Soil Vital Signs: A New Index for Assessing Forest Soil Health

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Objective:

To integrate all the FIA measured physical and chemical properties of soils into a single index value as an indicator of forest soil quality or health

Approach:

•Each measured mineral soil physical or chemical property is assigned an index number of -1, 0, 1, or 2 depending on whether its numerical value is above or below assigned threshold values.
•Threshold values were selected based on known physiological responses of vegetation to soil properties, or in the absence of plant response data, threshold values were based on the relative distribution of soil property values in the entire database of FIA soil samples (Table 1).
•A soil property index of 0 indicates a suboptimal level of a nutrient or a potentially deleterious level of a measured property. An index of 1 indicates an acceptable level of a property and an index of 2 indicates an optimal level. An index of -1 is assigned to exceptionally low pH and low Ca soils.
•All the individual index levels are summed to obtain an overall soil quality index. This summary index is divided by the number of measured soil properties to express the index as a percentage of the total number of properties used to calculate the index. Thus, missing values do not contribute to the index. The percentage index is then re-scaled by dividing by the maximum possible percentage.

Soil quality index, % = (∑ individual soil property indexes/ (number of soil properties*maximum possible percentage))*10000

Table 1. Soil property threshold values and associated index values

Parameter	Level	Interpretation	Index
Bulk density	> 1.5 g/cm^3	Possible adverse effects	0
	< 1.5 g/cm^3	Adverse effects unlikely	1
Coarse fragments	> 50 %	Possible adverse effects	0
	< 50 %	Adverse effects unlikely	1
Soil pH	< 3.0	Severely acid – almost no plants can grow in this environment	-1
	3.0 – 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals	0
	4.0 – 5.5	Moderately acid – growth of acid intolerant plants is affected depending on levels of extractable Al, Mn, and other metals	1
	5.5 – 6.8	Slightly acid – optimum for many plant species, particularly more acid tolerant species	2
	6.8 - 7.2	Near neutral – optimum for many plant species except those that prefer acid soils	2
	7.2 – 7.5	Slightly alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and some metals (e.g., Zn)	1
	7.5 – 8.5	Moderately alkaline – preferred by plants adapted to this pH range, possible P and metal deficiencies	1
	> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities	0
Total organic carbon in mineral soils	> 5 %	High – excellent buildup of organic C with all associated benefits	2
	1 – 5 %	Moderate – adequate levels	1
	< 1 %	Low – could indicate possible loss of organic C from erosion or other processes, particularly in temperate or colder areas	0
Total nitrogen in mineral soils	> 0.5 %	High – excellent reserve of nitrogen	2
	0.1 – 0.5 %	Moderate – adequate levels	1
	0.1 %	Low – could indicate loss of organic N	0
Exchangeable Na percentage (exchangeable Na/ECEC x 100)	> 15 %	High – sodic soil with associated problems	0
	< 15 %	Adverse effects unlikely	1
K	> 500 mg/kg	High – excellent reserve	2
	100 – 500 mg/kg	Moderate – adequate levels for most plants	1
	< 100 mg/kg	Low – possible deficiencies	0
Mg	> 500 mg/kg	High – excellent reserve	2
	50 – 500 mg/kg	Moderate – adequate levels for most plants	1
	< 50 mg/kg	Low – possible deficiencies	0
Ca	> 1000 mg/kg	High – excellent reserve, probably calcareous soil	2
	100 – 1000 mg/kg	Moderate – adequate levels for most plants	1
	10 – 100 mg/kg	Low – possible deficiencies	0
	< 10 mg/kg	Very low – severe Ca depletion, adverse effects more likely	-1
Al	> 100 mg/kg	High – adverse effects more likely	0
	10 – 100 mg/kg	Moderate – only Al sensitive plants likely to be affected	1
	1 – 10 mg/kg	Low – adverse effects unlikely	2
	< 1 mg/kg	Very low – probably an alkaline soil	2
Mn	> 100 mg/kg	High – possible adverse effects to Mn sensitive plants	0
	10 – 100 mg/kg	Moderate – adverse effects or deficiencies less likely	1
	1 -10 mg/kg	Low - adverse effects unlikely, possible deficiencies	1
	< 1 mg/kg	Very low – deficiencies more likely	0
Fe	> 10 mg/kg	High – effects unknown	1
	0.1 – 10 mg/kg	Moderate – effects unknown	1
	< 0.1 mg/kg	Low – possible deficiencies, possibly calcareous soil	0
Ni	> 5 mg/kg	High – possible toxicity to Ni sensitive plants, may indicate serpentine soils, mining areas, or industrial sources of Ni	0
	0.1 – 5 mg/kg	Moderate – effects unknown	1
	< 0.1 mg/kg	Low – adverse effects highly unlikely	1
Cu	> 1 mg/kg	High – possible toxicity to Cu sensitive plants, may indicate mining areas or industrial sources of Cu	0
	0.1 – 1 mg/kg	Moderate – effects unknown, but adverse effects unlikely	1
	< 0.1 mg/kg	Low – possible deficiencies in organic, calcareous, or sandy soils	0
Zn	> 10 mg/kg	High – possible toxicity to Zn sensitive plants, may indicate mining areas or industrial sources of Zn	0
	1 -10 mg/kg	Moderate – effects unknown, but adverse effects unlikely	1
	< 1 mg/kg	Low – possible deficiencies in calcareous or sandy soils	0
Cd	> 0.5 mg/kg	High – possible adverse effects	0
	0.1 – 0.5 mg/kg	Moderate – effects unknown, but adverse effects less likely	1
	< 0.1 mg/kg	Low – adverse effects unlikely	1
Pb	> 1 mg/kg	High – adverse effects more likely, may indicate mining areas or industrial sources of Pb	0
	0.1 – 1 mg/kg	Moderate – effects unknown, but adverse effects less likely	1
	< 0.1 mg/kg	Low – adverse effects unlikely	1
S	> 100 mg/kg	High – may indicate gypsum soils, atmospheric deposition, mining areas, or industrial sources	0
	1 – 100 mg/kg	Moderate – adverse effects unlikely	1
	< 1 mg/kg	Low – possible deficiencies in calcareous or sandy soils	0
0.03 M NF_4 + 0.025 M HCl (Bray 1) P	> 30 mg/kg	High – excellent reserve of available P for plants in acid soils, possible adverse effects to water quality from erosion of high P soils	1
	15 – 30 mg/kg	Moderate – adequate levels for plant growth	1
	< 15 mg/kg	Low – P deficiencies likely	0
pH 8.5, 0.5 M $NaHCO_3$ (Olsen) P	> 30 mg/kg	High – excellent reserve of available P in slightly acidic to alkaline soils, possible adverse effects to water quality from erosion of high P soils	1
	10 – 30 mg/kg	Moderate – adequate levels for plant growth	1
	< 10 mg/kg	Low – P deficiencies likely	0

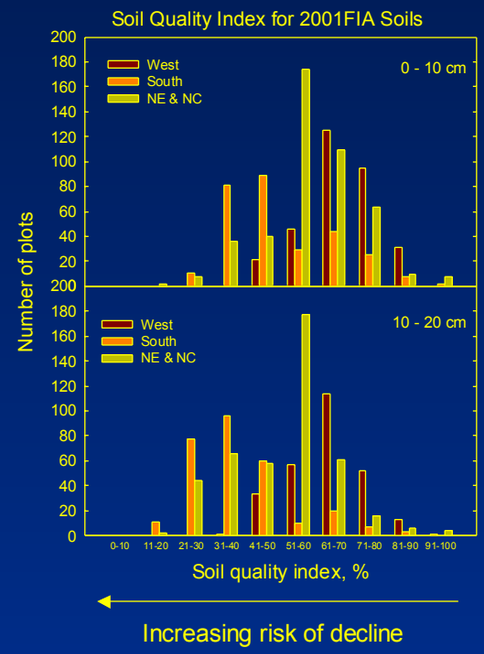

Fig. 1. Histogram of soil quality index values for FIA soil samples collected in 2001

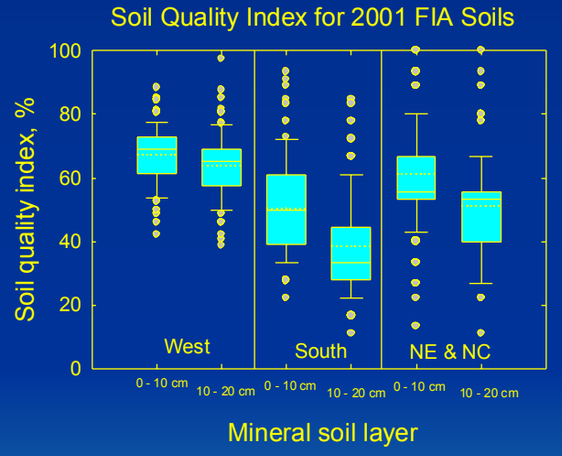

Fig. 2. Box plot of soil quality index values for FIA soil samples collected in the western states in 2001. The 25th and 50th percentiles are shown as a box around the median (solid line) value. The mean is shown as a dotted line. The 10th and 90th percentiles are shown as error bars and outliers are shown as points.

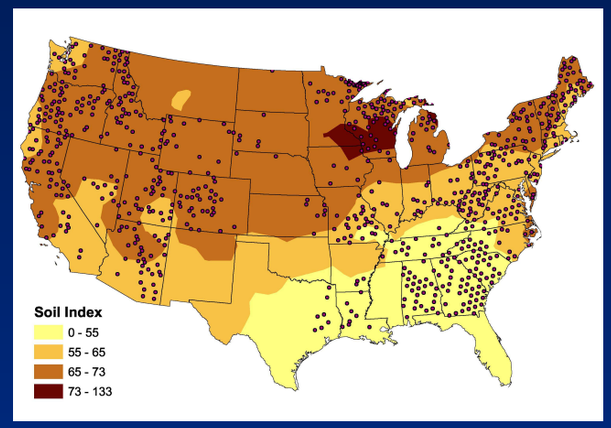

Fig. 3. National distribution of soil quality index values for FIA soil samples collected in 2001.

Table 2. Minimum, mean, and maximum soil quality index values for FIA soil samples collected in 2001

Region	Soil mineral layer	Minimum, %	Mean, %	Maximum, %
West	0 – 10 cm	42	67	89
	10 – 20 cm	39	64	97
South	0 – 10 cm	22	50	93
	10 – 20 cm	11	39	84
NE & NC	0 – 10 cm	13	62	100
	10 – 20 cm	11	51	100

Summary:

•The soil quality index is a measure (i.e., vital sign) of overall forest soil health.
•Most of the soils sampled in the FIA program have a soil quality index in the 30 to 80 range (Figs. 1 & 2, Table 2).
•The 10 – 20 cm layer tends to have lower soil quality index values than the 0 – 10 cm layer because it tends to have a higher bulk density, higher acidity, and lower organic matter and nutrient contents.
•More highly weathered soils in the south and east tend to have lower soil quality index values than western soils (Fig. 3).
•Low soil quality index values indicate an increased risk of forest health decline, while higher index values indicate a decreased risk of decline.