Reprint from

"NUCLEAR TECHNIQUES IN IMPROVING PASTURE MANAGEMENT"

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1983

ASSESSING NUTRIENT CYCLING IN THE SOIL/PLANT/ANIMAL SYSTEM OF SEMI-ARID PASTURE LANDS

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Abstract

ASSESSING NUTRIENT CYCLING IN THE SOIL/PLANT/ANIMAL SYSTEM OF SEMI-ARID PASTURE LANDS.

Isotopic labelling is helpful in understanding the fate of nutrient fertilizers and determining the chemical and biochemical mechanisms that affect nutrient cycling through the soil/plant/animal system. Use of isotopic P and S in grassland systems is briefly discussed. Plant growth is discussed in response to nutrient levels in soil extracts and plant tissue. Optimizing plant growth will generally ensure high yields of quality forage that will result in good animal performance.

Soils provide a medium not only to physically support plants, but also to hold water and provide nutrients for plant growth. The ability to manipulate plant growth is greatly dependent on an understanding of the processes associated with nutrients in soils, water and plants. Those interested in utilizing forages would add the grazing animal to this complex system.

Isotopes have been successfully used to evaluate the basic aspects of soil chemistry such as cation-exchange equilibrium, availability of various nutrient sources and leaching rate [1]. Isotopes have also aided studies of such biochemical mechanisms as nutrient uptake by plants [2], redistribution within the plant and subsequent decomposition rates [1].

Isotopes are very useful in nutrient cycling studies. One may wish to identify the rate or movement of a nutrient from one part (pool or compartment) in the system to another. Movement may involve nutrients in inorganic and organic forms as well as those that have several oxidation stages, e.g. N, P and S.

Results of nutrient cycling studies on grasslands, emphasizing the soil and plant system, have been summarized for N, P, S, K, Ca and Mg [3]. A nutrient cycling study involving ^{35}S was conducted on a grass/legume pasture grazed by sheep [4]. These researches indentified flow rates and pool sizes for S in the soil, plant and animal parts of the system. Information gained from the study was very helpful in understanding the fate of fertilizer S.

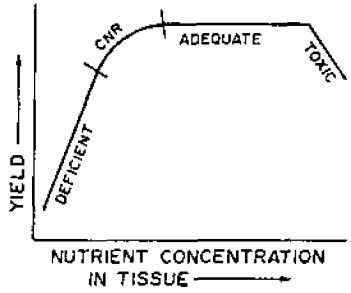

FIG.1. Relationship between crop yield and nutrient concentration in the supporting soil or the plant tissue.

TABLE I. DEFICIENT, MARGINAL AND ADEQUATE LEVELS OF SOIL PHOSPHORUS FOR CROP GROWTH AS DETERMINED FOR VARIOUS EXTRACTANTS [5]

Extractant	Relative soil P level		
	Deficient (ppm)	Marginal (ppm)	Adequate (ppm)
0.25 N H_2SO_4 + 0.05 N HCl Mehlich I	0–16	17–37	>38
0.03 N NH_4F + 0.025 N HCl Bray and Kurtz 1	0–15	16–30	>30
0.5 N $NaHCO_3$ Olsen	0–5	6–10	>10

Use of isotopes and mathematical modelling, aided by the computer, has greatly enhanced nutrient cycling studies. There are, however, many situations where an appropriate isotope does not exist or it is not feasible or necessary to use one. Such is the case for routine evaluation of soil fertility and plant nutrition. The objective is to provide adequate nutrient levels in the soil and plant tissue for optimum plant growth. Plant yield will increase, plateau and then decrease as nutrient levels in the soil and/or plant tissue increase (Fig.1). The critical nutrient range (CNR) is the level of soil or plant tissue nutrient above which it is reasonably certain that the crop is amply supplied and below which it is deficient. To maintain higher nutrient levels in the soil or plant tissue may be uneconomical because of fertilizer costs, reduced crop quality, or both.

TABLE II. LEVEL OF EXTRACTABLE SOIL SULPHUR ABOVE WHICH A PLANT GROWTH RESPONSE TO FERTILIZER SULPHUR WOULD NOT BE EXPECTED [7]

Extractant	Crop	Extractable S (ppm)
Ammonium acetate (NH_4OAc)	Millet	6–7
$Ca(H_2PO_4)_2$	Corn	8
	Alfalfa	10
	Wheat, oats, barley	7
	Alfalfa, clover	12
NaH_2PO_4 in NH_4OAc	Mixed pasture	10
$Ca(H_2PO_4)_2$ in NH_4OAc	Alfalfa	9

TABLE III. DEFICIENT, MARGINAL AND ADEQUATE LEVELS OF DTPA-EXTRACTABLE SOIL MICRONUTRIENTS CORRESPONDING TO THE GROWTH OF SENSITIVE CROPS [8]

Nutrient	Nutrient concentration extracted from soil		
	Deficient (ppm)	Marginal (ppm)	Adequate (ppm)
Zinc	<0.5	0.5–1.0	>1.0
Iron	<2.5	2.5–4.5	>4.5
Manganese	<1.0	–	>1.0
Copper	<0.2	–	>0.2

TABLE IV. DEFICIENT, MARGINAL AND ADEQUATE LEVELS OF NH_4HCO_3-DTPA-EXTRACTABLE MACRO- AND MICRONUTRIENTS IN ALKALINE SOILS AS DETERMINED NECESSARY FOR CROP GROWTH [9]

Nutrient	Nutrient concentration extracted from soil		
	Deficient (ppm)	Marginal (ppm)	Adequate (ppm)
Phosphorus[a]	<3 <(7)[b]	4–7 (8–14)	8–11 (15–22)
Potassium[c]	<60	61–20	>120
Zinc	<0.9	1–1.5	>1.5
Iron[d]	<2	2–4	>4
Copper	<0.5	–	>0.5
Manganese	<1.8	–	>1.8

[a] The P values shown here as deficient, marginal and adequate were identified as very low, low and medium for alfalfa and low, medium and high, respectively, for corn sorghum, small grains and grasses.

[b] Values in parentheses are for $NaHCO_3$-extractable soil P.

[c] Similar ranges were identified for ammonium-acetate-extractable K.

[d] A critical soil Fe level for sorghum was established at 4.8 ppm by Havlin and Soltanpour [10].

Soil analysis may be a good tool for diagnosing the nutrient availability for many plants. Extensive correlation studies must be conducted between nutrient levels extracted from soils and the corresponding plant growth. Nutrient extractability will vary between extractants and between soils because of the pH, soil texture, presence of free calcium carbonate, cation exchange capacity, organic matter, nutrient interactions, etc.

Thus it is not unexpected to find that marginal soil P levels (corresponding to CNR) vary between extractants (Table I) [5]. For example, in an evaluation of nine extractants, the 0.03 N NH_4F + 0.025 N HCl extractant shown in Table I was best correlated with forage growth ($r = 0.82$) on soils with a pH of 5.3 to 6.5 [6]. The 0.5 N $NaHCO_3$ extractant was correlated with forage yield ($r = 0.73$) in the above study and is generally superior to other extractants when evaluating P levels in alkaline soils.

Extractable soil S levels corresponding to the CNR or a single value are given in Table II [7] for four extractants.

Testing soils for trace mineral levels is done in many laboratories. Zinc deficiency is most common in the western and southern United States of America

TABLE V. CRITICAL, ADEQUATE, AND HIGH NUTRIENT RANGES IN WHOLE-PLANT TISSUE FOR GROWTH OF WHEAT, BARLEY, RYE, OATS, BROME GRASS, ORCHARD GRASS AND TIMOTHY SAMPLED AT THE BOOT STAGE[a,b]

Nutrient	Nutrient concentration in tissue		
	Critical	Adequate	High
Nitrogen (%)	1.5–2.0	2.1–3.0	>3.0
Phosphorus (%)	0.15–0.20	0.21–0.5	>0.5
Potassium (%)	1.2–1.5	1.6–2.5	>2.5
Calcium (%)	<0.20	0.20–0.5	>0.5
Magnesium (%)	<0.13	0.14–0.4	>0.4
Sulphur (%)[c]	0.15–0.19	0.20–0.4	>0.4
Zinc (ppm)	10–14	20–50	70–300
Boron (ppm)	<3	3–40	41–50
Manganese (ppm)	15–20	20–100	100–250
Iron (ppm)	<20	20–250	>250
Copper (ppm)	3–5	6–15	16–30

[a] Data are adapted from Refs [13–15].
[b] Values will vary for specific crops, plant part and time of sampling.
[c] N:S greater than 17 indicates likely S deficiency.

and in other arid and semi-arid areas around the world [8]. Copper deficiency is common on peats and mucks and rarely occurs on mineral soils except on the very old and weathered soils of countries like Australia [8]. Manganese deficiency is common in humid and moderate rainfall areas (greater than 500 mm), whereas Fe deficiency (lime-induced chlorosis) is common in sensitive crops grown in semi-arid areas of the western United States.

Excellent correlations have been obtained between crop growth and soil trace mineral extracted with the chelate-DTPA (0.005M diethylene triamine pentaacetic acid). The DTPA-extractable soil micro-nutrient levels corresponding to crop growth are shown in Table III [8].

Progress has been made toward the successful use of a single extractant (NH_4HCO_3-DTPA) for P, K, Zn, Fe, Cu and Mn [9]. Soil test values corresponding to deficient, marginal or adequate levels of crop response are given in Table IV [9, 10]. More verification is needed before this extractant and the corresponding test levels are unquestionably accepted.

TABLE VI. CRITICAL, ADEQUATE AND HIGH NUTRIENT RANGES IN THE TOP 15 CM OF FIRST-CUTTING TISSUE FOR GROWTH OF ALFALFA, SWEET CLOVER AND RED CLOVER SAMPLED BETWEEN BUD AND FIRST BLOOM[a,b]

Nutrient	Nutrient concentration in tissue		
	Critical	Adequate	High
Nitrogen (%)	1.3–2.5	2.6–3.7	>3.7
Phosphorus (%)	0.20–0.25	0.26–0.70	>0.7
Potassium (%)	1.8–2.4	2.4–3.7	3.8–4.8
Calcium (%)	1–2	2–3	>3
Magnesium (%)	0.2–0.3	0.3–1	>1
Sulphur (%)[c]	0.2–0.25	0.3–0.5	>0.5
Zinc (ppm)	10–14	20–71	71–300
Boron (ppm)	15–25	30–80	>80
Manganese (ppm)	15–20	21–200	200–700
Iron (ppm)	<30	30–250	>250
Copper (ppm)	3–5	5–30	>30
Molybdenum (ppm)[d]	0.4–0.5	1–10	>10

[a] Data are adapted from Refs [13–15].
[b] Values will vary for specific crops, plant part and time of sampling.
[c] N:S greater than 15 or SO_4-S less than 500 ppm indicates S deficiency [16].
[d] Leaf and petiole sample.

TABLE VII. TEN-YEAR MEANS OF FORAGE DRY MATTER PRODUCTION, ANIMAL STOCKING RATE AND BEEF PRODUCTION ON CRESTED WHEAT GRASS FERTILIZED WITH NITROGEN OR GROWN WITH ALFALFA [17]

Parameter	Treatment			
	N rate (kg/ha)			Wheat grass + alfalfa
	0	45	90	
Beef production (kg/ha)	113	189	197	150
Stocking rate (animal density/ha)	94	163	175	190
Forage production (kg/ha)	1950	3090	3490	2510

TABLE VIII. EFFECT OF NITROGEN, PHOSPHORUS AND SULPHUR FERTILIZATION ON CATTLE GAINS COMPARED WITH THOSE PRODUCED ON UNFERTILIZED SUB-CLOVER ANNUAL GRASS PASTURE [18]

Fertilizer rate (kg/ha)			Live weight gains attributed to fertilization (kg/ha)	Beef produced per kg fertilizer N (kg/ha)
N	P	S		
64	0	0	76	1.19
80	0	72	117	1.46
77	29	40	154	2.00

Soil K, Ca and Mg values are rarely deficient in semi-arid and arid soils. The topic is included in Ref. [11] and will not be discussed here.

Nitrogen, on the other hand, is almost always deficient for plant growth and is only surpassed in importance by soil moisture that limits maximum forage yields in semi-arid areas. Soil tests to determine N availability are discussed by Dahnke and Vasey [12].

Plant analysis is an excellent tool for diagnosing the nutrient needs for most plants. Nutrient levels vary from one part of the plant to another and change with age or maturity.

Consequently, the plant part taken and the sampling time will depend on research that has been developed to show deficient or adequate levels in a specific plant part and at a certain growth stage for maximum crop production.

The user of such data should recognize the limitations of plant tissue analysis. Concentrations of nutrients in a plant are a result of both plant growth and nutrient supply. Consequently, the concentration of a given nutrient is meaningful only if all other growth factors are adequate. Thus, if the supply of N is limiting growth, the tissue concentrations of elements such a P, K and Zn are not a valid indication of the potential supply of these elements. A nutrient- or drought-stressed plant may have high levels of some nutrients; even some that under less stressful conditions might be deficient. The stage of plant growth or stage of maturity is a major factor in evaluating plant tissue nutrient levels.

Critical, adequate and high nutrient ranges are given for whole plant tissue of grasses (Table V) [13–15] and legumes (Table VI) [13–16].

The effect of soil fertility on forages goes beyond the production of dry matter. Changes in quality might also be expected in some cases. Table VII [17]

shows not only the forage yield of crested wheat grass fertilized with N and grown with alfalfa, but the increased stocking rate and beef production resulting from the treatments.

Data from another study (Table VIII) [18] show the live weight beef gains attributable to fertilization with N, P, S or combinations of these nutrients. Beef production per unit of N clearly demonstrates the benefits of P and S fertilization to make more efficient use of N.

Very valuable insights into forage production have been achieved in the past. Those interested in grassland production systems are encouraged to read the review by Trumble [19]. He provides an excellent discussion on the approach to modern grassland improvement and the considerations that must be given to various environmental parameters including climatic conditions of rainfall, evaporation, drought, temperature and light. Soil fertility factors and general pasture management are discussed in addition to specific lines of agronomic investigation including water requirements, factors affecting mineral concentrations in forage, forage plant improvement and grass/legume interactions.

ANNEX

Common names of plants used in the text
and their equivalent Latin binomials

Alfalfa	*Medicago sativa* L.
Barley	*Hordeum vulgare* L.
Brome grass	*Bromus inermis* Leyss.
Corn	*Zea mays* L.
Crested wheat grass	*Agropyron desertorum* (Fisch. ex Link) Schult.
Millet	*Pennisetum typhoides* (Burn. f.) Stapf & C.E. Hubb
Oats	*Avena sativa* L.
Orchard grass	*Dactylis glomerata* L.
Red clover	*Trifolium pratense* L.
Rye	*Secale cereale* L.
Sorghum	*Sorghum bicolor* (L.) Moench
Subterranean clover	*Trifolium subterraneum* L.
Sweet clover	*Melilotus officinalis* (L.) Lam.
Timothy	*Phleum pratense* L.
Wheat	*Triticum aestivum* L.

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