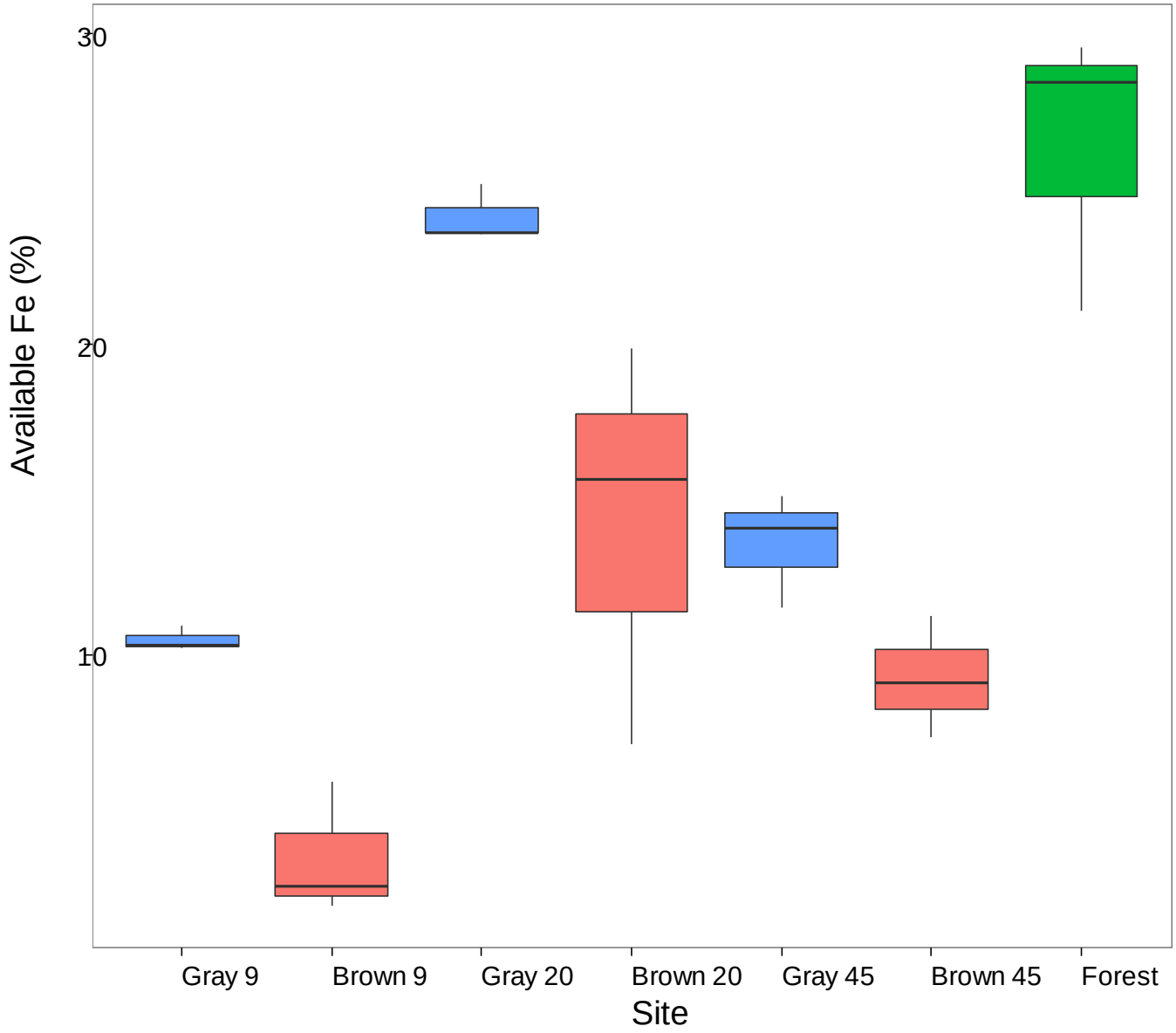
Wilson-Kokes, L., C. Delong, C. Thomas, P. Emerson, K. O'Dell, and J. Skousen. 2013a. Hardwood tree growth on amended mine soils in West Virginia. J. Environ. Qual. 42:1363-1371.

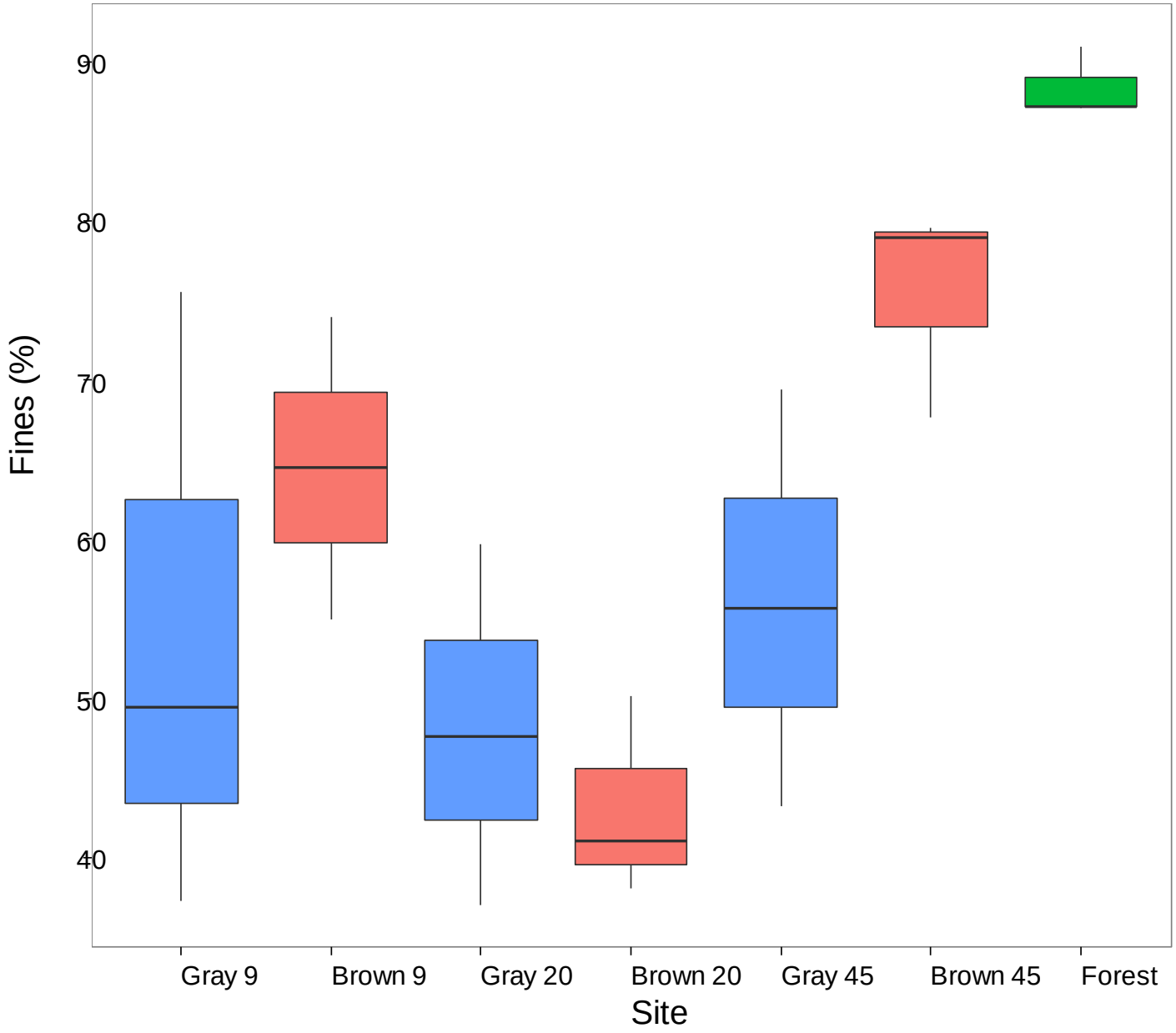
Wilson-Kokes, L., P. Emerson, C. Delong, C. Thomas, and J. Skousen. 2013b. Hardwood tree growth after eight years on brown and gray mine soils in West Virginia. J. Environ. Qual. 43:1353-1362.

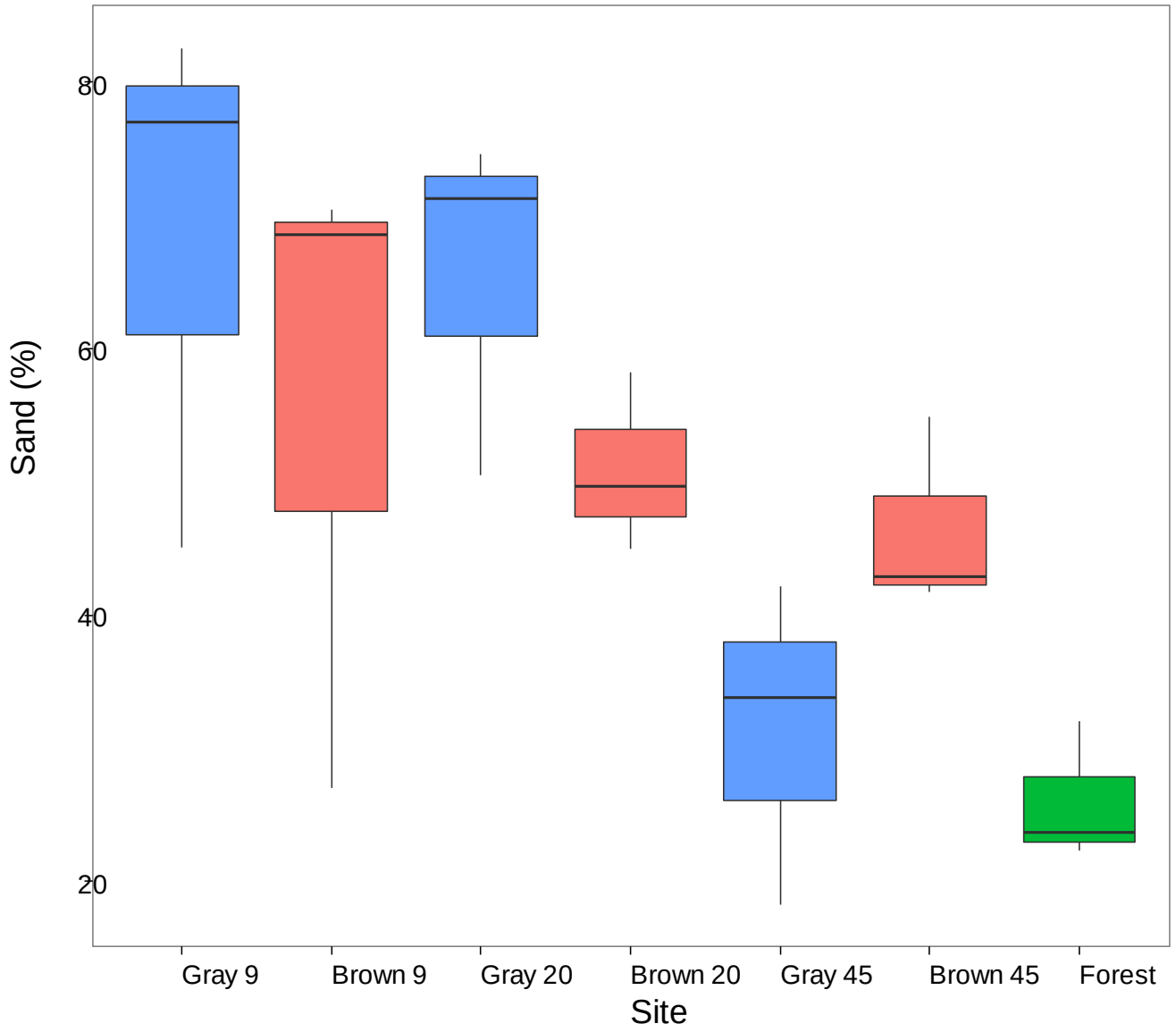

Available Mn (%)
100
80
60
40
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

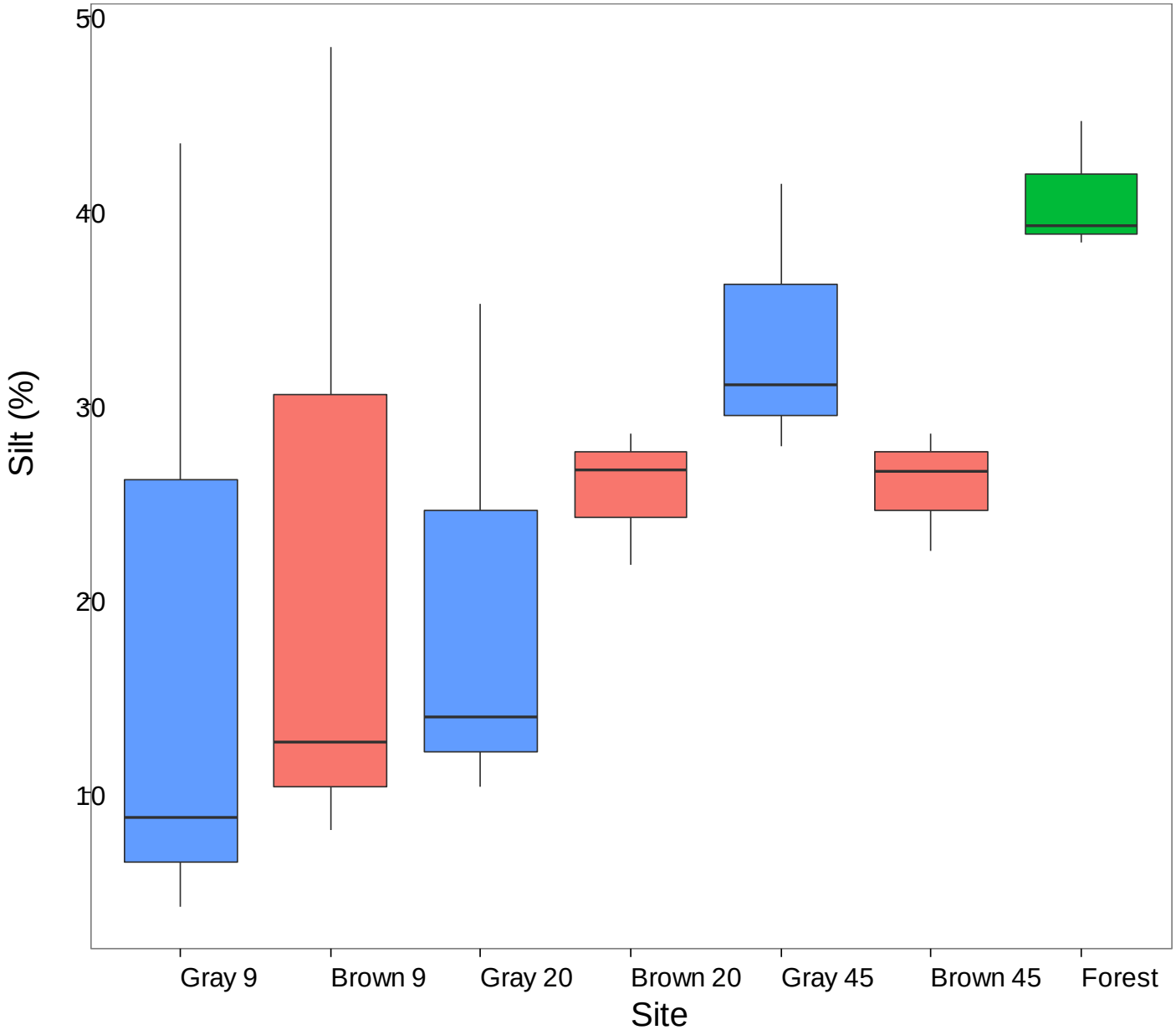

Available Cu (%)
100
75
50
25
0
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site

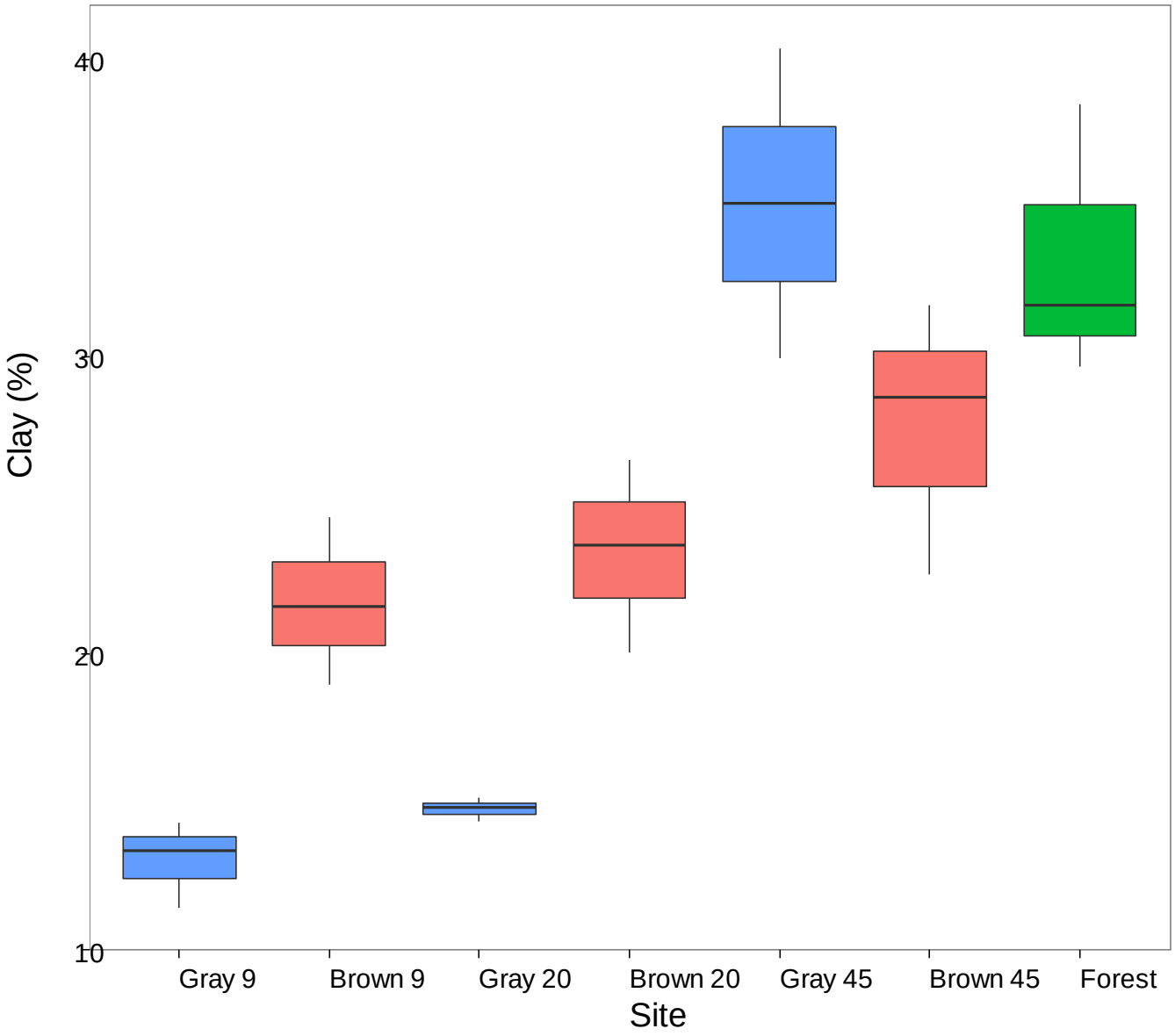

Available Zn (%)
80
70
60
50
40
30
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site


30
20
10
Available Fe (%)
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site


Fines (%)
90
80
70
60
50
40
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site


Sand (%)
80
60
40
20
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site


50
40
30
20
10
Silt (%)
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site


Clay (%)
40
30
20
10
Gray 9
Brown 9
Gray 20
Brown 20
Gray 45
Brown 45
Forest
Site