SOIL TEST INTERPRETATIONS

AND

RECOMMENDATIONS HANDBOOK

Originally written 1983
By Daryl D. Buchholz

Revised
5/2004

Contributors:
James R. Brown
Deanna K. Crocker
John D. Garrett
Roger G. Hanson
John A. Lory
Manjula V. Nathan
Peter C. Scharf
Howell N. Wheaton

University of Missouri – College of Agriculture

Division of Plant Sciences

TABLE OF CONTENTS

List of Tables

LIST OF FIGURES

INTRODUCTION

This handbook contains information relating to soil test interpretations, and fertilizer and limestone suggestions used by the University of Missouri Soil Testing Service. This information is used with chemical soil tests currently used by the University of Missouri soil testing labs.

This handbook is designed to facilitate individuals familiar with Missouri's soil testing program in deriving interpretations and suggested treatments based upon soil test levels.

Major contributors to this handbook include Daryl D. Buchholz, James R. Brown, Roger G. Hanson, Howell N. Wheaton, John D. Garrett, Robin R. Rodriguez, Don Backfisch, John Lory, Peter Scharf, and Manjula Nathan.

Figures 1, 2, and 3 are the front and back of the Soil Information Form (MP-188) and the Soil Test Report Form (MP-189) currently being used.

Various other sources should be consulted for more in-depth discussion of soil test interpretations and information on Missouri's soil testing program. These sources include:

Fisher, T. R. 1974. Some Considerations for Interpretations of Soil Tests for Phosphorus and Potassium. Missouri Agricultural Experiment Station Research Bulletin No. 1007.

Brown, J. R., R. G. Hanson, and D. D. Buchholz. 1980. Interpretations of Missouri Soil Test Results. University of Missouri Agronomy Department Miscellaneous Publication 80-04.

Brown, J. R. and Robin R. Rodriguez. 1982. Soil Testing in Missouri. University of Missouri Extension Circular 923.

Computer programming assistance has come through Deanna Crocker, Michael Hess, Ken Kuebler, Mark Gardner, and Richard Ahrens.

The author would also like to thank the many members of the Agronomy Department who have been involved in various ways in helping to establish meaningful soil test interpretations and suggested fertilizer and limestone application rates.

Nitrogen

The Soil Test

Nitrogen is a mobile nutrient in the soil. Nearly all soils in Missouri require nitrogen for optimum production of crops requiring nitrogen uptake. The soil test used to estimate the nitrogen-supplying power is the organic matter test. Some nitrogen adjustments are also made on the basis of soil texture and time of year that the major portion of the crop growth takes place. Table I outlines the nitrogen-supplying power of soils for nearly all row crops and small grains.

The Rating System

Soils are not rated on the basis of organic matter content. This is because rapid changes in organic matter do not occur under normal crop management. As can be noted, soils containing higher amounts of organic matter generally are capable of releasing higher quantities of nitrogen.

The Recommendations

A. Forages

Nitrogen recommendations on forage crops generally make no adjustments on the basis of organic matter. Legumes fix their own nitrogen and, therefore, generally, do not have recommendations for additional nitrogen fertilizer. Table II lists the nitrogen recommendation equations used for all forage crops that do need nitrogen. Crops not listed have no nitrogen requirement.

B. Row Crops and Small Grains

Nitrogen needs for a crop are determined on the need to produce the vegetation and grain portions. The crop needs for nitrogen on a per unit basis are given in Table III. Total nitrogen needs are calculated using the equation:

$$NR = (V_m)\ (N_v) + (Y_g)\ (N_g)$$

Where: NR = total nitrogen requirement
V_m = pounds of vegetative material per acre
N_v = pounds nitrogen per pound of vegetative material
Y_g = Yield goal
N_g = pounds of nitrogen per yield unit (grain)

Nitrogen requirements (NR) minus the nitrogen-supplying power of the soil (Table I) based on organic matter content will indicate the nitrogen rate necessary to produce the yield goal for the selected crop.

Table IV outlines nitrogen calculations used for each row or small grain crop in obtaining nitrogen requirements.

Cotton (Crop Code 102) nitrogen recommendations are not dependent upon organic matter but, rather, the soil texture as indicated by cation exchange capacity. The equation used for determining nitrogen recommendations on cotton is:

$$NR = 0.1 * (yield - 500) + CEC + 50$$

with the limits of the lowest recommended rate being 50 pounds nitrogen per acre. No adjustment is made on the basis of soil organic matter.

Corn (Crop code 103) nitrogen requirements are adjusted on the basis of yield goal and the assumed population required to achieve a given yield level. These populations are as follows:

----------Dryland----------		----------Irrigated----------	
Yield Goal	Population	Yield Goal	Population
bu/a	**plants/a**	**bu/a**	**plants/a**
< 60	14,000	< 140	20,000
60-99	16,000	140-179	23,000
100-119	18,000	180-219	26,000
120-139	20,000	220-259	29,000
140-169	22,000	> 260	32,000
> 170	25,000		

The total nitrogen requirements can be determined using this basic equation:
NR = (population/acre) x (4 lbs N/1000 plants) + (0.9 lbs N/bu) x (Yield Goal)

This total nitrogen requirement should then be reduced according to the nitrogen-supplying power of the soil (Table I).

Table I. Nitrogen rate adjustments based upon soil texture and organic matter for warm-season grain and row crops.

Soil Texture	Cation Exchange Capacity	Organic Matter	Soil N Credit
	meq/100g	(%)	lbs. N/A
Sand – Sandy loam	≤ 10	≤ 0.5	20
		0.6 to 1.4	OM x 40
		≥ 1.5	60
Silt loam – Loam	10-18	≤ 2.0	40
		2.1 to 3.9	OM x 20
		≥ 4.0	80
Clay loam - Clay	≥ 18	≤ 2.0	20
		2.1 to 4.9	OM x 10
		≥ 5.0	50

Table II. Equations for determining nitrogen requirements on forage crops

Crop Code	Crop	N recommendation equation	
1	Alfalfa, Alfalfa – Grass Establishment		
3	Clover, Clover – Grass Establishment	Organic Matter	Lbs. N/acre
		< 2.0%	30
		≥ 2.0	20
4	Cool Season Grass Establishment	≤ 1.9%	40
		2.0 – 2.9%	30
		≥ 3/0%	20
8	Wildlife food plot	117 – OM adjustment	
9	Bermudagrass establishment	≤ 1.9%	40
		2.0 – 2.9%	30
		≥ 3/0%	20
13	Bluegrass Pasture	(Yield goal) x (0.6 # N/cow day)	
14	Bermudagrass Hay	(Yield goal) x (50 # N/Ton)	
15	Bermudagrass Pasture	(Yield goal) x (0.6 # N/cow day)	
18	Cool Season Grass Hay	(Yield goal) x (40 # N/Ton)	
19	Cool Season Grass Pasture	(Yield goal) x (0.6 # N/cow day)	
20	Cool Season Grass-Seed, Residue Hay or Pasture	100-130 lbs. N/acre	
21	Cool Season Grass – Stockpile Fall Growth	160 lbs. N/acre	
24	Sudangrass and etc. Hay	(Yield goal) x (40#N/Ton)	
25	Sudangrass and etc. Pasture	(Yield goal) x (0.6#N/cow day)	
26	Warm Season Grass Hay	60 lbs. N/acre	
27	Warm Season Grass Pasture		

Table III. Nitrogen values for use in recommending N fertilizer for row crops and small grains

			Vegetative*			Harvested Product		
Crop Code	Crop	Yield Unit	Yield Lbs/A	N %	Needed*** lbs/A	N %	Lb. N per Yield Unit	Soil OM+ Adjustment
100	Barley	bu/A	3000	0.6	18	2.0	0.96	no
101	Buckwheat	lbs/A	2000	2.5	50	5.0	.05	yes
102	Cotton	lbs/A	-	-	-	-	-	no
103	Corn, grain	bu/A	SEE TEXT			1.6	0.9	yes
104	Corn silage	T/A	-	-	-	0.45	9.0	yes
105	DC** - Wheat + Soybeans	bu/A	same as wheat----------					no
106	DC – Wheat + Sunflower	bu/A	same as wheat----------					no
107	DC – Wheat + Grain Sorghum	bu/A	same as wheat----------					no
108	DC – Wheat + Sorghum Silage	bu/A	same as wheat----------					no
109	Oats	bu/A	4000	0.6	24	2.0	0.64	no
110	Popcorn	lbs/A	6000	1.2	72	1.6	0.016	yes
111	Rice	lbs/A	5000	0.6	30	1.3	0.013	yes
112	Rye	bu/A	3000	0.5	15	2.1	1.18	no
113	Grain Sorghum	lbs/A	6000	1.0	60	1.4	.014	yes
114	Sorghum Silage	T/A	NA	NA	NA	.65	13.0	yes
115	Soybeans	bu/A	NA	NA	0	NA	0	no
116	Sugarbeets	T/A	-	-	-	-	4.0	yes
117	Sunflower	lbs/A	3000	1.0	30	2.6	.026	yes
118	Tobacco	lbs/A	-	-	145	3.6	.036	yes
119	Wheat	bu/A	3000	0.6	18	2.1	1.26	no

** DC = Double Crop

* Vegetative refers to stalks, stover, straw or crop residues. The yield is assumed for average conditions.

*** Needed N = Yield X (%N x 100)

+ See Table I

Table IV. Equations for determining nitrogen requirements of row and small grain crops.

Crop Code	Crop	
100	Barley	18 + (Yield goal) x (0.96) – (Organic Matter Adjustment)*
101	Buckwheat	12 + (Yield goal) x (0.02) – (Organic Matter Adjustment)*
102	Cotton	0.1 * (yield goal – 500) + CEC + 50
103	Corn, grain	$\left[\frac{\text{Plant population}}{1000}\right]$ x (4) + (0.9) x (Yield goal) – (Organic Matter Matter Adjustment)*
104	Corn, Silage	(Yield goal) x (9.0) – (Organic Matter Adjustment)*
105	Double crop	See wheat and soybeans.
106	Double crop	See wheat and sunflowers.
107	Double crop	See wheat and grain sorghum.
108	Double crop	See wheat and sorghum silage.
109	Oats	24 + (yield goal) x (0.64) – (Organic Matter Adjustment)*
110	Popcorn	72 + (Yield goal) x (0.016) – (Organic Matter Adjustment)*
111	Rice	30 + (Yield goal) x (0.013) – (Organic Matter Adjustment)*
112	Rye	15 + (Yield goal) x (1.18) – (Organic Matter Adjustment)*
113	Grain Sorghum	60 + (Yield goal) x (0.014) – (Organic Matter Adjustment)*
114	Sorghum silage	13 x (Yield goal) – (Organic Matter Adjustment)*
115	Soybeans	None Recommended
116	Sugarbeets	(4) x (Yield goal) – (Organic Matter Adjustment)*
117	Sunflowers	30 + (Yield goal) x (0.026) – (Organic Matter Adjustment)*
118	Tobacco	145 + (Yield goal) x (0.036) – (Organic Matter Adjustment)*
119	Wheat	18 + (Yield goal) x (1.26) – (Organic Matter Adjustment)*

* See Table I for organic matter adjustment.

AVAILABLE PHOSPHORUS

The Soil Test

The soil test to determine available phosphorus is the Bray I or weak Bray test. Results are expressed in pounds of P per acre.

The Rating System

Crops and crop rotations require different levels of available phosphorus. Generally, even in row crops, it is recognized that phosphorus response varies. Soybeans are not as responsive as corn or wheat, for example. However, it is suggested that phosphorus soil test levels be built to a sufficient level so as not to be limiting in general row crop production, regardless of the specific crop. Phosphorus soil test level suggested for row crops and small grains is 45 pounds P per acre. At this level, the potential for response to additional fertilizer phosphorus is low. A maintenance application of fertilizer is suggested for soil tests between 45 and 70 pounds of available P per acre. Forages do well at slightly lower levels of available phosphorus, with suggested soil test levels of either 30 or 40 lb P/acre. Table V lists fertility indices and the corresponding soil test levels. Fertility index for a given soil test level depends on the desired soil test level for a given crop. The equation used to determine fertility index when the soil test is less than desired is as follows:

$$FI = (200/STP_d) \times STP_o - (100/STP_d^2) \times STP_o^2$$

Where FI = fertility index
STP_d = desired soil test P level (30, 40, or 45 lbs. P/A)
STP_o = observed or actual soil test P level

The fertility index for soil test levels greater than the desired level is calculated using the equation:

$$FI = \frac{100 \times STP_o}{STP_d}$$

Table V. Bray I soil test ratings, fertility indices, and corresponding soil test values.

Rating	Fertility Index (FI)	Soil test levels corresponding to FI for desired Bray P-I Soil Test = 30	40	45
Very Low	0-50	0-9	0-12	0-14
Low	50-75	9-15	12-20	14-22
Medium	75-100	15-30	20-40	22-45
High	100-150	30-45	40-60	45-70
Very High	150-300	45-90	60-120	70-135
Extremely High	300 +	90 +	120 +	135 +

Information on the desired soil test level for each crop is given in Table VI.

General definitions and interpretations for ratings of soil tests are given in Table VII.

The Recommendations

Phosphorus soil test interpretations and subsequent fertilizer recommendations are based upon the concept of buildup plus maintenance fertilization outlined by T.R. Fisher in Missouri Agricultural Experiment Station Research Bulletin 1007 titled, "Some Considerations for Interpretation of Soil Tests for Phosphorus and Potassium" and dated December 1974.

The fertilizer suggestion can be defined by its two components, buildup and maintenance where:

Lbs. P_2O_5/acre = Buildup P_2O_5 + Maintenance P_2O_5

The first component provides for fertilizer P_2O_5 requirements to increase the soil test level to the desired level over a specified number of years.

The equation used to calculate annual buildup is:

$$\text{Buildup } P_2O_5 = 110 \times (STP_d^{0.5} - STP_o^{0.5})/\text{Years}$$

Where: STP_d = desired soil test level in lbs. P/A (30, 40, or 45)
STP_o = observed or actual soil test level
Years = suggested number of years to increase soil test to desired level

The desired Bray I soil test level and suggested number of years to increase soil test levels to the desired level are given in Table VI for each crop. Fertilizer P_2O_5 rates required to increase Bray I soil test levels to the desired level in 4 or 8 years are given in Table VIII.

Maintenance requirements are determined using the following equation:

$$\text{Maintenance } P_2O_5 = (\text{Yield goal}) \times (P_2O_5 \text{ removal/unit yield})$$

Phosphorus P_2O_5 removal is given for each crop in Table VI. In establishment of forages, no maintenance fertilizer is suggested. Double crop options utilize removal of both crops in maintenance calculations.

As phosphorus soil test levels increase above the desired level, response to fertilizer P_2O_5 addition is not likely. Therefore, only maintenance or less fertilizer is recommended using the following equation:

$$\text{Lbs. } P_2O_5/\text{acre} = (\text{Yield goal})\,(P_2O_5 \text{ removal}) \left[1 - \frac{2(FI-100)}{100} \right]$$

where: FI = the fertility index as calculated in previous section on rating system

When suggested P_2O_5 rates are less than 20 lbs/acre, but greater than zero, 20 lbs. P_2O_5/acre is suggested.

Table VI. Phosphorus removal and desired Bray P-1 soil test level for forages

Crop Code	Crop	Yield Unit	Phosphorus Removal lbs P_2O_5/ yield unit	Desired Soil Test Level lbs P/A	Suggested Years for Buildup
1	Alfalfa, alfalfa – grass establishment	-	-	45	4
2	Birdsfoot trefoil – grass establishment	-	-	30	4
3	Clover, clover - grass establishment	-	-	40	4
4	Cool season grass establishment	-	-	40	4
5	Lespedeza – grass establishment	-	-	30	4
6	Overseeding legumes into existing grass	-	-	40	4
7	Warm season grass establishment	-	-	30	4
8	Wildlife Food Plot	cwt	0.0093	45	8
9	Bermuda grass est	-	-	40	4
10	Alfalfa, alfalfa – grass hay	ton/a	10.0	40	8
11	Alfalfa – grass pasture	cd/a	0.05	40	8
12	Birdsfoot trefoil – grass pasture	cd/a	0.04	30	8
13	Bluegrass pasture	cd/a	0.05	40	8
14	Bermudagrass hay	ton/a	9.0	40	8
15	Bermudagrass pasture	cd/a	0.05	40	8
16	Clover, clover – grass hay	ton/a	8.2	40	8
17	Clover, Clover – grass pasture	cd/a	0.03	40	8
18	Cool season grass hay	ton/a	9.0	40	8
19	Cool season grass pasture	cd/a	0.05	40	8
20	Cool season grass seed	-	-	40	8
21	Cool season grass – stockpile Fall growth	-	-	40	8
22	Lespedeza – grass hay	ton/a	8.8	30	8
23	Lespedeza – grass pasture	cd/a	0.04	30	8
24	Sudangrass hay	ton/a	6.9	40	8
25	Sudangrass pasture	cd/a	0.03	40	8
26	Warm season grass hay	ton/a	2.0	30	8
27	Warm season grass pasture	cd/a	0.01	30	8

Table VI (continued). Phosphorus removal and desired Bray P-1 soil test level for row crops

Crop Code	Crop	Yield Unit	Phosphorus Removal lbs P_2O_5/ yield unit	Desired Soil Test Level lbs P/A	Suggested Years for Buildup*
100	Barley	bu/A	0.38	45	8
101	Buckwheat	lbs/A	0.007	45	8
102	Cotton	lbs/A	0.038	45	8
103	Corn (grain)	bu/A	0.45	45	8
104	Corn (silage)	ton/A	3.6	45	8
105	Double Crop: Wheat – Soybeans**	bu/A	-	45	8
106	Double Crop: Wheat – Sunflowers**	bu/A	-	45	8
107	Double Crop: Wheat – Grain Sorghum**	bu/A	-	45	8
108	Double Crop: Wheat – Sorghum silage**	bu/A	_	45	8
109	Oats	bu/A	0.26	45	8
110	Popcorn	lbs/A	0.008	45	8
111	Rice	lbs/A	0.0065	10	8
112	Rye	bu/A	0.34	45	8
113	Sorghum (grain)	lbs/A	0.0093	45	8
114	Sorghum (silage)	ton/A	4.6	45	8
115	Soybeans	bu/A	0.84	45	8
116	Sugarbeets	ton/A	1.33	45	8
117	Sunflowers	lbs/A	0.0083	45	8
118	Tobacco	bu/A	0.004	45	8
119	Wheat	bu/A	0.60	45	8
201	Southern peas	-	-	45	8

*Shorter buildup periods may be selected by the user and may be particularly appropriate for variable-rate fertilizer applications.
**Double crop maintenance P is calculated using the yield goal entered for wheat plus the assumed yields for double crops given in the appendix.

Table VII. Definitions of interpretive ratings for phosphorus and potassium soil tests

Rating	Fertility Index	Definition
Very Low	< 50	A large buildup of available nutrient is needed. Starters and banding will improve the efficiency of the fertilizer used.
Low	50-75	A moderate buildup is necessary. Banding of fertilizer may be beneficial.
Medium	75-100	A slight buildup is desired, which may be accomplished with applications slightly in excess of maintenance requirements.
High	100-150	No buildup is necessary. Available nutrient levels should be maintained with maintenance treatments.
Very High	150-300	The available nutrient level is presently adequate; no annual maintenance treatments are needed. Monitor the level of available nutrients by soil testing every three to four years.
Extremely High	> 300	The available nutrient level is sufficiently high so as to potentially cause nutrient imbalance. Use plant analysis to monitor the situation

Table VIII. Annual fertilizer P_2O_5 rates required to build Bray P-I soil test level to the desired level in 4 or 8 years.

Observed Bray P-I Soil Test Level (lbs. P/A)	Desired Bray P-I Soil Test Level (lbs. P/A)					
	30		40		45	
	4 yrs.	8 yrs.	4 yrs.	8 yrs.	4 yrs.	8 yrs.
	(lbs. P_2O_5/A)					
2	112	56	135	68	146	73
4	96	48	119	60	129	65
6	83	42	106	53	117	58
8	73	36	96	48	107	53
10	64	32	87	43	98	49
12	55	28	79	39	89	45
14	48	24	71	36	82	41
16	41	20	64	32	74	37
18	34	17	57	29	68	34
20	28	14	51	25	61	31
22	22	11	45	22	55	28
24	16	8	39	20	50	25
26	10	5	34	17	44	22
28	5	3	28	14	39	19
30	0	0	23	12	34	17
32	0	0	18	9	29	14
34	0	0	14	7	24	12
36	0	0	9	4	19	10
38	0	0	4	2	15	7
40	0	0	0	0	11	5
42	0	0	0	0	6	3
44	0	0	0	0	2	1

EXCHANGEABLE POTASSIUM

The Soil Test

The soil test used to determine the exchangeable potassium level is an extraction with neutral, one normal ammonium acetate. Results are recorded in pounds of K per acre. Cation exchange capacity (CEC) is also used in making interpretations and recommendations. The CEC is calculated by adding the milli-equivalents of calcium, magnesium, potassium, and hydrogen. CEC is expressed in milli-equivalents (meq) per 100 grams of soil.

The Rating System

Desired potassium soil test levels vary with crop to be grown and soil CEC. Forages, except pure alfalfa stands, have a desired potassium level of 160 lbs. K per acre plus 5 times the CEC. Row crops desire a level of 220 lbs. K per acre plus 5 times CEC.

As soil CEC increases, desired potassium soil test levels increase at a rate of 5 lbs. of K per acre with each 1 meq/100g of CEC. For example, corn growing on a soil with a CEC of meq/100g would have a desired potassium level of 220 + 5(10) = 270 lbs. K/acre.

Ratings for potassium are calculated using the following equation when soil test levels are less than desired:

$$FI = (200/STK_d) \times STK_o - (100/STK_d^2) \times STK_o^2$$

Where: FI = fertility index
STK_d = desired soil test K level (160 + 5(CEC) or 220 + 5(CEC) lb. K/ac)
CEC = cation exchange capacity (meq/100g)
STK_o = observed or actual soil test K level

When potassium soil tests are greater than desired, the fertility index is calculated using the equation:

$$FI = \frac{100 \times STK_o}{STK_d}$$

Relative ratings, fertility indices, and desired soil test levels interpretation information are given in Table XI.

The Recommendations

Suggested potassium fertilization rates are based on a concept very similar to phosphorus interpretations. The components of buildup and maintenance fertilization are again used.

The buildup component for potassium is designed to gradually increase the K soil test level to the desired level over about an 8-year period.
The equation used to calculate annual buildup is:

$$\text{Buildup } K_2O = \frac{75.5\ (STK_d^{0.5} - STK_o^{0.5})}{\text{Years}}$$

Where: STK_d = desired soil test level (160 + 5(CEC) or 220 + 5(CEC) lbs. K/acre)
STK_o = observed or actual soil test level (lbs. K/acre)
CEC = cation exchange capacity (meq/100g)
Years = suggested number of years to increase soil test to desired level

The desired K soil test level and suggested number of years to build up soil test levels to the desired level are given in Table X for each crop. Fertilizer K_2O rates necessary to build up K soil test levels over 8 years to a desired level of 160 + 5(CEC) and 220 + 5(CEC) are given in Tables XI and XII, respectively.

Maintenance fertilizer requirements are determined using the following equation:

$$\text{Maintenance } K_2O = (\text{Yield goal}) \times (K_2O \text{ removal/unit yield})$$

Potassium (K_2O) removal per yield unit is given for each crop in Table X. In establishment of forages, no maintenance fertilizer is suggested. Double crop options utilize removal of both crops in maintenance calculations.

The suggested fertilizer rate to use annually can then be determined by the equation:

$$\text{Suggested } K_2O/\text{acre} = \text{Buildup } K_2O + \text{Maintenance } K_2O$$

when the soil test for potassium is less than desired.

If the soil test for potassium is greater than the target level, crop use of soil available potassium is recommended to draw down the available K soil test level. Maintenance or partial

maintenance fertilizer rates are suggested when soil tests are in the high rating. Calculations for suggested K_2O rates when soil tests are high are made using the equation:

$$\text{Suggested } K_2O/\text{acre} = (\text{Yield goal})\,(K_2O \text{ removal}) \left[1 - \frac{2(FI-100)}{100}\right]$$

where: FI = the fertility index as calculated in the previous section on rating system.

When calculated potassium fertilizer rates are less than 20 lbs. K_2O/acre, but greater than zero, 20 lbs. K_2O/acre is suggested.

When soil test potassium is in the very high or extremely high range, no potassium fertilizer is suggested.

Table IX. Potassium soil test interpretations and ratings.

Rating	Fertility Index (FI)	Desired Exchangeable Potassium Level (lbs. K/A) 160 + 5 (CEC) CEC 6	160 + 5 (CEC) CEC 12	160 + 5 (CEC) CEC 18	220 + 5(CEC) CEC 6	220 + 5(CEC) CEC 12	220 + 5(CEC) CEC 18
		(lbs. K/A soil test)					
Very Low	0-50	0-56	0-65	0-74	0-74	0-83	0-91
Low	50-75	56-95	65-110	74-125	74-125	83-140	95-155
Medium	75-100	95-190	110-220	125-250	125-250	140-280	155-310
High	100-150	190-285	220-330	250-375	250-375	280-420	310-465
Very High	150-300	285-570	330-660	375-750	375-750	420-840	465-930
Extremely High	300+	570+	660+	750+	750+	840+	930+

Table X. Potassium removal and desired exchangeable potassium soil test level for forages

Crop Code	Crop	Yield unit	Potassium Removal lbs K_2O/ yield unit	Desired Soil Test Level lbs K/a	Suggested Years for Buildup
1	Alfalfa, alfalfa – grass establishment	-	-	220 + (5 x CEC)	8
2	Birdsfoot trefoil – grass establishment	-	-	160 + (5 x CEC)	8
3	Clover, clover - grass establishment	-	-	160 + (5 x CEC)	8
4	Cool season grass establishment	-	-	160 + (5 x CEC)	8
5	Lespedeza – grass establishment	-	-	160 + (5 x CEC)	8
6	Overseeding legumes into existing grass	-	-	160 + (5 x CEC)	8
7	Warm season grass establishment	-	-	160 + (5 x CEC)	8
8	Wildlife food plot	lb/a	0.006	220 + (5 x CEC)	8
9	Bermudagrass establishment	-	-	160 + (5 x CEC)	8
10	Alfalfa, alfalfa – grass hay	ton/a	45	220 + (5 x CEC)	8
11	Alfalfa – grass pasture	cd/a	0.23	160 + (5 x CEC)	8
12	Birdsfoot trefoil – grass pasture	cd/a	0.10	160 + (5 x CEC)	8
13	Bluegrass pasture	cd/a	0.15	160 + (5 x CEC)	8
14	Bermudagrass hay	ton/a	34	160 + (5 x CEC)	8
15	Bermudagrass pasture	cd/a	0.17	160 + (5 x CEC)	8
16	Clover, clover – grass hay	ton/a	38	160 + (5 x CEC)	8
17	Clover, Clover – grass pasture	cd/a	0.19	160 + (5 x CEC)	8
18	Cool season grass hay	ton/a	34	160 + (5 x CEC)	8
19	Cool season grass pasture	cd/a	0.17	160 + (5 x CEC)	8
20	Cool season grass seed	-	-	160 + (5 x CEC)	8
21	Cool season grass – stockpile Fall growth	-	-	160 + (5 x CEC)	8
22	Lespedeza – grass hay	ton/a	20	160 + (5 x CEC)	8
23	Lespedeza – grass pasture	cd/a	0.10	160 + (5 x CEC)	8
24	Sudangrass hay	ton/a	19	160 + (5 x CEC)	8
25	Sudangrass pasture	cd/a	0.09	160 + (5 x CEC)	8
26	Warm season grass hay	ton/a	14.6	160 + (5 x CEC)	8
27	Warm season grass pasture	cd/a	0.07	160 + (5 x CEC)	8

Table X (continued). Potassium removal and desired exchangeable potassium soil test level for row crops

Crop Code	Crop	Yield unit	Potassium Removal lbs K_2O/ yield unit	Desired Soil Test Level lbs K/a	Suggested Years for Buildup*
100	Barley	bu/a	0.24	220 + (5 x CEC)	8
101	Buckwheat	lbs/a	0.003	220 + (5 x CEC)	8
102	Cotton	lbs/a	0.035	220 + (5 x CEC)	8
103	Corn (grain)	bu/a	0.30	220 + (5 x CEC)	8
104	Corn (silage)	ton/a	9.0	220 + (5 x CEC)	8
105	Double Crop: Wheat – Soybeans**	bu/a	-	220 + (5 x CEC)	8
106	Double Crop: Wheat – Sunflowers**	bu/a	-	220 + (5 x CEC)	8
107	Double Crop: Wheat – Grain Sorghum**	bu/a	-	220 + (5 x CEC)	8
108	Double Crop: Wheat – Sorghum silage**	bu/a	-	220 + (5 x CEC)	8
109	Oats	bu/a	0.19	220 + (5 x CEC)	8
110	Popcorn	lbs/a	0.005	220 + (5 x CEC)	8
111	Rice	lbs/a	0.004	125 + (5 x CEC)	8
112	Rye	bu/a	0.34	220 + (5 x CEC)	8
113	Sorghum (grain)	lbs/a	0.006	220 + (5 x CEC)	8
114	Sorghum (silage)	ton/a	10.0	220 + (5 x CEC)	8
115	Soybeans	bu/a	1.44	220 + (5 x CEC)	8
116	Sugarbeets	ton/a	3.33	220 + (5 x CEC)	8
117	Sunflowers	lbs/a	0.007	220 + (5 x CEC)	8
118	Tobacco	lbs/a	0.04	220 + (5 x CEC)	8
119	Wheat	bu/a	0.30	220 + (5 x CEC)	8
201	Southern peas	-	-	160 + (5 x CEC)	8

*Shorter buildup periods may be selected by the user and may be particularly appropriate for variable-rate fertilizer applications.
**Double crop maintenance K is calculated using the yield goal entered for wheat plus the assumed yields for double crops given in the appendix.

Table XI. Annual fertilizer K_2O rates required to build exchangeable potassium soil test levels to 160 + 5 x (CEC) in 8 years.

	CEC (meq/100g)				
Soil Test Level	4	8	12	16	20
(lbs. K/a)	----------(lbs. K_2O/A)----------				
40	67	74	80	86	92
60	54	60	67	73	79
80	42	49	56	62	68
100	32	39	46	52	58
120	23	30	36	43	49
140	15	22	28	34	40
160	7	14	21	27	33
180	0	7	13	20	26
200	0	0	7	13	19
220	0	0	0	6	12
240	0	0	0	0	6
260	0	0	0	0	0
Target level	180	200	220	240	260

Table XII. Annual fertilizer K_2O rates required to build exchangeable potassium soil test levels to 220 + 5 x (CEC) in 8 years.

	CEC (meq/100g)				
Soil Test Level	4	8	12	16	20
(lbs. K/A)	----------(lbs. K_2O/A)----------				
40	86	92	98	104	109
60	73	79	85	90	96
80	62	68	74	79	84
100	52	58	64	69	74
120	43	49	55	60	65
140	34	40	46	52	57
160	27	33	39	44	49
180	20	26	31	37	42
200	13	19	24	30	35
220	6	12	18	23	29
240	0	6	12	17	23
260	0	0	6	11	17
280	0	0	0	6	11
300	0	0	0	0	5
320	0	0	0	0	0
Target level	240	260	280	300	320

SOIL ACIDITY AND LIMESTONE RECOMMENDATIONS

The Soil Test

Soil acidity is measured on the basis of the salt pH (pH_s) of the soil. The pH_s measures the active acidity in the soil and indicates whether limestone applications are needed. To determine the amount of reserve acidity or limestone requirement to neutralize the soil acidity, the milli-equivalents of neutralizable acidity is measured by the Woodruff Buffer.

The Rating System

A general rating scheme for the pH_s measurement for crops is shown below. The rating has been divided into two groupings. Alfalfa is a sensitive crop to soil acidity and, therefore, has a separate rating.

Rating	Alfalfa	All Other Crops
	---------- pH_s Range----------	
Very low	< 5.0	< 4.5
Low	5.0-5.8	4.5-5.3
Medium	5.8-6.5	5.3-6.0
High	6.5-7.5	6.0-7.5
Very High	> 7.5	> 7.5

Soils with a pH_s rating of very low or low have a definite need for limestone. These soils may be limiting yield potential due to severe soil acidity. A medium pH_s indicates a need for limestone in the near future, but soil acidity is likely not causing yield reductions at the time of the test. Soils rated high have a soil pH_s optimum for crop growth and limestone is not needed in the next two or three years.

Limestone Recommendations

Limestone recommendations for all crops are based upon a single application of the suggested amount of effective neutralizing material (ENM). The suggested amount should bring the pH_s of the soil to within the optimum range for crop growth. When multiple crop options are selected, the suggested lime rate is based upon the crop demanding the highest pH_s.

The crops and optimum pH_s ranges for the soil regions in Missouri are given in Table XIII. All soils used for row crops should be limed to a pH_s of 6.1 to 6.5. Soils growing forage crops vary in optimum pH_s levels. Alfalfa and clover need a slightly higher pH_s for optimum growth. Forage crops grown in the Cherokee Prairies, Ozarks, and Ozark Border areas (Soil Regions 5, 6, 7, and 8) generally have a higher optimum pH_s range due to high levels of subsoil acidity.

To determine the recommended rate of effective neutralizing material (ENM), locate the desired pH_s range according to the cropping plan and soil region from which the sample was obtained (Table XIII). Then refer to the appropriate table (Tables XIV-XVI) to determine ENM requirements based upon the level of neutralizable acidity and pH_s.

To determine limestone needs in tons/acre, divide the ENM requirement by the ENM index for the liming material to be used. All liming materials are sold with a guaranteed ENM value as provided for by the Missouri Liming Law.

Table XIII. Desired Soil pH_s range for crops in Missouri

Crop Code	Crop	Soil Regions: 5, 6, 7, 8 Cherokee Prairies, Ozarks, and Ozark Borders	Soil Regions: 1, 2, 3, 4, 9, 10, 11, 12 All Other Soils
1	Alfalfa establishment	6.6-7.0	6.1-6.5
2	Birdsfoot trefoil – Grass est.	6.1-6.5	5.6-6.0
3	Clover establishment	6.1-6.5	5.6-6.0
4	Cool season grass est.	5.6-6.0	5.6-6.0
5	Lespedeza – Grass est.	6.1-6.5	5.6-6.0
6	Overseeding legumes	6.1-6.5	5.6-6.0
7	Warm season grass est.	5.6-6.0	5.6-6.0
10, 11	Alfalfa	6.6-7.0	6.1-6.5
12	Birdsfoot – trefoil pasture	6.1-6.5	5.6-6.0
13	Bluegrass pasture	5.6-6.0	5.6-6.0
14, 15	Bermudagrass	5.6-6.0	5.6-6.0
16, 17	Clover	6.1-6.5	5.6-6.0
18,19.20,21	Cool season grasses	5.6-6.0	5.6-6.0
22, 23	Lespedeza	6.1-6.5	5.6-6.0
24, 25	Sudangrass	5.6-6.0	5.6-6.0
26, 27	Warm season grasses	5.6-6.0	5.6-6.0
100-119	All row crops	6.1-6.5	6.1-6.5

Table XIV. ENM (effective neutralizing material) requirements to increase the soil pH_s to the 5.6 – 6.0 range based upon soil pH_s and neutralizable acidity (NA).

$$ENM = (400)\left[NA - \frac{NA}{19.109 - 4.802(pH_s) + 0.297(pH_s)^2}\right]$$

Neutralizable Acidity meq/100g	pH_s 4.0	4.4	4.8	5.2	5.5
	Lbs. ENM/A				
1.0	314	298	262	216	162
2.0	628	586	524	431	324
3.0	942	878	787	647	487
4.0	1256	1171	1049	863	649
5.0	1570	1464	1311	1078	811
6.0	1884	1757	1573	1294	973
7.0	2198	2049	1835	1509	1136
8.0	2512	2342	2097	1725	1298
9.0	2826	2635	2360	1941	1460
10.0	3140	2928	2622	2156	1622

Table XV. ENM (effective neutralizing material) requirements to increase the soil pH_s to the 6.1 – 6.5 range based upon soil pH_s and neutralizable acidity (NA).

$$ENM = (400)\left[NA - \frac{NA}{41.425 - 10.307(pH_s) + 0.629(pH_s)^2}\right]$$

Neutralizable Acidity meq/100g	pH_s 4.0	4.4	4.8	5.2	5.5	6.0
	Lbs. ENM/A					
1.0	361	352	338	317	283	220
2.0	722	703	676	635	567	441
3.0	1083	1055	1014	952	850	661
4.0	1444	1406	1352	1269	1134	882
5.0	1805	1758	1690	1587	1417	1102
6.0	2166	2109	2028	1904	1701	1322
7.0	2527	2461	2365	2221	1984	1543
8.0	2888	2812	2703	2538	2267	1763
9.0	3249	3164	3041	2856	2551	1983
10.0	3610	3515	3379	3173	2834	2204

Table XVI. ENM (effective neutralizing material) requirements to increase the soil pH_s to the 6.6 – 7.0 range based upon soil neutralizable acidity (NA).

ENM = (400) (NA)

Neutralizable Acidity meq/100g	ENM (lbs/A)
1.0	400
2.0	800
3.0	1200
4.0	1600
5.0	2000
6.0	2400
7.0	2800
8.0	3200
9.0	3600
10.0	4000

EXCHANGEABLE MAGNESIUM

The Soil Test

Exchangeable magnesium is extracted from the soil using neutral, one normal ammonium acetate.

The Rating System

The rating of a magnesium soil test is based upon the magnesium saturation level of the soil cation exchange. Higher levels of magnesium saturation are suggested on forages to help prevent grass tetany. Two general groupings are used for the magnesium ratings.

Rating	Forage Grasses	All Other Crops
	% Mg Saturation of CEC	
Very low	< 5	< 2
Low	5 – 10	2 – 5
Medium	10 – 15	5 – 10
High	15 – 35	10 – 32.5
Very high	35 – 55	32.5 – 55
Extremely high	> 55	> 55

Magnesium Recommendations

Corrective magnesium is suggested as effective magnesium (E.M.) when the magnesium saturation of the total cation exchange of a soil falls below 5%. Soils containing between 5.1 and 9.9 percent magnesium saturation are considered to be less than optimum in magnesium and a resulting triple asterisk (***) will appear in the recommendations. This is to indicate that if dolomitic limestone is readily available, it may be used but crop response to magnesium is not likely. Table XVII outlines the suggested magnesium rates to be used as corrective treatments. Soils low in magnesium should be retested after four years to determine levels of magnesium following treatments.

To determine the quantity of a magnesium liming material necessary to correct soils low in exchangeable magnesium, divide the effective magnesium (E.M.) by the effective magnesium index for the liming material to be used.

Table XVII. Effective magnesium requirements to correct soil magnesium.

	----------Cation Exchange Capacity (meq/100g)----------						
Exchangeable Magnesium	6	10	14	18	22	26	30
(lbs. Mg/A)	----------Effective Magnesium (E.M.) lbs/A----------						
40	60	100	140	180	220	260	300
80	50	80	110	135	175	210	240
120	35	60	85	110	130	155	180
160	25	40	55	70	90	105	120
200	20	20	30	35	45	50	60
240	0	0	0	0	0	0	0

EXCHANGEABLE CALCIUM

The Soil Test

Exchangeable calcium is extracted using neutral, one normal ammonium acetate.

The Ratings

Ratings for calcium are based on the soil pH_s level and not on the calcium soil test. If the pH_s is very low or low, calcium is rated medium. Calcium is rated high if the pH_s is medium or higher.

Recommendations

Calcium is rarely, if ever, deficient in field soils. No recommendations for calcium are made on the basis of soil test exchangeable calcium. Exchangeable calcium is primarily used to aid in determining the estimated soil cation exchange capacity.

SULFUR

The Soil Test

There are two suggested soil tests to be used for interpreting sulfur needs: 1) extractable sulfate-sulfur using 500 ppm P as $Ca(H_2PO_4)_2 \cdot 2\ H_2O$ in 2 N acetic acid as the extractant and 2) cation exchange capacity determined by summing the milliequivalents of exchangeable calcium, magnesium, potassium and hydrogen.

The Rating System

The rating system used for sulfur involves both soil sulfate-sulfur and cation exchange capacity. Research by Dr. R.G. Hanson has indicated that soils with either a sulfate-sulfur content greater than 7.5 ppm SO_4-S or a cation exchange capacity greater than 6.5 meq/100g are not likely to respond to fertilizer sulfur application. A simple table can be used to show rating for the sulfur status of Missouri soils (Table XVIII).

Table XVIII. Ratings for sulfur status of soils.

Soil Sulfate-Sulfur (ppm SO_4-S)	Cation Exchange Capacity (meq/100g) 0-6.5	6.5 +
	-------Sulfur Status------	
0-7.5	Low	Medium
7.5 +	Medium	High

The Suggested Treatment

For row crops, small grains, and alfalfa, apply 10 to 20 pounds of S per acre, annually, when soil test rating for S is low. Most other forages do not require S even when the soil sulfur status is low.

Sulfur is not suggested on soils testing adequate based on either cation exchange capacity or the sulfate-sulfur soil test.

Table XIX. Suggested sulfur application rates when the soil sulfur status is low dependent on sulfate-sulfur soil test and cation exchange capacity.

Crop Code	Crops	Sulfur Rate (lbs. S/A)
2-7, 11-27	All forages except alfalfa hay	0
1, 10, 11, 101-110	Alfalfa and all row crops and small grains	15

MICRONUTRIENTS (ZINC, IRON, MANGANESE, COPPER)

The Soil Test

The soil test used for micronutrient analysis is termed the DTPA extraction method. Results are expressed in parts per million (ppm) of each micronutrient.

The Rating System

The rating system used for soil tests is based on information from Soltanpour, P.N. and A.P. Schwab. 1977. Communications in Soil Science and Plant Analysis. 8(3). 195-207. Table XX shows relative ratings for levels of the four micronutrients.

Zinc deficiencies have been noted in Missouri on soils with sandy texture, low organic matter and on graded or eroded areas where subsoils are exposed.

Iron, manganese, and copper have not been shown to be deficient in any widespread cases in Missouri. Only in very isolated cases would deficiency of any of these micronutrients be expected.

Table XX Ratings for DTPA extractable micronutrient soil test levels.

Soil Test Rating	Zinc	Iron	Manganese	Copper
	ppm			
Low	0-0.5	0-2.0	0-1.0	0-0.2
Medium	0.5-1.0	2.1-4.5	-	-
High	1.0 +	4.6 +	1.0 +	0.2 +

The Suggested Treatments

Zinc

The zinc ratings and recommendations are for use in corn and grain sorghum. These recommendations are for a single corrective soil application that should last from three to five years. Some zinc fertilizers are highly insoluble and poor sources of zinc. Zinc sulfate is recommended. If chelates are used, decrease application by 1/3 to 1/2 and apply annually. Monitor levels with frequent soil tests and plant analyses.

DTPA Soil Test Level	Rating	Suggested Application Rate
ppm Zn		lbs. Zn/acre
0 – 0.5	Low	10
0.5 – 1.0	Medium	5
1.0 +	High	0

Iron

Foliar sprays of 0.5 to 3 pounds of actual iron per acre have been shown to be most effective. These may be suggested when soils test low in iron and when visual deficiency symptoms are seen. This is most likely to occur on high pH soils in the Missouri River bottom. Soil applications of iron have not been very effective in correcting iron deficiencies. Long-term correction can best be achieved with the application of farmyard manure.

Copper

Soils testing low in copper should be monitored for deficiency symptoms. Foliar application according to manufacturer's suggested rates per acre should be adequate to correct any deficiency symptoms that may occur. Soil applications of 2 to 8 pounds of copper per acre may be used, but will be of doubtful value. One-half that rate would be suggested if using soil applied chelates.

Manganese

Soils testing low in manganese should be monitored for deficiency symptoms. Foliar applications of 1-2 pounds of actual manganese per acre should correct any deficiencies that may occur.

CATION EXCHANGE CAPACITY

Soil cation exchange capacity (CEC) is determined by adding the milli-equivalents of calcium, magnesium, potassium, and hydrogen based upon soil tests measuring those nutrients. This is only an estimate of the CEC and in should not be confused with other more accurate methods of measurement.

The Rating System

Soil CEC is used as a method of estimating the soil texture.

Cation Exchange Capacity meq/100g	Soil Texture
≤ 5.0	Sand
5.1 – 10.0	Sandy loam
10.1 – 18.0	Silt loam
18.1 – 24.0	Clay loam
> 24.0	Clay

The method used to calculate CEC is:

$$\text{meq/100g} = \frac{\text{lbs. Ca/A}}{400} + \frac{\text{lbs. Mg/A}}{240} + \frac{\text{lbs. K/A}}{780} + \text{meq of neutralizable acidity}$$

Cation saturation can also be determined from these calculations. Convert lb/acre to meq/100g of the cation (as above), then divide by the CEC of the soil. Example:

$$\text{lbs. Ca/A} = 2400$$

$$\text{meq Ca/100g} = \frac{2400}{400} = 6$$

$$\text{CEC} = 10.0 \text{ meq/100g}$$

$$\text{Therefore, \% calcium saturation} = \frac{6}{10} = 60\%$$

APPENDIX

Table A. The following table lists the assumed yield goals for the second crop in a double crop system.

Crop code	Crop	Yield goal for 2nd crop
105	Wheat – soybean	30 bu/a (40 if irrigated)
106	Wheat – sunflower	1000 lbs/a
107	Wheat – grain sorghum	5000 lbs/a
108	Wheat – sorghum silage	10 tons/a