BAKER SOIL TEST® DEVELOPMENT AND FIELD CASE STUDIES PROVIDE THEORY AND DATA SHOWING THAT PLANTS DON'T GROW IN SOILS.

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Abstract

Initial experiments conducted in 1977 by the senior author involved the use of chemical ion activities of the solution phase of coal combustion by-products (CCB's) and cement kiln dusts (CKD's) used for land reclamation. Using combinations of soil and CCB's or CKD's in layers with depths ranging from no soil and no ash to combinations up to 4 feet, we found that from the point of view of plant nutrition, CCB's and CKD's are equivalent to soil. However, both materials are more susceptible to erosion than soils. Using standard erosion station methods, we found that with proper water management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and as a substitute for soil in several applications. The cellulose to organic matter connection is important with respect to substrate air-water relations. The Baker Soil Test (BST) is used routinely to evaluate mixtures of wastes used under field conditions as synthetic soils. Data and experience from these sites and our projections for the future are the subjects reviewed here.

Introduction

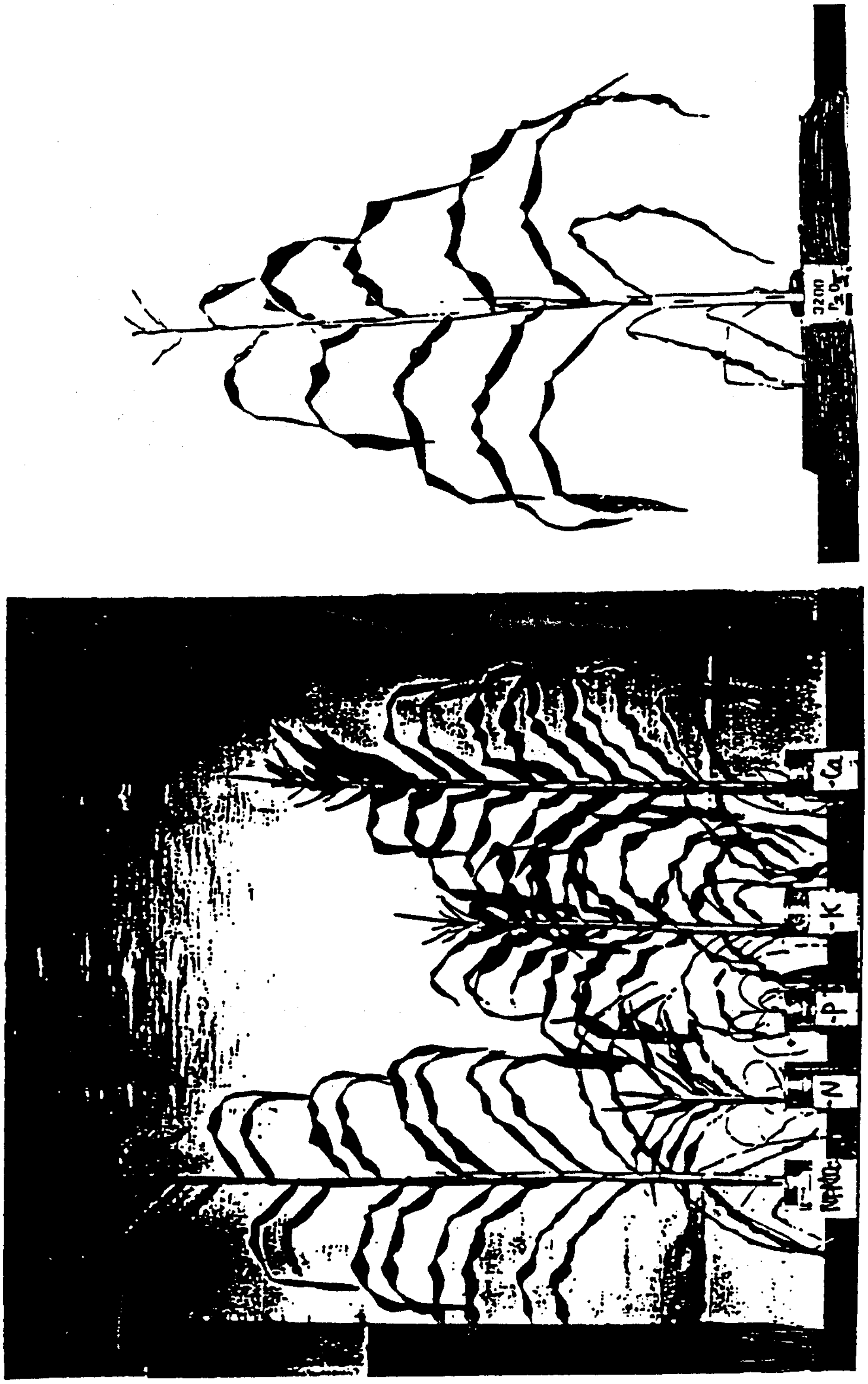
With a Ph. D. in Soils from the University of Missouri and a Year at the University of Minnesota, Northeast Experiment Station, the senior author's career at Penn State University started in 1961. With help from many Penn State graduate assistants and Leon Marshall, his research aide for 30 years, numerous investigations were conducted to evaluate and explain data enabling integrated land and waste management systems for crop production and environmental quality. The Baker Soil Test@ (BST), (Official ASTM Method D5435-93 "Standard Diagnostic Soil Test for Plant Growth and Food Chain Protection") enables the use of mixtures of non-soil, silicate wastes and selected organic wastes as soil substitutes A high surface area per unit volume of soil per plant is important for crop production. Based on theory and experience as a University of Missouri student, Dale produced a mature corn plant in soil contained within a one quart oil can (Plate 1). The "rootless wonders" and related results were important factors leading eventually to the Baker Soil Test from theory and case studies. As evaluated by the BST, fly ash (CCB's) and CKD's, sewage sludges, manures, and industrial wastes have been used as synthetic soils.

Magic Green Corporation@ Utilizes CKD's for Increased Crop Yields

Gregory, "Greg", Wommack has excellent field evidence that combinations of existing N, P, & K commercial fertilizers combined with CKD's result in synergistic crop growth responses. His technology is now being offered local growers and marketing agencies for distribution as the products "Ura-Cal®",“Potassa-Cal®" and "Combined Nutrient Positioning@" technology. Magic Green Corporation@ materials are being offered to marketing partners for distribution in the USA and abroad.

The Wommack technology is an example of needed land management technology. Land managers must seek an understanding of the components of their systems. Interacting effect involving differential responses of crops to new technology will be important as the Magic Green Corporations technology evolves. Cement Kiln Dust CKD' s) as a source of potassium was mentioned by Tisdale and Nelson. Land Managers must seek an understanding of the components of existing systems. Interacting

Plate 1. Corn plants grown in greenhouse studies by Dr. Baker while a student at the University of Missouri, showed that phosphorus was the most limiting element when corn plants were grown in no. 10 tin cans. This led to his trial in which a mature corn plant was grown in a 1 quart can of soil receiving 3200 lbs. of phosphorus as P_2O_5 per acre (2,000,000 lbs.) equivalent.



Technology evolves. Land management decision making requires that one seek an understanding of the components of the system and their interactions. Crop Production requires a knowledge of cultural practices and soil management, as affected by climatic conditions, and other components of each system. Scientific bases for management practices often are discovered after they have become standards.

Education and Experience are Essential for Land Managers

Dr. Baker, as an undergraduate at the University of Missouri, was employed during the summer months for 3 years as a student trainee for a career appointment as a USDA-SCS Farm Planner in Higginsvillle, MO. He holds this work as his enlightening experience. With the freedom to seek help when he was not sure that he could provide the best advice to farmers, he gained confidence as he assisted farm operators in making Land Management Decisions. The authors are well aware that in order to serve the farm production sector with new products and reliable decision support, they must seek an understanding of the components of each system and their interactions. Crop production requires a knowledge of cultural practices and soil management, as affected by climatic conditions and all other art and science components of each system.

While attending the Southwest Fertilizer Industry Conference in San Antonio, Texas; Dr. Baker was impressed with the knowledge and dedication of Gregory Wommack and his crop production experiences with CKD's. Greg was invited to coauthor this manuscript in order to provide readers with another approach for providing "decision support". Decision support requires that we seek an understanding of the needs and goals of clients without just being critical of existing systems. For some systems, especially daii operations, that Dr. Baker works with, are so complicated that one has to "leave it to the operator" when it comes to many of the business management decisions that must be made. Here, we only consider field operations involving waste utilization and problem solving for environmental quality and compatible land use systems involving CKD's and CCB's. User initiated decision support for the management of land and industrial wastes for erosion control, crop production, and interactions provide exciting, new vocations, within the LMD areas of emphasis.

Theory and practices applied to case studies over time involve concerted efforts to integrate land and waste management systems. For this manuscript, attention is focused on the concepts leading to the Baker Soil Test (BST) and its application for land management, which includes the theory supporting **the** conclusion included in the title that "plants don't grow in soil". It is important that soil management include the concepts relating to the importance of the soil solution as the continuous phase from which plants obtain water and the required nutrients. In addition, the approach of authors regarding CKD's as components of crop management systems and related university research are worthy of emulation.

Land Reclamation Studies Indicated a Need for A New Approach to Soil Testing

Mine land reclamation has been under investigation by Baker and others for many years. Often land reclamation programs fail because the site has very low pH associated with phytotoxic levels of Al and Mn, limiting water holding capacities and/or steep, long slopes causing excessive soil erosion. With proper site preparation, including the return of overburden soil with topography and vegetative cover to prevent excessive erosion, the next major step requires the BST and surface application of waste mixtures to serve as mulch, a source of plant nutrients, and erosion control. Many wastes now going to land-fills are suitable for the production of synthetic soils and mulch materials for reclamation of many disturbed sites. For agricultural lands, we must take precautions to protect the food chain and environmental quality. The elements cadmium and copper require special attention to protect animal and human health, and soil productivity for the respective elements.

Using standard erosion station methods, we found that with runoff management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and/or as substitutes for soils. Using a slope of 9%, with a slope length of 22.3 m, a K factor from 0.71 to 0.82 were obtained by Lehrsch, et.al.. 1981. With erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and/or as substitutes for soil in many applications. For field plots with slopes of 9 %, fly-ash erosion was somewhat greater than for soil, but acceptable, for slope lengths of 100 feet. In 1975, Baker, et al. demonstrated that CKD's were more effective than lime for vacuum filter processing of sewage sludge. However, the plant operators speculated that the silicate waste was more abrasive to equipment than hydrated lime. Therefore, the sludge conditioning technology was never adopted. Risser, Doty and Baker in 1980 demonstrated that CKD's are useful as a lime-potash fertilizer. With our past experience, we are delighted with the technology under development by Magic Green Corporation.

Magic Green Corporation@ CKD's and Pulverized Limestone Compared for Liming

For each material (dry kiln dust and pulverized limestone) 300 grams were placed in 500 ml beakers and distilled water was added to produce saturated pastes (no air or free water were present within or on top of the suspensions at equilibrium). Under vacuum to remove capillary water, the 300 g of limestone with a guaranteed calcium carbonate equivalence of 103% held 75.2 g water, while the 300 g of CKD material held 159.3 g of water. As expected, the silicate material has a substantially higher water holding capacity than pulverized limestone. The pH of the CKD suspension was 12.57 and the liquid filtrate had a pH of 13. For the limestone suspension, the pH was 9.08 and the filtrate had a pH of 8.95, which is higher than the theoretical pH of 8.1 for pure calcium carbonate ($CaCO_3$) in equilibrium with the CO_2 pressure of the atmosphere. From these results it is obvious that by blending fertilizers containing Wommack's CKD's which are banded 4 inches to the side of the rows and 2 inches deep, the plant environment is enriched with water, Ca^{++}, and other many components included in Table 1.

The analyses presented in Table 1 were performed to ascertain if any potentially toxic elements could be encountered by animals consuming crops grown where CKD's are used as a nutrient source. The composition of the CKD is compatible with soil and soil parent materials for all parameters. Since the CKD's are produced from bedrock that is also parent material for soils, no adverse effects were expected. From an environmental quality perspective, however, one should verify that no adverse effects are possible.

Soil Biology Related to the Physical Chemistry of Soil Solutions

The soil solution, as the continuous phase in soil-plant systems, even in relatively dry soil, insures that growing plants stand in water, which exists as a continuous film, stretched over soil particles and plant root surfaces. As the soil dries, the thickness of water films decrease and water properties change to conform with the structure of both the soil solid phase and the plant vascular system even as the living plants wilt. When plants wilt, the water films approach water of hydration which is immobile (the structure of adsorbed water is more ice like than free water).

Productive soils include those with deep, well drained profiles that allow plant rooting depths of 4 feet or more. While nutrient availability with depth is important with respect to water availability to plants, nutrient management within the soil surface plow layer can provide crops with all essential chemical elements taken up as chemical ions by plants. The deep, well drained silt loam soils developed under prairie vegetation represent the more productive agricultural soils of the USA because of their greater plant available water holding capacities. The silt loam soil texture, which prevails in loess soils where the native vegetation was prairie grasses; have nearly ideal air-water relations for farm crops. While water availability over the growing season is very important, nutrient availability is often the limiting factor for crop production. Justus von Leibig (1803-1873), a German chemist, made historically valuable statements regarding the factors which determine plant growth:

1. Most of the carbon in plants comes from CO_2 (carbon dioxide within the atmosphere).
2. Hydrogen and oxygen come from water.
3. The alkaline metals are needed for acid neutralization of from plant metabolite activity.
4. Phosphates are necessary for seed formation.

Table 1. Total Chemical Composition of Water Filtrate Removed Under Vacuum To Determine the Water Holding Capacity of The Material.

ICP Metal	Filtrate (ppm)	Total (ppm)	ICP Metal	Filtrate (ppm)	Total (ppm)
Ag	<0.003	<1.13	Mo	0.360	1.51
Al	<0.01	7638.002	Na	285.55	3773.58
As	0.004	8.516	Nb	<0.005	<1.89
Au	0.029	<1.89	Nd	<0.005	10.059
B	0.022	12.254	Ni	<0.006	19.244
Ba	0.720	48.420	Oe	<0.005	<1.89
Be	<0.004	<1.51	P	<0.50	234.879
Bi	<0.005	<1.89	Pb	0.038	42.029
Br	1.921	<188.68	Pd	<0.005	<1.89
Ca	391.587	341,195.174	Pr	<0.005	5.200
Cd	<0.003	1.225	Pt	<0.005	<1.89
Ce	<0.005	12.136	Rb	14.235	11.674
Cl	2660.725	18,833	Re	0.008	<1.89
CO	<0.004	2.285	Rh	<0.005	<1.89
Cr	0.204	8.596	Ru	<0.005	<1.89
Cs	4.245	6.359	Sb	0.008	<1.51
Cu	0.016	2.271	Sc	<0.005	2.522
Dy	<0.005	<1.89	Se	0.391	<1.13
Er	<0.005	<1.89	Si	<0.50	<188.68
Eu	<0.005	<1.89	Sm	<0.005	<1.89
Fe	0.154	6018.106	Sn	<0.003	<1.13
Ga	<0.005	2.090	Sr	5.273	148.454
Gd	<0.005	<1.89	Ta	<0.005	<1.89
Ge	<0.005	<1.89	Tb	<0.005	<1.89
Hf	<0.005	<1.89	Te	<0.005	<1.89
Hg	<0.0005	<0.19	Th	<0.005	<1.89
HO	<0.005	<1.89	Ti	2.254	827.278
I	4.19	<188.68	Tl	0.019	<0.75
In	<0.005	<1.89	Tm	<0.005	<1.89
Ir	<0.005	<1.89	U	<0.005	<1.89
K	88.492	38,382.75	V	0.010	77.629
La	<0.005	15.51	W	<0.005	<1.89
Li	1.681	9.005	Y	<0.004	<1.509
Lu	<0.005	<1.89	Yb	<0.005	<1.89
Mg	<10.00	7,184.04	Zn	<0.004	39.575
Mn	0.034	372.83	Zr	<0.005	5.346

Please note that 2 g of the solid sample was digested in both nitric and hydrochloric acid, and then diluted to a final volume of 100 ml. This solution was then analyzed by ICP-Mass Spectrometer. The filtrate was directly injected into the ICP-Mass Spectrometer.

5. nonessential materials.

While all of Leibig's ideas were not correct, he eventually developed his "Law of the Minimum", which, in effect, says that the growth of plants is limited by the plant nutrient element or growth factor present in the smallest relative quantity, with all others being present in adequate amounts. Plants require C as CO_2 from the atmosphere above and below the soil surface, H as H_20 from water within the rooting area and from deposition on leaves, 0 as O_2 from the atmosphere; P as $H_2PO_4^-$ or HPO_4^{-2}, K as K^+, N as NO_3^- and/or NH_4^+, S as SO_4^{-2}, Ca^{+2}, Fe^{+2} or $^{+3}$, Mg^{+2}, (C HOPKNS CA Fe, Mg) and other trace elements including Mn, Zn, Cu, Mo, B, and Cl. It is interesting that aluminum (AL) and Silicon (Si), the most abundant elements in soils are not essential for higher plants or and animals..

The Baker Soil Test® (BST) Applied to Land Reclamation Studies

Mine land reclamation has been under investigation by Baker, graduate students, and colleagues for many years. Often reclamation programs fail because the sites have a very low pH associated with phytotoxic levels of Al and Mn, limiting water holding capacities, and/or steep, long slopes causing excessive soil erosion. With appropriate site preparation including the return of overburden surface soil combined with topography and vegetative cover to prevent excessive erosion, and use of the BST, the next major step should include the surface application of waste mixtures to serve as mulch, a source of plant nutrients, and soil erosion control. Many wastes now going to landfills are suitable for the production of synthetic soils and mulch materials for reclamation of many disturbed sites. Magic Green Corporation has demonstrated some of the technology for which Land Management Decisions, Inc was founded.

Using standard erosion station methods, we found that with runoff management for erosion control, CCB's and CKD's can be used as cover soil for land reclamation, and/or as substitutes for soils id many applications. Using a slope of 9%, with a length of 22.3 m, a K factor ranging from 0.71 to 0.82 were obtained. For field plots with a slope of 9%, fly-ash erosion was somewhat greater than for soil, but acceptable, for a slope of 9 %, with a length of 100 feet. In 1975, Baker, Welch, Stout and Doty demonstrated that CKD's were more effective than lime for vacuum filter processing of sewage sludge. However, the plant operators speculated that the silicate waste would be more abrasive to their equipment than hydrated lime. Therefore, the technology has never been accepted. Kisser, Doty and Baker demonstrated that CKD's are useful as lime-potash fertilizer. From our past experience, we are looking forward to the time when the Magic Green Corporation becomes established.

Clients currently use the Baker Soil Test to provide the data and interpretations required for the use of CCB's and CKD's combined with other wastes to produce synthetic sails and/or soil conditioners. The cellulose (organic matter) connection is important with respect to air-water relations. The methods have been successfully applied to fly-ash piles, ash amelioration of abandoned mine lands and severely eroded sites.

It has been known for centuries that the soil solution is the continuous phase in soils-plant systems. Even in relatively dry soil, growing plants stand in water which exists as continuous firma, stretched over soil particle and plant root surfaces. As the soil dries the thickness of water films decrease, and water properties change to conform with the structure of both the soil solid phase and the plant vascular system, even as living plants wilt.

Evolution of the The Baker Soil Test (BST) as Related to Soil-Plant Interactions

After six years at Penn State, Dr. Baker spent six months at Purdue University working with Dr. Philip Low. Low and his students had shown that silicate, clay gels when disturbed by tapping the container on the lab bench changed to a sol (liquid suspension). Using radioactive sodium (Na) as a tracer. Baker postulated and verified that the "physical change" was accompanied by a "chemical change" with respect to availability of Na ions to plants. Using radioactive Na, he found Na in a sodium saturated bentonite clay became higher in ionic activity and plant availability when the gel was disturbed by tapping on the laboratory bench (Low, Davey, Lee,& Baker, 1968; and Baker and Low, 1970).

Upon his return from Purdue University, Dr. Baker began to ponder the soil physical chemistry involved. He set up chemical equations that were known to be important to soil-water-plant relations and solved them simultaneously. To his surprise, all of the soil parameters fell out leaving only the solution chemistry (Baker, 1971). Baker asked the late Dr. Louis Kardos to check his results to see if he had made a mistake. He returned in a few hours feeling grim. He said to Dr. Baker, "No, you didn't make a mistake, but do you know what you have done?" Baker replied, "Yes, plants don't grow in soils".

An example of the Baker Soil Test (BST) report is presented as Figure 1. For routine soil test operations, the BST includes 2 pages of output, which includes concentrations of toxic metals. The results include a "small exchange", quantity and intensity parameters for each element expressed as the negative logarithm of the solution activity (pH, pK, pCa, pMg, pFe, pMn, pCu, pZn, pCd, etc.). As indicated above, The Baker Soil Test is not like other soil test methods, it measures the parameters of the soil solution in equilibrium with the solid phase of soils. The results include "small exchange", quantity and intensity parameters. (pH, pK, pCa, pMg, pFe, pMn, pCu, pZn, pCd, etc.).

We are at a dawning of new knowledge of waste-soil-plant relations. We may continue to rely on knowledge of soil properties and their management for crop production, but several factors indicate a need to begin to use suitable wastes to improve the air, water, and nutrient relationships of soils. Beneficial utilization of wastes that are now going to landfills, at a substantial cost, could lead to even more economical waste utilization and increased crop production. Colored slides are available to illustrate the concepts and data presented. One can rest assured that a soil management revolution is in the making. While the products developed by Wommack are not expected to be "cure alls", they are examples of products that combine common sense with technology and experience that show great promise for CKD's and synergistic effects yet to be quantified. Aspiring college students are urged to seek to integrate the knowledge they obtain from the pure sciences to better define and interpret soil properties using laws of physics and chemistry.

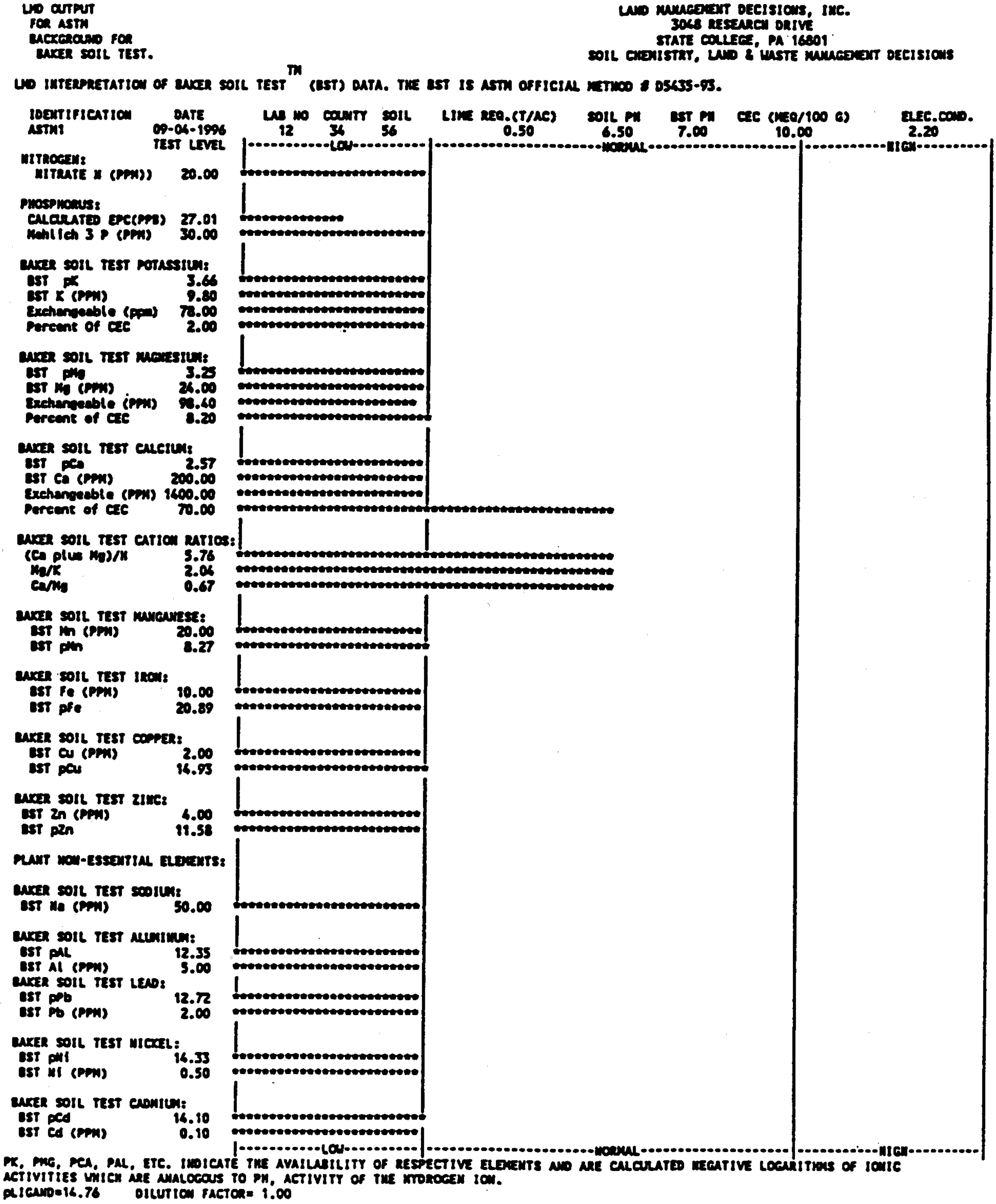
Summary

1. CKD's improve the three-phase systems called soils. An Ideal Soil System contains on a volume basis half solids and half pore space with half of the pore space full of water after the soil .is saturated and allowed to drain for 24 hours. The most important role of CCB's and CKD's as soil amendments involve their role as sources of nutrients and as "more soil" defined as "Those surface layers or deposits in which plants grow", Hunt, 1972.

2. The Baker Soil Test provides investigators with a means of evaluating CKD's, CCB's, etc. for use as soil amendments.

3. Chemical elements in the solid and solution phases provide the plant nutrient requirements of plants. In Figure 2, we present an over-simplified, but operational definition of soil systems. The oxides of the biologically nonessential elements, Al and Si, combined with the essential elements, Fe and Mg, may be considered as the major components of the matrix of all soils. However, it is water that is the continuous phase in soils and the compound that is central to all living organisms. Plant growth, then. relates to the properties of the aqueous solution phase which surrounds every soil particle which makes up the solid phase of soil or any media in which plants grow.

Figure 1. Copy of a Baker Soil Test output form for soil assumed to be at normal background levels for most parameters



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LMD OUTPUT                                                                 LAND MANAGEMENT DECISIONS, INC.
 FOR ASTM                                                                        3048 RESEARCH DRIVE
 BACKGROUND FOR                                                                STATE COLLEGE, PA 16801
  BAKER SOIL TEST.                                                 SOIL CHEMISTRY, LAND & WASTE MANAGEMENT DECISIONS
                                      TM
LMD INTERPRETATION OF BAKER SOIL TEST   (BST) DATA. THE BST IS ASTM OFFICIAL METHOD # D5435-93.

 IDENTIFICATION      DATE      LAB NO  COUNTY  SOIL   LIME REQ.(T/AC)   SOIL PH   BST PH   CEC (MEQ/100 G)      ELEC.COND.
 ASTM1             09-04-1996    12     34     56          0.50           6.50     7.00        10.00               2.20
                   TEST LEVEL  |-----------LOW----------|----------------------NORMAL----------------------|-----------HIGH----------|
NITROGEN:                      |                        |                                                  |                         |
  NITRATE N (PPM))    20.00    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
PHOSPHORUS:                    |                        |                                                  |                         |
 CALCULATED EPC(PPB)  27.01    **************           |                                                  |                         |
 Mehlich 3 P (PPM)    30.00    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST POTASSIUM:     |                        |                                                  |                         |
 BST  pK               3.66    ************************ |                                                  |                         |
 BST K (PPM)           9.80    ************************ |                                                  |                         |
 Exchangeable (ppm)   78.00    ************************ |                                                  |                         |
 Percent Of CEC        2.00    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST MAGNESIUM:     |                        |                                                  |                         |
 BST  pMg              3.25    ************************ |                                                  |                         |
 BST Mg (PPM)         24.00    ************************ |                                                  |                         |
 Exchangeable (PPM)   98.40    **********************   |                                                  |                         |
 Percent of CEC        8.20    **************************                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST CALCIUM:       |                        |                                                  |                         |
 BST  pCa              2.57    ************************ |                                                  |                         |
 BST Ca (PPM)        200.00    ************************ |                                                  |                         |
 Exchangeable (PPM) 1400.00    ************************ |                                                  |                         |
 Percent of CEC       70.00    **************************************************                          |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST CATION RATIOS: |                        |                                                  |                         |
 (Ca plus Mg)/K        5.76    **************************************************                          |                         |
  Mg/K                 2.04    **************************************************                          |                         |
  Ca/Mg                0.67    **************************************************                          |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST MANGANESE:     |                        |                                                  |                         |
  BST Mn (PPM)        20.00    ************************ |                                                  |                         |
  BST pMn              8.27    **************************                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST IRON:          |                        |                                                  |                         |
  BST Fe (PPM)        10.00    ************************ |                                                  |                         |
  BST pFe             20.89    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST COPPER:        |                        |                                                  |                         |
  BST Cu (PPM)         2.00    ************************ |                                                  |                         |
  BST pCu             14.93    **************************                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST ZINC:          |                        |                                                  |                         |
 BST Zn (PPM)          4.00    ************************ |                                                  |                         |
 BST pZn              11.58    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
PLANT NON-ESSENTIAL ELEMENTS:  |                        |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST SODIUM:        |                        |                                                  |                         |
 BST Na (PPM)         50.00    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST ALUMINUM:      |                        |                                                  |                         |
 BST pAL              12.35    ************************ |                                                  |                         |
 BST Al (PPM)          5.00    ************************ |                                                  |                         |
BAKER SOIL TEST LEAD:          |                        |                                                  |                         |
 BST pPb              12.72    ************************ |                                                  |                         |
 BST Pb (PPM)          2.00    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST NICKEL:        |                        |                                                  |                         |
 BST pNi              14.33    ************************ |                                                  |                         |
 BST Ni (PPM)          0.50    ************************ |                                                  |                         |
                               |                        |                                                  |                         |
BAKER SOIL TEST CADMIUM:       |                        |                                                  |                         |
 BST pCd              14.10    **************************                                                  |                         |
 BST Cd (PPM)          0.10    ************************ |                                                  |                         |
                               |-----------LOW----------|----------------------NORMAL----------------------|-----------HIGH----------|
PK, PMG, PCA, PAL, ETC. INDICATE THE AVAILABILITY OF RESPECTIVE ELEMENTS AND ARE CALCULATED NEGATIVE LOGARITHMS OF IONIC
ACTIVITIES WHICH ARE ANALOGOUS TO PH, ACTIVITY OF THE HYDROGEN ION.
pLIGAND=14.76     DILUTION FACTOR= 1.00
```

Figure 2: Master Variables with Al and Si

Mater Variable With Al and Si In Soil-Water-Plant Systems
pH_2O, pO_2, pH, **pCO_2, pNO_3, pNH_4, pCa, pMg, pK, pH_2PO_4, $pHPO_4$, pSO_4**

Essential Trace Elements:
pFe, pMn, pB, pZn, pCu, pMo, pCl (+ For Animals **pNa, pCo, pO_2, pI, pNi, pSe, pV)**

Non-Essential, Potentially Toxic Elemetnts:
pA1, pPb, pCr, pAs, pCd, pHg+ ? (pAg, pSb, pBr, pGe, pRb, pSr, pSn)

4. Ionic activities in soil-water systems and the Quantity/Intensity (Q/I) concept. The quantity (Q) value for an essential plant nutrient other than water, refers to the amount of that nutrient element of ionic form (I) that is in dynamic equilibria with the true activity Ai within the soil solutions. The (Q) value then may be thought of as the "labile pool", "adsorbed fraction", or other terms for the concentration © in the equation:

$$A_i = f_iC_i \qquad (I)$$

Where A_i is the chemical activity of ion, I, in true solution and f is the activity coefficient. The activity coefficient relates inversely to the bonding energy with which an ion (I) is retained as an adsorbed, exchangeable ion within the soil.

5. Decision support for users of the BST is based on LMD Technology gained from soil chemistry theory and experience.

6. By-product usage developed by Magic Green Corporation is an example of the "integrated Land and Waste Management Systems for soil improvement, increased crop production, and a truly sustainable agriculture for the 2 1 st century.

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