THE EFFECTS ON SOILS OF
AEROBICALLY AND ANAEROBICALLY DECOMPOSED
ORGANIC AGRICULTURAL RESIDUES:
A REVIEW OF THE LITERATURE

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PREFACE

One may view the physical foundation of life on earth as being broadly based on solar-energy-flow activation of intertwined climatic, hydrologic, edaphic (soil-based) and biotic cycles. While human activity has had its effects on these cycles throughout history, e.g. the desertification of Afghanistan, the Verde Islands and the eastern coast of the Mediterranean, the enormous recent growth in human population is putting unprecedented pressure on the entire, inter-related support system. Indeed, human-kind, through the various effects of its agricultural and industrial activities, is even becoming "a significant geological event" (Brown, 1984).

The following discussion will deal largely with the interactions between human agricultural activity and the soil upon which this activity depends. More specifically, it will focus on the recycling of organic materials through the soil and the importance of this cycle of return in the maintenance of long-term soil fertility. The overall approach is primarily biologically-based and follows closely the view that "Soil is a placenta or matrix, a living organism which is larger than the life it supports" (Jackson, 1980).

NOTES

This discussion is concerned with agricultural practice on mineral soils which may become depleted of organic matter. Thus, consideration of the highly organic Histosol order of soils is excluded.

Since this discussion is primarily concerned with agriculture, the "organic residues" referred to may be considered to include animal manures and bedding, night soil, crop wastes and forest litter. The residue from centralized sewage treatment facilities, with its potentially-high concentrations of heavy metals, is another topic in itself and is mentioned only briefly in the sections dealing with health and nutrients.

The variety of units used in the literature reviewed for this discussion is quite great. Throughout the text, most units are reported in SI, English and the original unit of the noted sources if it differs. The units in cited tables and charts remain as they appear in the source. For conversion of these figures, one should note that:

1 meter = 3.28 feet	and	1 foot = 0.305 meter;
1 liter = 0.264 gallon	and	1 gallon = 3.79 liters;
1 kilogram = 2.20 pounds	and	1 pound = 0.454 kilogram;
1 hectare = 2.47 acres	and	1 acre = 0.405 hectare; and
1 Mg/hectare = 0.445 ton/acre	and	1 ton/acre = 2.24 Mg/hectare.

Having maintained continuous agricultural production on much of the same land for around 4000 years, the Chinese are likely the world's experts on the recycling of organic materials for the preservation of soil fertility. Over the last two decades, the People's Republic of China has also become a world leader in the use of anaerobic digestion bio-technology. While reports of this work are still somewhat incomplete from a rigorous, scientific point of view, the sheer magnitude of the effort would appear to require some acceptance of test results, especially in the area of crop yields which are easily measured.

The combinations and permutations of soil minerals, organic materials, micro-climates and flora and fauna result in a nearly infinite variety of actual and potential interactions. Thus, while this discussion includes numerous generalized statements, site-specific characteristics must be taken into account for any applications of this information.

I would like to thank Dr. Thomas Huntington of the University of Pennsylvania and reviewers from the Institute for Alternative Agriculture, Inc., for their corrections to and comments on the original text of this discussion.

I. INTRODUCTION - ORGANIC MATTER IN THE SOIL

Organic materials (OM) in the soil can be seen as being composed of relatively stable humus and biologically active materials which are constantly recycled through a myriad of microscopic and macroscopic soil organisms. The importance of this material to agricultural soils relates to biological, chemical and physiological qualities developed through interaction of OM and soil organisms with the mineral, aqueous and atmospheric constituents of the soil. While these interactions may vary, an increase in the level of soil organic material generally includes the following effects (largely after Brady, 1984, and Parr, 1983):

-- Soil color is darkened.

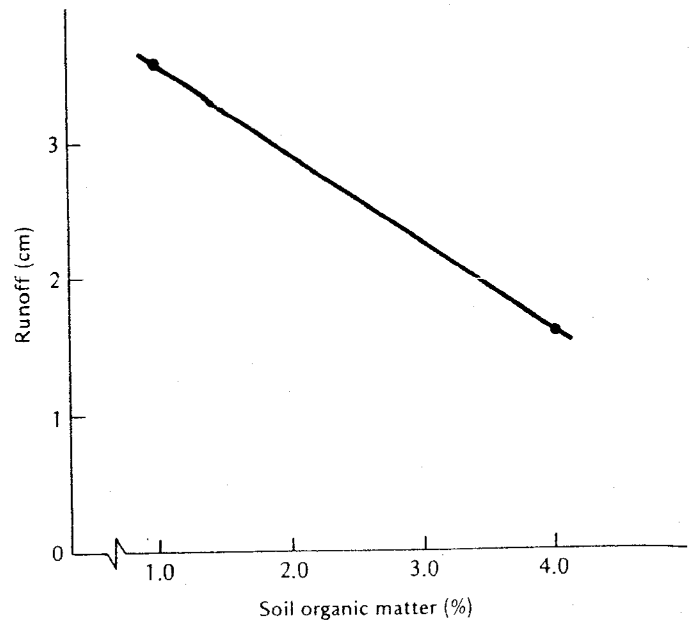
-- Water infiltration, holding capacity and content are all increased. Concomitantly, drought susceptibility, erosion and resulting sedimentation, and nutrient runoff and leaching resulting in eutrification of water bodies are all decreased. A change in soil OM of 1% changes the erodability factor (K) in the Universal Soil Loss Equation by 10% as well as improving the structural index and the permeability class (Papendick, 1984). Livestock manure applied at a rate of 16 tons/acre (35.8 Mg/hectare) to Iowa corn land with a slope of 9% reduced erosion from 22.1 to 4.7 tons/acre (49.5 to 10.5 Mg/hectare) (Pimentel, 1976). Figure I.1 gives a graphic representation of the effect of OM levels of runoff.

-- Aeration and permeability [pore size] are increased and bulk density is decreased. Summerfeldt (1985) found that bulk density decreased at a rate of 0.002 Mg/cubic meter per Mg of manure applied per hectare per year (0.0036 ton/cubic yard per ton of manure applied per acre per year).

-- Soil structure is improved through encouragement of granulation and aggregation while crusting, plasticity and cohesion are reduced.

Figure I.1

General relationship of the soil organic matter content to the runoff from 44 different Indiana soils, which received 2.5 in. of rain in 1 hr. [*From Wischmeier and Mannering* (*1965*).]



(Brady, 1984, p.542)

-- Plant nutrients are more available [once decomposition is complete]. Cation exchange capacity is increased. OM colloids have 2-30 times the capacity of mineral colloids (by weight) and account for 30-90% of the adsorbing capacity of mineral soils (Brady, 1984). More nutrients are held in organic forms and more mineral elements are released by the action of humic acids.

-- The pH buffering capacity of the soil is increased (Arnott, 1982).

-- Soil biota increase in both number and variety, thus offering a greater opportunity for biological control of soil-borne pathogens (Lumsden, 1983).

-- Due largely to increased moisture retention, soil temperatures tend to decrease. This decrease is somewhat mitigated by increased absorption of solar energy through darkening color and increased metabolic activity in the soil.

While the inherent capability of soil to produce crops is closely related to the level of OM [and nitrogen] in the soil (Brady, 1984), this level tends to decrease when the land is used for agriculture; and the more intensive the cultivation, the faster the rate of OM loss. The total organic matter content of a soil is well approximated by multiplying 1.7 times the total carbon content (Brady, 1984). Table I.1 shows an increase in yield potential with

Table I.1

Normalization of Yield Potential Variation with Soil Carbon.

Michigan Soil Management Groups	Yield potential[a] (qu/ha)	Average sampled soil carbon[b] (% C)	Interpolated yield potential at 1.16% C[c] (qu/ha)	Yield potential normalized to yield potential at 1.16% C[d]
Clays			60	
1a	60	1.16		1.00
1b	69	2.03		1.16
1c	75	2.15		1.26
Clay Loams			68	
1.5a	66	1.05		.97
1.5b	72	1.45		1.06
1.5c	79	2.15		1.16
Loams			73	
2.5a	69	.93		.94
2.5b	75	1.28		1.03
2.5c	82	1.63		1.12

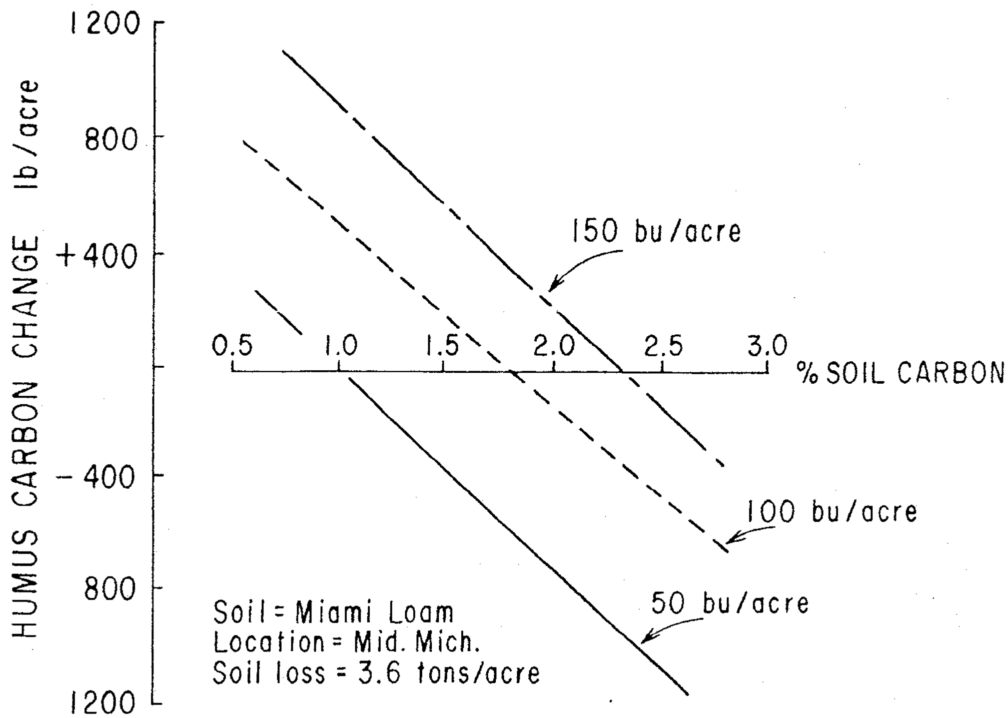
(a) Referred to as suggested yield goal in Ref. 3. 100 bu/A equals 62.7 qu/ha.
(b) Mokma et al. [13] show the range as well as the above-tabulated average for each soil. The range was smallest for soil 1a (.81 - 1.40%) and greatest for soil 1.5c (1.40 - 2.85%).
(c) Estimated graphically from plots of second and third columns for each major soil group.
(d) Second column divided by fourth column entry for each major soil group.

(Lucas, 1977, p. 342)

increase in carbon content of all soils investigated. Although land use history will likely result in many exceptions, one might generally expect such a relationship to hold for all mineral soils.

The root tissue of crops can be quite massive. With the bumper crops grown on much of U.S. cropland this can amount to about 2500 kg/ha (2228 lb/acre) for oats, 4500 (4010) for corn and 8500 (7574) for sugar cane (Brady, 1984). Figure I.2 shows how changes in soil carbon relate to yields for corn. Given high fertilizer inputs and minimal erosion, this mass of tissue may be

Figure I.2



Yearly soil humus changes as related to yield of corn and the soil carbon change.

(Lucas, 1978, p.8)

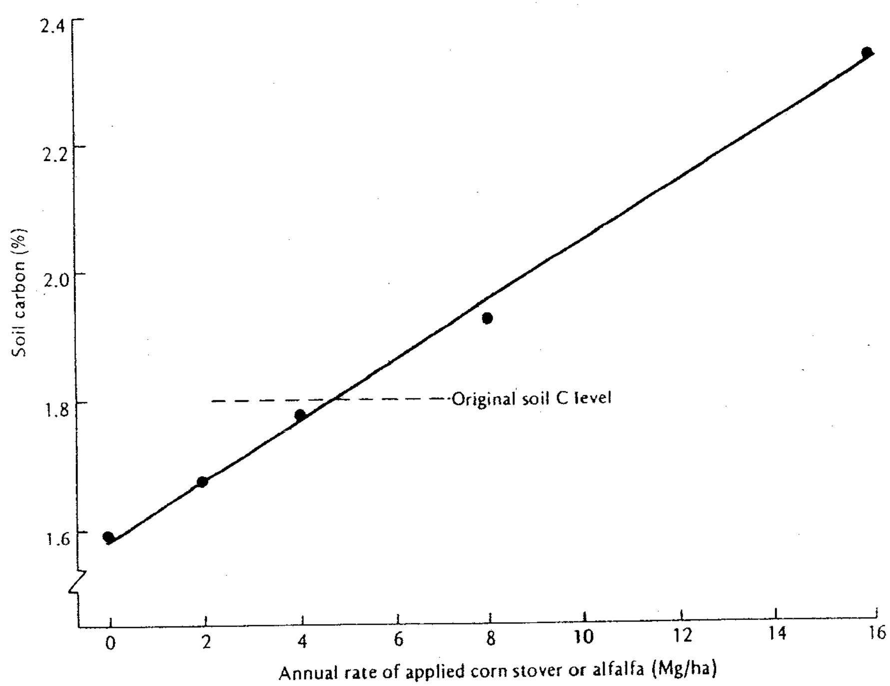
adequate for maintaining OM levels. However, with the lower fertilizer inputs and higher rates of errosion common to most of the world's cropland, the root tissue alone, while quite helpful, is not sufficient to maintain adequate OM levels. ["Adequate" is certainly an arguable term, but for the purposes of discussion, a figure of 2.5% seems reasonable (Jackson, 1980).]

Most U.S. cropland soils have already lost at least 40% of their original OM (and nitrogen) (Clarke, 1980). The efficiency of chemical fertilizer used in the U.S., as a ratio of output per input, decreased from 3.7 in 1945 to 2.8 in 1970 (Demmel, 1976). An average of 14 ton/acre (31.4 Mg/hectare) of topsoil is lost through erosion from cultivated land each year in the United States. At 2.5% OM, the average loss of humus would be about 1000 lb/acre (1121 kg/ hectare) and would require 5000 lb (2270 kg) of plant residue for replacement (Lucas, 1978).

While tropical soils have not received nearly as much scientific attention as temperate soils, OM interactions in these soils is not significantly different except for the rate of biological activity. Since each increase of 10 degrees C (18 degrees F) in soil temperature results in a doubling of biological activity, OM may decompose about five times faster in tropical soils. However, since OM can also be produced at about five times the rate possible in temperate zones, the result [in undisturbed forests, at least] is much the same (Sanchez, 1976).

It is possible, however, to intensively farm land while maintaining or even building up the level of OM. [See Figure I.3.] Summerfeldt (1985)

Figure I.3

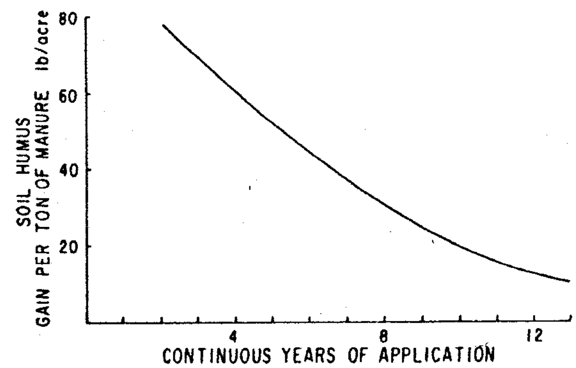


The effect of applying different rates of residues for 11 consecutive years on the carbon content of a typic Hapludoll soil. The Crop was corn, and conventional tillage was used. [*From Larson et al. (1972); used with permission of The American Society of Agronomy.*]

(Brady, 1984, p.279)

found that soil OM in the first 15 cm (5.91 in) increased at a rate of 0.025% per Mg of manure applied per hectare per year (0.011% per ton of manure applied per acre per year) regardless of the method of incorporation or moisture regimen. Lucas (1978) on the other hand, suggests that the gain in soil humus per unit of applied manure decreases with heavier and longer applications. [See Figure I.4.] While Summerfeldt's linear figure is appealing, it seems more likely that Lucas's curvilinear results would more closely correspond to the actual situation.

Figure I.4



Pounds of soil humus gain per ton of manure applied to a Metea loamy sand testing 2.0 percent organic matter--Average for the 10,20 and 30 ton application rates.

(Lucas, 1978, p.4)

The increasing accessibility of computers has led to the application of this tool to the understanding of soil organic dynamics. Lucas (et al., 1977) developed the program shown in Figure I.5. This model gives some idea of the factors involved with soil OM levels. Of particular note are the breadth of some of the percentage flows and the variety and breadth of "Rate Modifiers."

The soil ecosystem is extremely diverse and includes autotrophs as well as primary, secondary and tertiary comsumers. Since the primary consequence of soil metabolism is the burning-off of carbon to release nutrients (Mitchel, 1978), consumers are overwhelmingly dominant, and their food chain is based almost entirely on the OM in the soil.

Soil microflora include bacteria, actinomycetes, fungi and algae. The most important of these is bacteria due to a near monopoly on nitrogen

Figure I.5

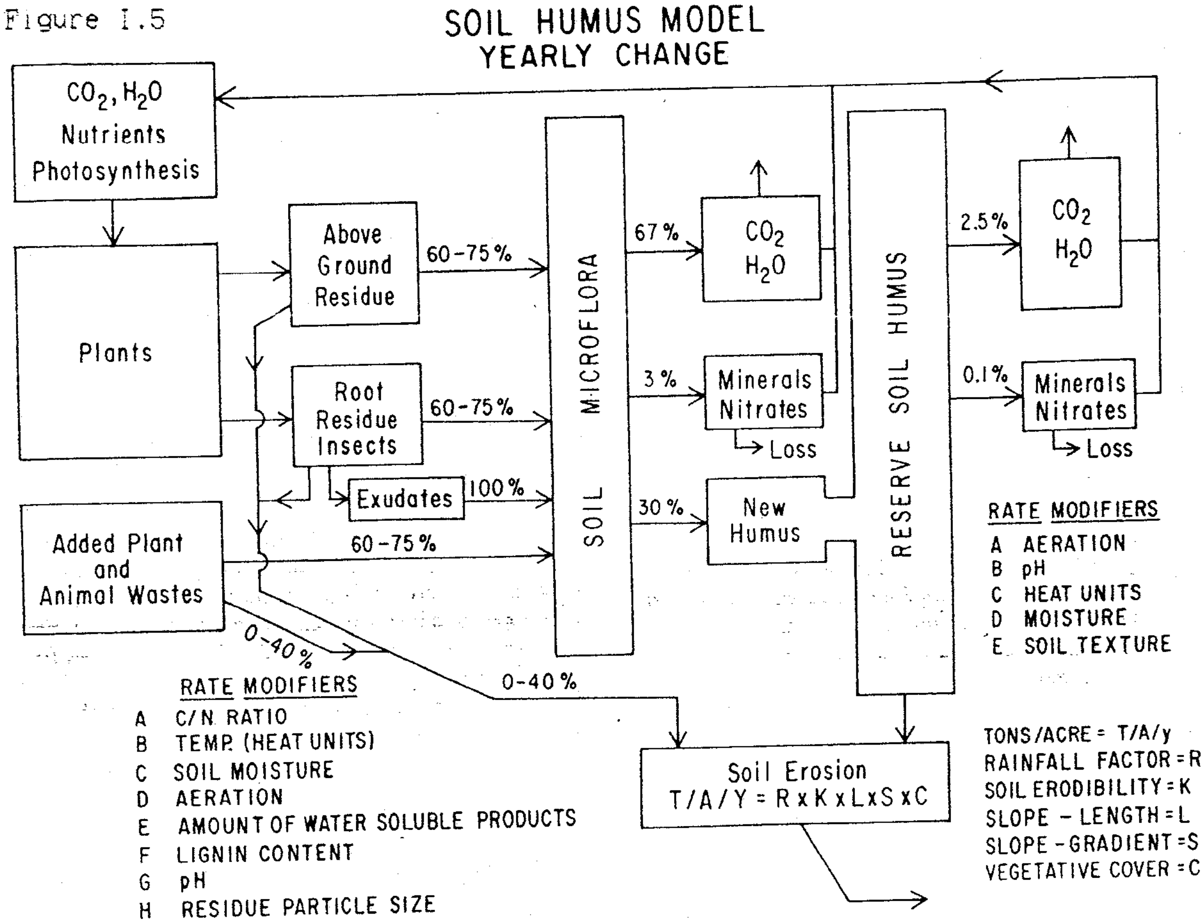


Fig. 3 Soil humus model--yearly change.

(Lucas, 1978, p.6)

oxidation and fixation, nitrification, and sulfur oxidation (Brady, 1984). They also include the primary means of nutrient decomposition/recirculation.

Soil fauna range from protozoa, through nematodes and earthworms, to centipedes. Earthworm populations are especially significant, especially in the top 25 cm (9.85 in) of soil. They bring phosphorus and potassium up from the subsoil (Cox, 1975), and can pass, i.e. turn, or plow, up to 34 Mg per hectare per year (76.5 tons per acre per year) while leaving up to 18 Mg (19.8 tons) of castings. They also increase both the size and stability of soil aggregates (Brady, 1984). In the tropics, termites pass comperable quantities of materials but, due to their [symbiants'] metabolism, are less helpful to crop productivity (Brady, 1984).

II. PATHWAYS FOR RECYLING OF ORGANIC RESIDUES

Throughout most of agricultural history, animal manures [including human] have been nearly always returned to the soil. This permitted a recycling of the nutrients required for plant growth and a maintenance of at least some level of soil organics. Some Asian lands have been farmed almost continuously for several thousand years. With the recent advents of chemical fertilizers and the [over-] emphasis on N-P-K, highly concentrated livestock production systems and the current trend toward increased human urbanization, and extreme over-population leading to the direct burning of manure for cooking fuel, this cycle of return has been interrupted.

Concern about the various effects of this interruption has been growing around the world, and there are increasing attempts to raise the amount of organics returned to agricultural soils, e.g. "no-till" farming methods in the U.S. and the large biogas programs in several Asian nations. Much of this work was intensified by the "energy crises" of the 1970's. The energy intensiveness of industrial farming systems has been questioned, and there is [or at least should be] an increasing, general awareness of solar/biological energy flows and the environmental effects of our extensive use of fossil fuels in both their "natural" and processed [e.g. nitrogen fertilizer, plastic, etc.] forms.

Figure II.1 on the following page shows some of the alternative routes by which organic residues may be utlizised.

Direct burning is increasing in some of the more highly-populated areas of Asia and Africa. Through this option, all OM and nitrogen is lost and only an ash remains. While return of this ash to the soil does help with the supply of other nutrients, this alternative is fairly useless for maintaining soil organics. The other thermochemical options offer much the same result.

Figure II.1
OPTIONS FOR UTILIZATION OF ORGANIC RESIDUES AND RESULTANT PRODUCTS

ORGANIC RESIDUES

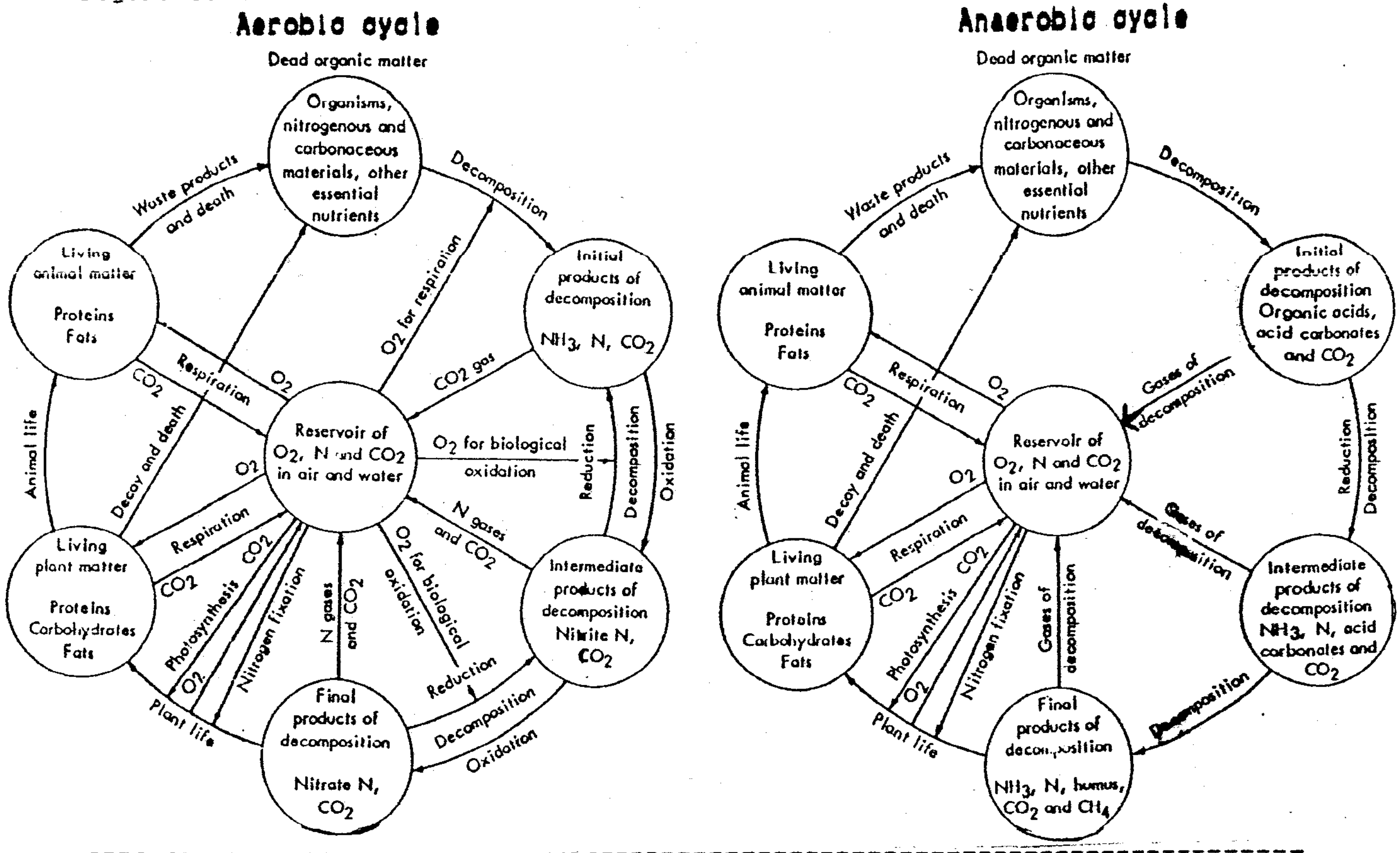
THERMOCHEMICAL PROCESSES				**BIOLOGICAL DECOMPOSITION**		
DIRECT BURNING	PYROLYSIS	HYDROCARBONIZATION		**ANAEROBIC PROCESSES**	**AEROBIC PROCESSES**	BIO-CHEMICAL PROCESSES
		HYDRO-GASIFICATION	HYDRO-GENATION			
HEAT ASH	CHAR OIL GAS	GAS ASH	SOLID ASH	**BIO-GAS** **SLUDGE**	**GASES** **HUMUS**	ALCOHOL PROTEIN

(adapted from Ifeadi, 1975, p.378)

Of the biological processes, the bio-chemical option, requiring an enzymatic-hydrolysis pretreatment, highly-controlled conditions, and a large capital investment, is not really a means for returning material to the soils. The solids from the process would best be used for providing feed for livestock, and thus would require further treatment via one of the two remaining options before final incorporation into croplands. Thus, the two pathways by which organics can actually be recycled are aerobic and anaerobic decomposition. As seen in Figure II.2, the cycles have much in common.

Through both pathways organic materials are largely broken down by bacterial metabolic action and large amounts of CO_2 are released. The primary differences lie in: (A) the large oxygen requirements for the aerobic path and the requirement of the obligate anaerobes for no free oxygen; (B) the nitrogen transformations ending with mostly nitrogen gas and nitrates via the aerobic path and ammonia via the anaerobic path [See Section V.]; and, (C) solar energy, originally stored through photosysthesis, being released as heat through the aerobic path while it is largely contained in the methane molecule

Figure II.2 CARBON AND NITROGEN CYCLES IN ORGANIC DECOMPOSITION



(adapted [i.e. direction of flow of "gases of decomposition" of "initial products of decomposition" of "ANAEROBIC CYCLE" reversed] from Imhoff, 1940, pp. 26-27)

formed through the anaerobic pathway. Table II.1 offers a concise view of various aspects of the two processes.

Both aerobic and anaerobic decomposition occur naturally--the path taken depending almost entirely on the levels of oxygen in the soil. All soils and most bodies of water have an aerobic surface zone and an anaerobic deeper zone. The depth of the transition varies with the rise and fall of the water table and permeability of the soil and dissolved oxygen levels in water. Forest litter and fresh manure spread thinnly on agricultural land are generally decomposed aerobically. Litter sinking into a bog [or food eaten by a large animal such as a cow or human] primarily decompose anaerobically. Fresh manure spread thickly or turned deeply under the surface of a wet field

Table II.1 SOME SELECTED ASPECTS OF AEROBIC ANS ANAEROBIC DECOMPOSITION

CONSIDERATION	AEROBIC DECOMPOSITION	ANAEROBIC DECOMPOSITION
Moisture Levels	40-60%	99+% to less than 50% although less than ~75 % results in very slow activity
Particle Size	for both, generally speaking, the smaller the size, the quicker the process	
Oxygen (as O_2)	large amounts necessary	fatal
Reduction in Carbon	for both, under controlled conditions, loss of dry-weight carbon can be over 60% of that in the original material	
Carbon Dioxide	all carbon lost is in this form	generally between 30-40% of biogas is CO_2
Nitrogen	loss of up to 50% [usually closer to 25%] as N_2 or NH_3 without close control; nitrates dominant in the final product	little control necessary for recovery of essentially all original; ammonia dominant in final product
Carbon/Nitrogen Ratio	both processes have optimums somewhere between 20-35:1 [The problem is that none of the usual laboratory tests give the biologically "decomposable" quantities of C or N. Thus the only way to really determine these levels is to check the losses after the processes have occurred.]	
Other Nutirents	potential leaching of soluable forms in uncovered piles	very well maintained
pH	final products from both processes are neutral to slightly alkaline	
Photosynthetic Energy	largely released as heat	largely contained in the methane produced
Time Required	both can be accomplished in days [or less for digestion of very dilute organic waters] under very controlled conditions--usually weeks or months, although years are required for complete decomposition	
Pathogen Destruction	complete destruction IF all materials reach >55 degrees C for a few hours	very significant, although a subsequent composting of the sludge is necessary for total destruction [espicially of Ascaris eggs]

(Based on innumerable sources)

would also decompose anaerobically until enough drying occurred for air to permeate throughout.

Controlled aerobic decomposition is termed "composting." Numerous terms have been used to refer to anaerobic decomposition, especially over the last couple decades of more intensive investigation. Since the process is basically a continuation of the decomposition occurring in the gastro-intestinal tracts of larger organisms, anaerobic decomposition will herein be referred to as "digestion".

Table III.1

Effect of digester fertilizer on the physical and chemical properties of soils

Location	Treatment	pH	Organic matter (%)	Total nitrogen (%)	Total P (P_2O_5) (%)	Available P (P_2O_5) (%)	Density gm/cm³	Porosity (%)
Chiyu County (2 yrs)	Control	6.85	1.040	0.064	0.096	13.2	1.44	45.66
	Digester sludge	6.80	1.210	0.068	0.110	14.4	1.41	46.59
	Increase	.....	0.17	0.004	0.014	1.2	-0.03	0.93
Diyu County (1 yr)	Control	8.30	1.035	0.071	0.109	16.3	1.27	52.59
	Digester sludge	8.35	1.286	0.101	0.110	20.4	1.16	57.35
	Increase	......	0.25	0.03.	0.001	4.1	-0.11	4.76

(UNEP, 1981, p. 56)

Table III.2 **Effect of Digester Sludge on Physical and Chemical Properties of Soil.**

Location	Time	Treatment	Organic matter%	Total N%	Total P_2O_5%	Available %	Volume wt. gm/cm³	Porosity %
Chu-Xian	2 years	1. Control	1.04	0.064	0.096	13.2	1.44	45.66
		2. Digester Sludge	1.21	0.068	0.110	14.4	1.41	46.59
	3 years	1. Control	1.31	0.0744	0.114	29.6	-	-
		2. Digester Sludge	1.48	0.0892	0.127	33.7	-	-
Dayi	1 year	1. Control	1.035	0.071	0.109	16.3	1.27	52.59
		2. Digester Sludge	1.286	0.101	0.11	20.4	1.26	57.09
	2 years	1. Control	1.122	0.0706	0.118	37.2	1.363	50.09
		2. Digester Sludge	1.384	0.057	0.108	66.7	1.207	57.14

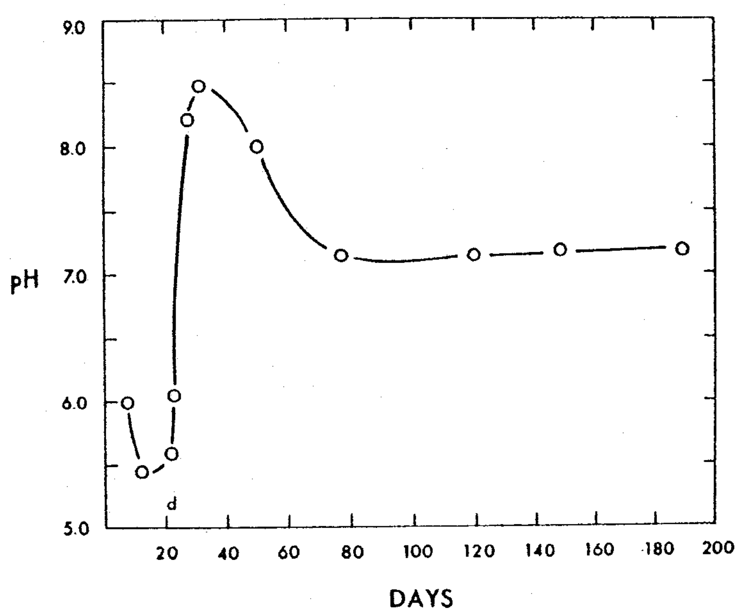
(Gunnerson, 1986, p. 63)

in the production of volatile fatty acids which inhibit plant growth and can be fatal (McAllister, 1977). Since oxygen (as O_2) is fatal to obligate anaerobes and facultative anaerobes generally "prefer" the aerobic pathways, lighter, more porous, well-drained soils can more easily accept larger quantities of digester effluent than can heavier, wet soils with higher levels of clay.

With regard to carbon/nitrogen (C/N) ratios, the two pathways are quite similar. The optimum range for the original material is fairly broad--generally within a range of 20 to 40:1. The ratio of the final products of both processes generally range from 10 to 20:1 (Arnott, 1982; Gooden, 1986), which is comparable to the 8 to 15:1 level in most areable soils (Brady, 1984).

While the decomposition of fresh OM in the soil has a depressing effect upon pH levels, the application of the already-decomposed products of composting and digestion generally result in a slight rise in soil pH. The levels in a compost pile are shown in Figure III.1. [Some higher final pH

Figure III.1



A typical pH profile for a compost heap constructed from plant wastes.

(Poincelot, 1974, p. 25)

levels are reported, e.g. 8.7-9.6 by Godden (1986), but one might suspect that the process had not reached completion.] A similar graphing of pH during digestion would show a greater decrease in the first few days with a gradual rise over a few weeks, to a stable pH of slightly over neutral. [Low C/N ratios may result in higher pH levels, but consideration of this is reserved for Section V.]

There have been few reported scientific investigations dealing specifically with the comparative effects of compost and digester effluent on soil structure and biological activity. Guidi, et al. (1983), reported that, on some Italian Entisols, soil aggregates were more stable when low rates of digester effluent were applied, while stability at higher application rates was better with compost.

Digester effluent has also been found to give a "higher level of stimulation" to bacterial life (Koch, 1982). This may be due to the higher levels of ammonia nitrogen or higher proportion of readily oxidizable substrate in the digester effluent as opposed to compost. (See Section V.) Considering the essentially infinite variety of soils, organic matter, possible interactions and potential benefits, it would seem that much more attention might be devoted to this area.

IV. ENVIRONMENTAL, ANIMAL AND HUMAN HEALTH

Decomposition of organic matter is largely a process of the stabilization of nutrients by means of the energy available through the breakdown of carbon bonds. It is after this process has occurred that OM is really useful in crop production. Until this process has occurred, improperly treated organic residues have a large potential for fouling the environment and spreading enteric and other diseases among animals and humans.

It is thought that anaerobic bacteria developed very early in earth's history when there was little or no free oxygen in the atmosphere. They continue to exist today in oxygen-free environments such as beneath the aerated zone of soils and waters and in the digestive tracts of large animals. However, most life on earth today, including the roots of agricultural crops, requires oxygen for its various metabolic processes. The aerobic organisms of decay are quite efficient at obtaining oxygen from their immediate environment. They have the potential for using up essentially all that may be available in a given environment, thereby suffocating themselves, if they are not otherwise limited by nutrients or energy [i.e. carbonacious materials]. Fresh organic residues contain large amounts of both nutrients and energy. It is especially important that quantities of this material be kept out of bodies of water, since the relatively small quantities of dissolved oxygen [when compared to well-aerated soil] will be quickly depleted leading to the death of most aquatic plants and animals and the dominance of anaerobic organisms. This is the process that occurs beneath the surface of swamps where the oxygen demand for aerobic composition of large quantities of OM far exceeds dissolved oxygen levels in the water. It also occurs when too large a quantity of fresh OM is placed on wet, poorly drained soil.

If the long-term pollution of water is to be avoided, the rate of application of undecomposed residues must not exceed the assimilation capacity of the land to which it is applied. Both well composted and digested materials avoid these problems. Also, since it is largely volatile organic solids that are stabilized [i.e. comsumed by the bacteria], there is little odor problem in spreading these decomposed materials.

The other primary potential hazard in agricultural utilization of organic residue is the potential for the transmittance of fecally-borne diseases. Table IV.1 delineates the fate of some disease vectors in the soil and the effects on these organisms of the heat of composting. Of particular note is the long viability of many of the vectors in the soil and their complete destruction at high temperatures. Since most livestock manures [and night soil] are returned to the land without reaching the high temperatures recommended, it is easy to understand how high levels of these infections persist.

Table IV.2 delineates the effects of digestion on many of these pathogenic organisms. While digestion is also quite useful in this area, the

Table IV.1 Pathogen Survival in Composting and Agricultural Application of Human Wastes

Organism	Survival in: Composting	Agricultural Application
Enteric viruses	Killed rapidly at 60°C	May survive up to 5 months on soil
Salmonellae	Killed in 20 hours at 60°C	On soil, *S. typhi* up to 3 months; other species up to 1 year
Shigellae	Killed in 1 hour at 55°C or in 10 days at 40°C	Up to 3 months
E. coli	Killed rapidly above 60°C	Several months
Cholera vibrio	Killed rapidly above 55°C	Not more than 1 week
Leptospires	Killed in 10 minutes at 50°C	Up to 15 days on soil
Hookworm ova	Killed in 5 minutes at 50°C and 1 hour at 45°C	Up to 20 weeks on soil
Ascaris ova	Killed in 2 hours at 55°C, 20 hours at 50°C and 200 hours at 45°C	Several years
Schistosome ova	Killed in 1 hour at 50°C	Up to 1 month, if damp

Source: *Health Aspects of Excreta and Sullage Management*, World Bank, 1980.

(Panel, 1981, p.98)

survival of large numbers of Ascaris eggs suggest that composting of the digested sludge [as opposed to the generally egg-free liquid supernatent] is required for more complete safety in recycling these residues.

Table IV.2 PATHOGEN DESTRUCTION DURING ANAEROBIC DIGESTION

DISEASE ORGANISM	RETENTION TIME	REDUCTION IN VIABLE ORGANISMS	REFERENCES
Schistosome Eggs (winter)	37 days	100%	(Van Buren, 1976)
Schistosome Eggs (summer)	14 days	100%	(Van Buren, 1976)
Hookworm Eggs	30 days	100%	(Van Buren, 1976)
Flat/Tape worm Eggs	70 days	> 90%	(Van Buren, 1976)
Dysentery Bacillus	30 hours	100%	(Van Buren, 1976)
Paratyphoid Bacillus	44 days	100%	(Van Buren, 1976)
Average of Parasite Eggs	?	93.6%	(McGarry, 1979)
Ascarid Eggs	?	61%	(McGarry, 1979)
Spirochetes	31 hours	100%	(McGarry, 1979)
E. Coli	?	99.94%	(McGarry, 1979)
Salmonella sp.	2-20 days @ 22-37 deg C	82-96%	(Barnett, 1978)
Salmonella Typhosa	2-20 days @ 22-37 deg C	99%	(Barnett, 1978)
Myobacterium Tuberculosis	? @ 30 deg C	100%	(Barnett, 1978)
Oscaris Lumbricoide	15 days @ 29 deg C	90%	(Barnett, 1978)
Poliovirus-1	2 days @ 35 deg C	98.5%	(Barnett, 1978)

Sanitation regulations in many countries assure relative safety from the spread of disease from centralized sewage treatment facilities. In China, tentative sanitation regulations have been developed for the management of biogas digester liquid and solids. They include:

1) The liquid manure which is regularly taken out from the outlet compartment of the digester requires that:
  a) no living ova of Schistosoma or hookworm be found
  b) the reduction of the ova of roundworm be 95% or more
  c) the coli titre not exceed 10 to the 3-4
  d) the breeding of flies and mosquitoes be virtually prevented.
2) The residue cleaned out from the digester requires that:
  a) the fatality rate of the roundworm ova be 95-100%
  b) the coli titre not exceed 10 to the 1-2 (UNEP, 1981, p.57).

A period of composting is recommended if these criteria are not met.

It should also be noted that the viability of most weed seeds is destroyed by the heat of composting. The high levels of free ammonia in a biogas digester have largely the same effect. The Chinese also add liquid ammonia to their compost piles to decrease weed seed viability (UNEP, 1981). It is also worth noting that ammonia is reported aa virucidal in sludge (Sikora, 1986).

V. NUTRIENTS

While agricultural residues are critical as soil conditioners, their value for supplying nutrients should not be under-estimated. Before the advent of chemical fertilizer, and even today for a very large portion of the world's farmers, they comprised the principal source of nutrient supply.

Most of the nutrients in livestock feed pass through the animal. This generally includes about 3/4 of the nitrogen (N), 4/5 of the phosphorus (P) and 9/10 of the potassium (K) [to mention only a few] (Brady, 1984). Table V.1 gives some idea of the quantities of NPK in fresh livestock manure. While these percentages are rather low when compared to chemical fertilizer, Table V.2 shows that the total quantities can be highly significant.

Table V.1 Moisture and Nutrient Content of Manure from Farm Animals[a]

Animal	Feces/urine ratio	H_2O (%)	Nutrients (kg/Mg) N	P_2O_5	P	K_2O	K
Dairy cattle	80:20	85	5.0	1.4	0.6	3.8	3.1
Feeder cattle	80:20	85	6.0	2.4	1.0	3.6	3.0
Poultry	100:0	62	15.0	7.2	3.1	3.5	2.9
Swine	60:40	85	6.5	3.6	1.6	5.5	4.5
Sheep	67:33	66	11.5	3.5	1.6	10.4	8.6
Horse	80:20	66	7.5	2.3	1.0	6.6	5.5

[a] Average values from a number of references.

(Brady, 1984, p.632)

Table V.2 *Total Annual Production of Soil Nutrients Through Organic Wastes in the Developing World, 1971 (actual) and 1980 (estimated).*[(a)]

Source		Quantity of nutrient (10^6 tonnes)[(b)] N	P	K
Human	1971	12.25	2.87	2.61
	1980	15.26	3.57	3.25
Cattle	1971	17.80	4.91	14.12
	1980	22.25	6.14	17.65
Farm compost	1971	9.54	3.34	9.54
	1980	11.93	4.18	11.93
Urban compost	1971	.48	.38	.57
	1980	.60	.48	.71
Urban sewage	1971	1.43	.29	.86
	1980	1.79	.36	1.08
Other[(c)]	1971	6.63	4.44	11.35
	1980	8.29	5.55	14.19
Total	1971	48.13	16.23	39.05
	1980	60.12	20.28	48.81

(a) Source: Ref. 16.
(b) Excludes Central America and Oceania, includes Socialist Asia.
(c) Bone-meal, poultry litter, bagasse, sheep/goat litter, oil cake, press mud. (Several other sources were not included because of their small potential for the developing world as a whole.)

(Nagar, 1977, p.659)

Based on Chinese information, Table V.3 gives an idea of the differences in content of residues after different handling regimens. Of interest is the consistently higher levels of nearly all nutrients in the dried, digested slurry.

While scientific investigation continues to add staves to Liebig's barrel and various interactions tend to cloud the model, N, P and K are conventionally considered to be the primary nutrient elements required form

Table V.3 **Chemical Composition of Organic Digested Manures (Oven Dry Basis).**

	N %	P %	K %	Fe ppm	Mn ppm	Zn ppm	Cu ppm
Liquid slurry	1.45	1.10	1.10	4000	500	150	52
Sun dried slurry	1.60	1.40	1.20	4200	550	150	52
Farmyard manure	1.22	0.62	0.80	3700	490	100	45
Compost	1.30	1.00	1.00	4000	530	120	50

(Gunnerson, 1986, p.64)

the soil for the growth of most plants. Therefore, they will first be dealt with separately as much as possible. This will be followed by a brief consideration of micro- and trace elements and toxic heavy metals.

A. Nitrogen

Nitrogen is required by soil organisms and plants for the formulation of protein. The relevent forms of N for this discussion include:

N_2 - nitrogen gas released by some soil transformations; also the form "assimilated" by N-fixing organisms;

NO_2^- - toxic nitrite; nearly always a short-lived intermediate form of many soil transformations, except when extreme over-abundance of N accompanies very wet conditions;

NO_3^- - soluable nitrate; the form most readily taken up by plants but also most readily leached beneath the rooting zone--then becoming a potential water pollution hazard;

NH_3 - soluable ammonia; another form taken up by plants and soil organisms but potentially lost through volatization;

NH_4^+ - soluable ammonium; a form taken up by plants and the form retained on the soil exchange complex;

R-N - nitrogen assimilated as part of a plant or organism or the slow-release nitrogen present in humus; and

MinR-N - nitrogen fixed by or present in soil minerals.

The study of N availability is complicated by the numerous inter-related transformations it may undergo. These include (largely after Huntington, 1987):

Immobilization - the incorporation of N into organic tissues. It can be very simply represented by NH_4^+ or NO_3^- -----> R-N. This represents the point of most direct competition for N between soil organisms and crops. There seems to be some question in the literature as to the preference of plants for NO_3^- or NH_4^+ (Huntington, 1987; Gunnerson, 1986). While the importance of this distinction is somewhat blurred by the dynamic nature of the situation, the confusion may be somewhat explained by Knuth (1970) who suggests that NO_3^- is most readily assimilated by higher plants while nearly all soil microbes are more readily able to assimilate NH_4^+. While the N assimilated by soil organisms is temporarily unavailable to plants, it is made available upon death and decomposition of these organisms.

Mineralization - essentially the reverse of the Immobilization, occurring upon decomposition of OM. Simply represented, it is R-N -----> NH_4^+ or NO_3^-. This N is available to plants and other organisms, but the soluable NO_3^- may be leached beneath rooting levels.

Nitrification - an intermediate multi-step process in Mineralization. It may be represented simply by NH_4^+ -----> NO_3^-.

Denitrification - a micro-biological enzymatic process which may be either dissimilatory, in which case NO_3^- -----> N_2 with loss of N availability, or assimilatory, which is one type of Immobilization.

Volatilization - the reversible, abiotic, physiochemical reaction of NH_4^+ <-----> NH_3, which tends toward the right at high temperatures and pH above 6.5. Hirai, et al.(1986), note that NH_3 reseased from the soil is inhibitory to plant growth.

Biological Fixation - the process by which some soil organisms are able to obtain their metabolic N requirements from the air. Simply represented it is N_2 -----> NH_4^+ and R-N. The importance of this reaction for agricultural production is obvious. [One might consider the state of world agriculture today if the "Green Revolution's" talent, effort and techniques had been directed toward manifesting this potential rather than maximizing the uptake of various chemicals by a few selected crops.]

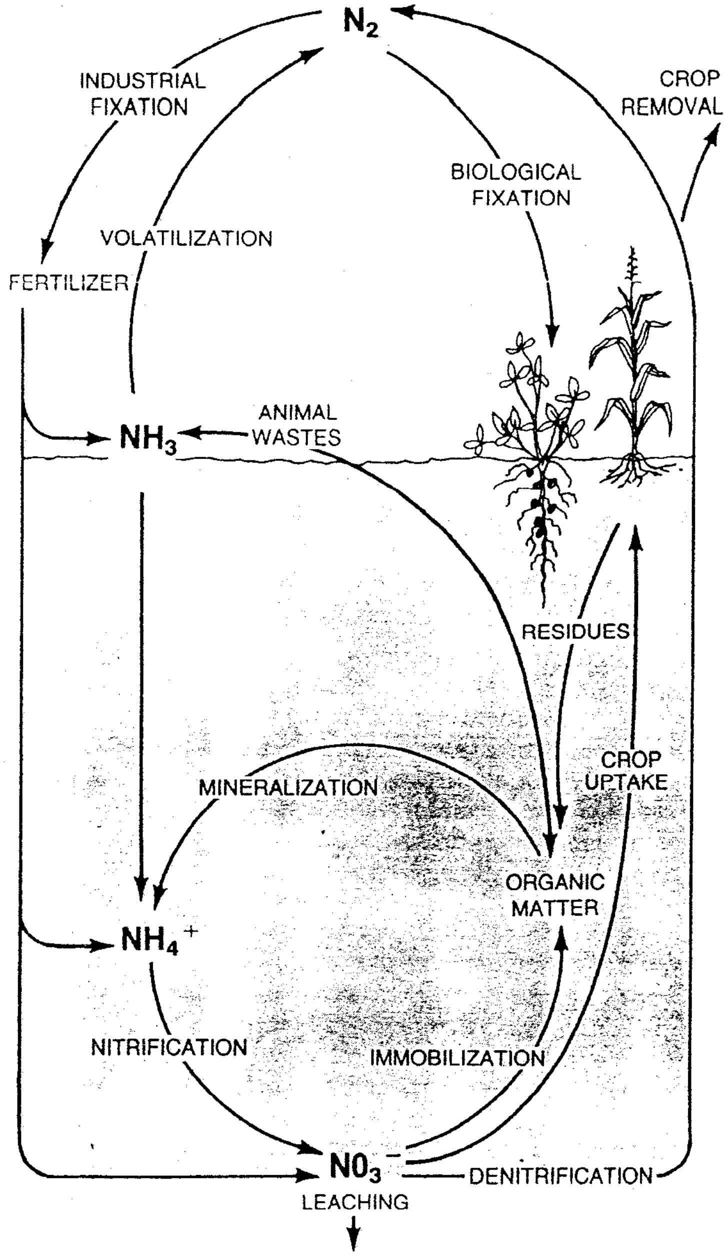
Mineral Fixation - the abiotic form of Immobilization whereby N is fixed as part of the soil mineral complex. It is simply represented by NH_4^+ -----> MinR-N. Also like Immobilization, this N is temporarily unavailable to plants but is maintained in the soil for possible uptake as weathering continues.

Most of these transformations are graphically depicted in Figure V.1.

For the most part, soil organisms obtain energy for their metabolic processes from the breakdown of carbon-carbon bonds. An over-abundance of N [as well as other nutrients] in the soil relative to carbonaceous materials leads to a predominence of N mineralization--with potential leaching losses of NO_3^- --and an over-abundance of carbonaceous materials leads to a predominence of immobilization--with temporary unavailability of N to plants. The transition point seems to be at a C/N ratio of about 20:1. The volatilization transformations are all generally accelerated by an over-abundance of N and higher moisture levels.

Given the above transformations, an adequate supply of N to crops would appear to rest largely at a point where biological activity is high enough for immobilization to be balanced by soil organism death and mineralization, such that only sufficient NO_3^- is available for plants. To the proceeding

Figure V.1



Nitrogen cycle: Transformations between N forms.

(Durst, [1985], p.1)

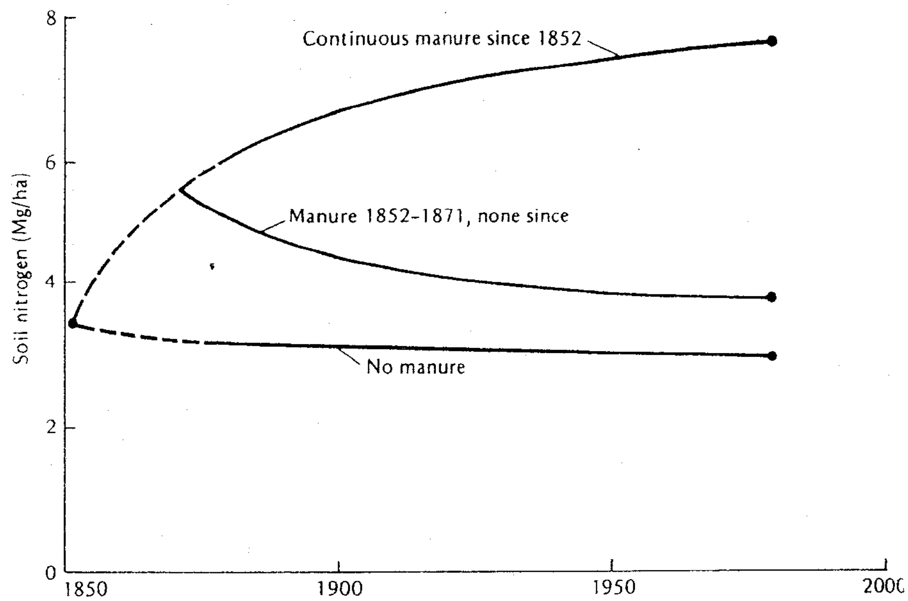
discussion can be added facts that:

- organic colloids are the primary source of N for plants (Brady, 1984);
- 80-90% of N in the soil is in organic form (UNEP, 1981); and
- chemical fertilizer N tends to volatize as NH_3 or leach as NO_3^- unless

quickly taken up by plants or undergoing one of the biological transformations.

With this in mind, it can be understood that a high level of OM and the biological activity that it supports, is vital to the maintenance of the productivity of agricultural lands. Figure V.2 shows that the effects of organic residue application can be quite long lasting. [It should be noted

Figure V.2



The effect of farm manure treatments on the nitrogen content of the top 23 cm of soil at the Rothamsted Experiment Station in England. Barley was grown continuously on all plots. Adding 35 Mg/ha of manure annually since 1852 greatly increased the soil nitrogen content. Note that the plots to which manure was applied from 1852 to 1871 and none since was reduced in nitrogen slowly over the next 100 years. The long lasting effect of manure is obvious. [*From Jenkinson and Johnston (1977); used with permission of the Rothamsted Experiment Station, Harpenden England.*]

(Brady, 1984, p.640)

that the crop in this case was barley and that N reduction would be significantly greater with a crop such as corn which has higher N requirements.

Conventional, minimal-management-input livestock wastes handling practices have the potential for losing 50-75% of the original N present in the residues (Staff, 1979). Safley, et al.(1986), suggest that an average of

23% of N is lost prior to land application. Losses from piled manure can be about 20% in two days, 45% in fourteen days, and 50% in thirty days (Gunnerson, 1986). One of the primary reasons for these losses is the high urea content in the residues [50-60% of the N in dairy cow wastes (Klausner, 1981)] which is rapidly hydrolyzed to volatile NH_3 (Gunnerson, 1986).

When fresh manure is spread on fields, volatilization of N can approach 100% (Lauer, 1975). Such losses are greatly reduced if the residues are plowed into the fields. In this case, the other previously mentioned N transformations come into play and any losses are due primarily to leaching of NO_3^- (Gunnerson, 1986). It is interesting to note that the amount of NO_3^- migrating in six months after fertilization is twice as high with chemical N as with organic fertilizers (Ott, 1983). [Certainly, climate, season, management techniques and soil tpye will affect this last figure.]

While reports often vary widely, complete composting can generally be considered to lose around 25% of the original N (Huntington, 1987; Ott, 1983). [One high-technology, proprietary operation viewed by this author in Jamaica in 1986 claimed 100% recovery.] Ott, et al.(1983), found NO_3^- losses in composting leachate to be less than 0.2% of the total N reduction indicating that the release of N_2 gas is of primary importance. Since compost piles can easily reach over 170 degrees F (76.7 degrees C), and since temperatures over 150 degrees F (65.6 degrees C) result in greatly increased losses, temperature monitoring is of considerable importance to organic N conservation. With the reservations mentioned in Table II.1, p.11, a C/N ratio of less than 30-40:1 also results in higher N losses (Sikora, 1983).

In regard to interactions of compost N with the soil, the [surprisingly scanty] literature includes such announcements as Ott, et al.(1983), reporting that NO_3^- migration was "slightly lower" with composted, rather than uncomposted, farm yard manure, and Loehr, et al.(1976), finding that there was no [statistically significant] difference between "aerobically stabilized" [as opposed to completely composted?] poultry manure in regard to both plant available nutrients and surface runoff. It should again be emphasized that there are innumerable variables involved with experiments concerning the land application of compost, or any other materials. These include soil series and phase, the rain or bright sun that happen to occur at the specific time of the research, the precise state of residue decomposition, etc., etc.

The only potential N losses in the digestion process are from the reduction of nitrates to N_2, and there are little nitrates in manure (Gunnerson, 1986). The net effect of digestion is to increase the amount of easily-available but easily-volatized ammoniacal N (Klausner, 1981)--by up to 100% (Gunnerson, 1986) or up to 260%.(UNEP, 1981) Lower than optimum C/N ratios result in higher pH values and higher ammoniacal N concentrations (Klausner, 1981).

The liquid supernatant contains most of the N originally fed into a digester--from 58-84% [generally toward the higher figure] (Field, 1984). While this liquid is certainly best injected into the soil for maximum N conservation, the importance of injection seems to be in some dispute. Kendall (1977) suggests that most NH_3 is lost within three days of surface spreading, while Gunnerson, et al.(1986), report that only 35% of ammoniacal N is lost in 72 days of drying. Kendall (1977) also reports that losses are highest on sandy soils with low water holding capacity and low cation exchange capacity (CEC). Watson (1983), in an experiment in pots aimed at investigating the claim that digestion increases "first year N recovery", found that recovery was only slightly ["not significantly"] higher than with fresh manure.

[This author would suggest that "first year availability" is a measurement unit relevant primarily to chemical N fertilizers and more especially to the marketing of them. It is certainly not an important parameter for considering the long-term maintenance of soil productivity and it is highly inappropriate to compare the "first year availability" of chemical fertilizer with that of organic materials which have much longer-term effects. A much more reasonable approach would be to compare overall "recovery effectiveness" after an equalibrium has been reached through several years of organic material addition.]

Watson (1983) also developed Table V.4 showing N use efficiencies of various options for utilization of digester effluent. The high efficiency for the liquid options are most notable and offer great potential for integrated systems. One must wonder about the time span used for developing some of the lower N use percentages. There would certainly be some significant changes in these figures if they are based on only first-year rather than long-term use.

The preceeding discussion shows that the final methods of handling and use of decomposed residues are certianly quite crucial for N conservation and recycling. As Tables V.5 and V.6 show, however, it does appear that digestion offers a much higher level of N conservation when the decomposition process is considered alone.

B. Phosphorus

By current industrialized agriculture convention, the second of the major plant nutrients is phosphorus (P). While P is often present in soils in substantial quantities, it has a strong tendency to form very insoluble phosphates by fixation with aluminum (Al), iron (Fe) and calcium (Ca), thus becoming relatively unavailable to plants (Huntington, 1987). This process is

Table V.4 Nitrogen Use Efficiency of Selected Food Production Systems Employing Digested Slurry

System	N use (%)	Product	Protein (%)	Reference
Complete slurry				
Land spreading	50-55	Grain, forage	15-30	Spedding, Walsingham, and Hoxley (1981)
Extensive aquaculture	35-40	Fish	50	Schroeder (1979)
Extensive algae	35-50	Feed	50-60	Hong et al. (1979)
Sludge hydroponics	35	Forage	12-18	Fry (1974); Sathianathan (1975)
Solids				
Composting	50-85	Soil conditioner	—	Poincelot (1975); Parr, Epstein, and Willson (1978)
Vermiculture	75	Soil conditioner, feed	—,60	Spedding, Walsingham, and Hoxley (1981)
Refeeding	50-90	Feed	25-35	Hashimoto, Prior, and Chen (1978)
Liquid				
High rate pond algae	80-90	Feed	65	Chung et al. (1978); Dodd (1979)
Hydroponics	80-100	Horticultural produce	—	Cooper (1979); Garroway (unpub.)
Yeast	95	Feed	50	Ingens and Clarke (1976)
Aquatic macrophytes	50-90	Forage	10-18	Dubusk, Williams, and Ryther (1977); Hanisak Williams, and Ryther (1980)

(Watson, 1983, p.161)

responsible for about 90% of the removal of available P from soils (Okubo, 1985).

Since the fixation of potential biologically active P increases as the soil pH decreases, and since OM additions to mineral soils tend to raise the pH, the importance of OM is here again quite important. As one might expect, when applying OM, the concentration of P [and K] near the soil surface are inversely related to the depth of tillage (Culliney, 1986). Sikora, et al. (1982), investegated the P uptake from sewage sludge [whether aerobically or

Table V.5

Comparative loss of nitrogen in biogas fertilizer and compost

		BEFORE FERMENTATION			AFTER FERMENTATION				
		Total nitrogen			Total nitrogen		Available nitrogen		
Raw materials	Method	%	gm/jar	Available nitrogen gm/jar	gm/jar	% of loss	gm/jar	% to total nitrogen	± (%)
Pig dung: hay =4:1	Biogas digester	1.42	17.55	3.3	15.8	10.00	8.04	50.9	+253.6
	Compost	1.42	17.55	3.2	12.3	29.60	1.50	12.1	-52.7
Pig dung: dung (cattle): hay=1:1:1	Biogas digester	1.95	23.71	3.4	22.68	4.35	12.03	50.3	+362.4
	Compost	1.95	23.71	3.4	18.50	29.80	0.94	5.0	-71.43
Pig dung: dung (cattle): feces=3:1:1	Biogas digester	2.98	37.23	6.5	36.23	2.97	26.00	71.6	+400.0
	Compost	2.98	37.23	6.5	31.76	14.70	5.32	16.7	-18.17

Source: Biogas Promotion Office, Zhejiang Province

(UNEP, 1981, p.53)

Table V.6

Comparative loss of nitrogen in digester fertilizer and farmyard manure (1 jin=0.5 kg)

	Total nitrogen		Ammoniacal nitrogen	
Treatment	jin	%	jin	%
Before treatment	0.950	100	0.168	100
Digester manure	0.940	98.9	0.438	260.7
Open-air pool manure	0.646	68.0	0.138	82.5
Compost (occasionally turned)	0.572	60.2	0.0301	17.8

Source: Geothermal Institute of Guangdong

(UNEP, 1981, p.53)

anaerobically decomposed is unfortunately unstated] on Evesboro (Typic Quartzipsamment) sandy loam and Fauquier (Ultic Hapludalf) silt loam and found P uptake to be two times greater on the former. When fescue was grown, they also found that, while additional chemical N and P increased P uptake, no chemical additions were necessary for adequate P levels to satisfy ruminant nutrient requirements. The different rates of uptake point to the tendency for P fixation to increase as soils age. This process reaches its climax in Oxisols where the high levels of sesquioxides result in rapid P fixation and increasing unavailability.

Since P does not exist in volatile forms in agricultural residues (Klausner, 1981), P is not lost in composting (Ott, 1983). Table V.7 shows

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Table V.7

Changes in the Primary Nutrients (N, P, K) of Farmyard Manure during Composting

Calculation basis[a]	Nutrients	Length of composting period (months) 0	2	4	12
Percent of current dry matter	N	2.1	2.9	3.0	2.6
	P_2O_5	1.1	2.0	2.1	2.3
	K_2O	1.6	1.6	2.4	2.5
Percent of initial dry matter	N	2.1	2.0	1.6	1.6
	P_2O_5	1.1	1.2	1.1	1.1
	K_2O	1.6	1.9	1.9	1.5
Percent of initial amount	N	100	95	86	76
	P_2O_5	100	109	100	100
	K_2O	100	90	90	72
Organic matter as percent of initial organic matter		100	68	46	38

[a] Figures are averages of values from 16 different composting windrows.

(Ott, 1983, p.148)

this to be true even after a year of the process. The optimum C/P ratio for composting is somewhere between 75-150:1 (Gray, 1971). P concentrations in compost may vary from .5-2% (Staff, 1979), depending largely on the original material and the state of decomposition.

In digestion, 59-86% of the P is in the sludge rather than the supernatant (Field, 1984). Again, since P in agricultural residues is not in volatile forms, losses from digestion should not occur (Klausner, 1981). Gunnerson, et al.(1986), report that digester sludge additions cause a large increase in the level of P in the topsoil. The Chinese report, however, that a very low C/N ratio, causing a high digester pH, can result in the release of some phosgene gas (PH_3) (UNEP, 1981).

Field, et al.(1984), found that extractable P was reduced by 19-30% through digestion, and suggested that this likely resulted from increased sorption by manure solids. Hensler (in Miner, 1975), however, developed Table V.8 which shows that P recovery was highest after digestion. These seemingly

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Table V.8

Effect of method of handling of dairy cow and steer manures on average yield and recovery of N, P, and K by one crop of corn grown on a Miami silt loam in pots.

Type of manure[a]	Yield[b]	Recovery by crop[b]		
		N	P	K
	g/pot	%	%	%
No manure	11.0	–	–	–
Dairy cow				
Fresh	19.5	44.0	19.5	40.5
Fermented	19.5	42.0	22.5	49.5
Aerobic liquid	17.0	18.5	19.5	38.0
Anaerobic liquid	22.5	52.5	29.0	48.0
Steer				
Fresh	32.0	53.0	23.5	73.5
Fermented	32.5	54.5	23.5	74.0
Aerobic liquid	20.5	13.0	14.5	34.5
Anaerobic liquid	33.0	65.5	27.5	83.0

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis including 2% oat straw. Tons/acre = tons/2,000,000 lb. of acre furrow slice.
[b]Average of three replications and drying treatments; recovery values calculated on fresh-weight basis for manure.

Source: R.F. Hensler, Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph.D. Thesis. University of Wisconsin. Madison. 1970.

(Hensler, in Miner, 1975, p.31)

conflicting reports are further complicated when one considers that Field dealt with chemical extraction and Hensler used anaerobic liquid. This again points out the problems with trying to formulate firm conclusions from the myriad of variables considered and techniques employed by different researchers.

The Chinese have developed a fertilizer they call biogas phosphohumate. It is produced by composting one part low-grade phosphorite powder with 10-20 parts digester sludge for a period of 1-3 months (Gunnerson, 1986). Table V.9 shows that the combination is quite beneficial for increasing yields.

Table V.9

Effect of biogas phosphohumate on the yield of major crops (1 jin=0.5 kg; 1 mu=0.066 ha)

	Rice (2)*			Wheat (13)*			Sweet Potato (3)*			Rape (5)*		
	Yield	*Increase*		*Yield*	*Increase*		*Yield*	*Increase*		*Yield*	*Increase*	
	jin/mu	jin/mu	%	jin/mu	jin/mu	%	jin/mu	jin/mu	%	jin/mu	jin/mu	%
1. Control	581.5	—	—	528.6	—	—	2772	—	—	246.0	—	—
2. Phosphorite powder 40-50 jin/mu	620.0	38.5	6.6	558.6	60.0	11.4	2959	187	6.7	246.0	0	0
3. Digester sludge 400-1000 jin/mu	634.3	52.8	9.1	581.4	72.8	13.8	3250	478	17.6	260.2	14.2	5.8
4. Biogas phosphohumate 440-1050	653.3	71.8	12.3	611.7	83.1	15.7	3302	530	19.1	268.0	22.0	8.9

*The number in parentheses indicates the number of experiments.

(UNEP, 1981, p.55)

C. Potassium

The third major plant nutrient under current convention is potassium. The primary problem with supply of adequate K for plant growth is, like P, fixation by soil compounds. However, while P is fixated by sesquioxides, K tends to be incorporated more into the lattice structure of mineral soils (Huntington, 1987).

Poonia, et al.(1986), found "meager" information on the effect of OM on K exchange equilibrium in soils, especially for arid and semi-arid tropical regions. What was found also showed "considerable differences" in the role of OM on K "specificity". It appears that they continued this trend by stating that quantity:intensity parameters of farm-yard-manure-treated and control soils were identical, and later that there was a considerable decrease in K preference in farm yard manure treated soils. They state that there is a lower K preference in surface soils than subsoils [the former assumedly having a higher OM content], but then claim that farm yard manure increased the K preference of soils (and suggested that this may be due to an increase in the proportion of K-specific interlayer exchange sites. This author is at a loss to reconcile such statements.

Much of the K in livestock residues is in soluble form (Ott, 1983) and is therefore susceptible to leaching. Such barnlot losses may average around 10% (Safley, 1986). The dominant reaction when residues are applied to the land is K exchange and fixation with the release of Ca, magnesium (Mg) and sodium (Na) (Ward, 1983). Although there are relatively high levels of soluble K salts in livestock residues [as well as salts of Na, Ca and Mg], unless quickly fixed, these are easily leached beneath rooting zones. Salinity problems are therefore unlikely to develop if application is limited by N requirements (Lucas, 1977).

The K level in compost generally varies from .5-2%, again depending on the original material and state of decomposition. As Table V.7 [included in the discussion of phosphorus] shows, K losses during the process can be substantial. Since these losses are primarily through leaching (Ott, 1983), they can be minimized by covering the pile.

In digestion, leaching loss does not occur so that all of the original K is conserved in the effluent. Field, et al.(1984), suggest that 60-80% of the total K is present in the supernatant and that its extractability is about the same as with fresh residues. While K recovery is largely dependent on the K status of the particular soil in question, Table V.8 [also included with the phosphorus discussion] shows that K recovery by crops was generally slightly higher with digested effluent than with other treatments.

D. Other Nutrients and Metals

While N, P and K are generally considered to be the primary plant nutrients, Table V.10 shows that crop requirements for [or uptake of] other elements are certainly significant, in some cases being higher than P. The actual quantities of these nutrients which crops may contain is dependent on numerous variables including soil type, water content, availability [which is largely pH determined), etc. (Brady, 1984; Hensler, 1970).

Table V.10 **Removal of different elements from soils by crops and animals.**

Crop	Yield per acre	Pounds removed per acre							Grams removed per acre			
		N	P	K	Ca	Mg	S	Na	Fe	Mn	Cu	Zn
Corn grain	100 bu	80	15	17	2	8	7	1	66	14	6	43
Grain sorghum	80 bu	80	14	15	2	8	7	2	90	30	20	28
Soybeans	32 bu	105	11	29	5	5	4	4	70	26	14	--
Peanuts	2500 lb	94	8	12	2	4	6	14	16	--	--	--
Cottonseed	1800 lb	62	13	20	3	6	4	5	114	10	41	--
Wheat	60 bu	81	15	18	2	4	6	3	73	80	11	23
Rice	6000 lb	78	14	9	3	4	3	3	96	48	9	5
Barley	75 bu	67	15	20	3	5	6	1	87	26	12	25
Sugarbeets	25 T	21	20	125	20	15	1	40	227	765	30	--
Corn silage	20 T	136	24	118	34	24	12	3	929	228	47	98
Alfalfa hay	7 T	332	31	212	197	38	43	19	1306	282	74	92
Coastal bermuda hay	9.5 T	243	29	270	74	27	--	--	--	--	--	--
Reed canarygrass hay	7 T	169	30	282	41	31	--	47	816	503	65	--
Potatoes	30 T	210	30	288	6	18	12	12	544	240	102	--
Tomatoes	20 T	71	11	98	5	6	--	1	92	--	--	--
Lettuce	12.5 T	34	5	42	5	3	--	2	55	--	--	--
Carrots	20 T	58	12	112	12	8	8	15	104	68	24	--
Snap beans	5 T	27	4	21	5	3	--	1	32	--	--	--
Dry beans	1800 lb	64	8	22	3	3	4	1	64	15	8	--
Loblolly pine	Annual growth	9	1	4	5	2	1	--	--	--	--	--
Beef gain	500 lb	10	4	1	8	1	1	1	46	--	--	--
Milk	4000 lb	22	4	6	5	1	1	2	1	1	--	--

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(Hart, 1974, p.193)

While many of these elements are available in soils in sufficient quantities or are conveniently added by atmospheric deposition, e.g. sulfur (S), the "conventional" emphasis on the supply of N, P and K through specific chemical fertilizers has a tendency to result in depletion of these other nutrients. Agricultural residues, on the other hand, can supply the full spectrum of these materials. Table V.11 shows the range of quantities of these other nutrients commonly found in manures. Mathers, et al.(1984) found that 22 Mg/hectare per year (49.5 ton/acre per year) of manure could supply all the nutrient needs of irrigated corn, wheat or grain sorghum on a Pullman clay loam. They noted that over three times that amount had a potential for causing salt or NH_3 damage to seedlings.

Table V.11 RANGE OF SECONDARY AND TRACE NUTRIENTS IN MANURES (KG/MG)

Calcium	2.4 -74.0	Boron	0.02 -0.12
Magnesium	1.6 - 5.8	Manganese	0.01 -0.18
Sulfur	1.0 - 6.2	Copper	0.01 -0.03
Iron	0.08- 0.93	Molybdenum	0.001-0.011
Zinc	0.03- 0.18		

(Brady, 1984, p.633)

This author has found very little information on the effects of various manure handling techniques on other plant nutrients, and even less on any soil interactions which might occur after the spreading of differently handled residues. Table V.3, p.20, does give the levels of some other nutrients under different handling procedures. The lower figures for farm yard manure are perhaps due to dilution or high carbon content. Ward (1983) states that the total Ca, K, Mg and Na salts leached after manure is added to soils is significantly less than the total salt inputs which would indicate either uptake by plants or colloidal adsorption.

In general, unprotected compost piles may be expected to lose through leaching some of the nutrients which exist in soluble forms. Compost piles protected from rainfall and digesters would not suffer such losses. Field, et al.(1984), found that about 55-80% of the Ca and Mg were contained in the digester sludge and that digestion reduced extractable Ca by about 10% and extractable Mg by 16-20%. [The correlation of chemical extractability with long-term plant availability is unstated.]

The use of both aerobically and anaerobically treated municipal sludge as soil conditioner and fertilizer on crop lands is somewhat problematic due to toxic metal concentrations--especially copper (Cu), cadmium (Cd), zinc (Zn) and nickel (Ni) (Booram, 1977). Tables V.12 and V.13 give an idea of the concentrations of these elements in such sludge. Soil pH is the primary influence governing the sorption of these heavy metals to soil constituents--a

Table V.12

MICROELEMENT CONTENT OF MUNICIPAL SEWAGE SLUDGES AT 43 TREATMENT PLANTS IN THE NORTHEAST

City[b]	Zn	Cd	Cu	Ni	Pb	Cd/Zn (%)
	(mg/kg dry sludge)					
1[c]	3450	100	1010	185	960	2.8
2[c]	3290	160	670	260	1230	4.9
3[c]	3420	7.3	3490	1260	500	0.21
4	1720	22.1	1100	34	540	1.28
5	1200	16.4	940	50	640	1.34
6	690	3.8	520	10	240	0.56
7	1140	61.4	1270	40	320	5.4
8	1190	9.7	900	54	490	0.82
9	5050	169.0	1510	980	350	3.3
10A[c]	1450	16.9	1450	77	440	1.16
10B[c]	5320	176.0	630	180	630	3.3
11	660	38.4	790	240	240	5.8
12	935	7.4	1080	36	640	0.79
13[c]	6430	683.0	1810	530	660	10.6
14	1410	8.9	1980	30	340	0.63
15	2380	11.1	690	38	505	0.47
16	1160	8.4	590	18	195	0.73
17	1350	19.2	2740	69	650	1.42
18	870	7.0	690	37	275	0.80
19	1430	6.6	600	24	500	0.46
20	228	0.6	2600	41	52	0.26
21	920	15.7	710	28	2080	1.71
22	1260	10.8	870	108	1420	0.85
23A	600	5.0	350	35	300	0.83
23B	960	10.0	265	40	140	1.04
23C	1320	16.0	495	50	700	1.21
25	1250	970	1170	88	270	0.78
26	1780	15.9	500	42	590	0.84
27[c]	2150	269.0	1340	120	1770	12.5
29A	4800	18.6	2590	210	620	0.38
29B	1200	9.4	860	160	470	0.78
30	1190	10.0	240	39	490	0.84
31	2590	9.0	620	25	2660	0.35
32	2000	13.3	820	44	520	0.66
33	1240	9.1	500	30	270	0.73
34	6120	22.6	660	49	4900	0.37
35	1560	17.6	570	40	340	1.12
36	1690	9.1	650	30	680	0.54
37	2100	12.6	2940	37	420	0.60
38	1080	13.0	770	25	470	1.20
39	2460	95.0	670	95	470	3.90
40	1540	8.0	1220	46	1300	0.52
41	1670	12.0	540	25	330	0.71

[a] Each value is the mean content of all samples of sludge obtained from a treatment plant to date.

[b] Numbers represent different municipalities; letters represent different treatment plants.

[c] Visits to treatment plants based on advance information about heavy metal release to the sewer, metal-caused digester upsets, etc.

(Lofy, 1975, p.9)

pH higher than 6.5 giving much less problem with metal uptake by plants than the lower pH ranges (Booram, 1977). Since these elements will remain in the soil almost indefinitely unless removed by crops, care must be taken to maintain the high pH levels for an equally long period. While Sikora, et al.(1986), found that sludge compost with high concentrations of heavy metals and chlorinated OM had no inhibitory effect on soil enzyme activity and

Table V.13 SUMMARY OF MEAN COMPOSITIONS OF ABOVE SLUDGES

Element	Minimum	Maximum	Mean	Median	Maximum Domestic [a]
Zn (ppm)	228	6430	2010	1430.0	2500
Cd (ppm)	0.6	970	72.2	13.0	25
Cu (ppm)	240	3490	1080.0	790.0	1000
Ni (ppm)	10	1260	129.0	42.0	200
Pb (ppm)	52	4900	735.0	500.0	1000
Cd/Zn (%)	0.26	78.0	3.64	0.84	1.00

(Lofy, 1975, p.9)

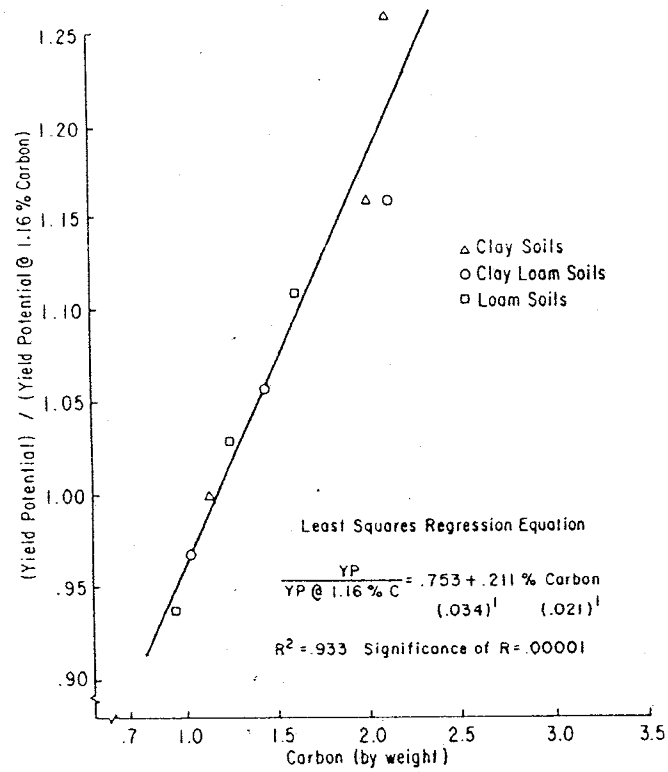
suggest that the probable cause was the age and highly stablized nature of the compost, failure to state the time-span and soil pH limit application of this finding.

While buildup of heavy metal concentrations in the soil from application of agricultural residues, no matter how treated, is rarely considered, modern livestock feeding practices may cause problems in this area. The amounts of Cu and Zn added to chicken and swine feed rations can raise the concentrations in residues to levels approximately equal to those found in municipal sewage sludges (Chaney, 1974). When various livestock residues are recycled as feed components for other livestock, e.g. pig waste to sheep (Dalgarno, 1975), the situation becomes much more complicated!

VI. YIELDS

While the specific interactions of specific nutrients in agricultural soils is interesting, the production of crops from these fields is perhaps more important. Increasing the level of OM in mineral soils appears to be an excellent method for increasing yields. Clark, et al.(1980), state that an increase in soil OM from 1.7-3.6% would raise the land's yield potential by 25%, and this figure includes no credit for nutrient additions. Lucas, et al. (1977), developed Figure VI.1 showing a constant increase in yield potential with increasing soil carbon.

Figure VI.1

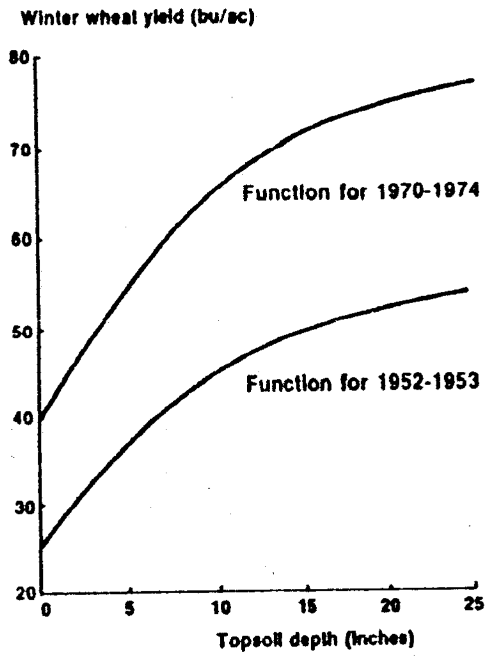


Effect of soil carbon on yield potential of corn.

(Lucas, 1978, p.343)

While Brady (1984) defines topsoil as the surface soil layer which is plowed, thus limiting it to a depth of about 25 cm, the more common definition seems to include much deeper layers and is, perhaps, based on some acceptable level of organic colloids. Figure VI.2 shows that topsoil depth is quite important even in a situation of rapid technological change. It is especially notable that yields from deep topsoil using early 1950's technology are higher than yields from shallow topsoil using [often more erosive] early 1970's technology [which includes higher seed yielding varieties]. Pimentel, et al. (1976), developed Table VI.1 and suggested that, while there are numerous variables influencing the situation, one can generally expect corn yields to fall by about four bushels per acre for each inch of topsoil lost.

Figure VI.2



Comparison of winter wheat yield-topsoil depth relationships from the 1950s and the 1970s, eastern Whitman County, Washington.
SOURCE: Young et al., 1985.

(Walker, 1986A, p.34)

Table VI.1

. Relation between topsoil depth and yield of corn drawn from selected studies (*69, 70, 72*). Compared with standard plots of 12-inch topsoil depth, corn yields were decreased by the amounts shown when corn was grown in soils of the depth indicated.

Topsoil depth (inches)	Yield (bushel/acre)		
	Range	Average	Decrease
0 to 2	25 to 56	36.2	10.8
2 to 4	28 to 69	47.0	9.3
4 to 6	39 to 83	56.3	8.4
6 to 8	49 to 97	64.7	4.3
8 to 10	50 to 102	69.0	5.3
10 to 12	50 to 125	74.3	

(Pimentel, 1976, p.153)

It appears that compost and digestion effluents are equally useful at building up soil organics, thus improving and increasing topsoil. Some care must be taken with both materials. Spreading digester effluents too thickly or at improper times, i.e. when the soil is water-logged, can increase anaerobic soil activity and lead to high levels of fatty acids wich inhibit plant growth and may even be fatal. However, application of immature compost can also result in production of these fatty acids (Hirai, 1986). Since plant growth is inhibited by NH_3 released from the soil (Hirai, 1986), the higher levels in digester supernatants, as opposed to compost, may cause some reduction in growth. [One might expect any inhibitory effect due to supernatant use to be rather small compared to the effects of anhydrous ammonia.]

There appears to be some controversy over the question of whether compost, digester effluents, or even fresh manure results in greater yields. Hensler (1970), in a study of dairy cow residues, found that fresh manure, fermented [slightly aerobically decomposed] solids and anaerobic liquid all gave approximately equal yields on a Maimi silt loam; that neither handling method nor time of application made any difference on a Rosseta soil; and that anaerobic liquid was slightly the best on a Withee soil.

Chinese information, on the other hand, shows consistently higher yields with digester effluents than with compost. Yields are about 10% higher for rice and about 13% higher for crops in general (FAO, 1978). Over the years of digester use, they have continued to obtain increases in crop yields (Gunnerson, 1986) Table VI.2 shows some of the yield increases over "open air

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Table VI.2

Fertility comparison between digester effluent and open-air pool manure (1 jin=0.5 kg — 1 mu=0.066 ha)

	Yield (jin/mu)		Increase		
	Digester effluent	*Control*	jin/mu	%	*Number of tests*
Rice	636.4	597.5	38.9	6.5	18
Maize	555.9	510.4	45.5	8.9	9
Wheat	450.0	390.5	59.5	15.2	29
Cotton	154.5	133.5	21.5	15.7	2
Rape	258.4	233.6	24.8	10.6	15

(UNEP, 1981, p.54)

pool manure." Table VI.3 shows increases over a more productive control which may or may not be compost. Table VI.4, developed in India, shows a comparison of yields of several crops using chemical fertilizer and digester supernatant.

Table VI.3

Effect of digester sludge on crop yields (1 jin=0.5 kg — 1 mu=0.066 ha)

	Amount digester sludge applied (jin/mu)	*Yield* (jin/mu)		*Increase*	
		Digester sludge	Control	jin/mu	%
Sweet potato	2,250	3,236.0	2,863.0	373.0	13.0
Rice	2,000	871.9	798.9	73.0	9.1
Maize	3,000	667.5	617.7	49.8	8.3
Cotton	3,000	166.6	154.3	12.3	7.9

(UNEP, 1981, p.54)

Table VI.4

Yield of Crops (kg plot^{-1}) Under Different Treatments

Treatments	*Wheat*	*Mustard*	*Bajra*	*Jawar*	*Bhindi*	*Tomato*	*Cauli-flower*	*Barseem*	*Guar*
T_0 (control)	1·132	0·269	0·507	0·514	2·366	5·706	10·023	18·147	8·136
T_1 (whole nitrogen supplied through chemical fertilizer)	2·928 (158·6)*	0·596 (121·5)	1·282 (152·8)	1·382 (168·8)	4·863 (105·5)	10·776 (88·8)	17·006 (69·6)	34·842 (92·0)	12·223 (50·2)
T_2 (half nitrogen supplied through chemical fertilizers and half through slurry)	2·429 (114·5)	0·507 (88·4)	1·038 (104·7)	1·127 (119·2)	4·790 (102·4)	10·810 (89·4)	17·456 (74·1)	37·143 (104·6)	12·450 (53·0)
T_3 (whole nitrogen supplied through slurry)	2·064 (82·3)	0·488 (81·4)	0·889 (75·3)	0·934 (81·7)	4·380 (85·1)	9·983 (74·9)	15·343 (53·0)	38·587 (112·6)	13·666 (67·9)
S Em	±0·064	±0·015	±0·056	±0·044	±0·055	±0·161	±0·215	±0·995	±0·112
CD at 5%	0·205	0·047	0·179	0·143	0·178	0·515	0·689	3·184	0·361

*Percentage increase in yield under different treatments over control is shown in parentheses.

(Dahiya, 1984, p.72)

It is notable that the supernatant alone gives very significant increases over the control and, in some cases, even out-performs the chemicals. Since there would be residual benefits from the effluent, e.g. trace element and OM increase, and residual costs from the chemicals, e.g. liming to counteract acidity, digestion is actually more attractive than shown.

VII. ECONOMICS, ENERGY AND THE ENVIRONMENT

As there have been many full books written concerning the interactive effects of economics, energy and the environment, a full discussion is certainly not appropriate in this brief discussion. An attempt will be made only to point out some of the relevent considerations.

The inter-relatedness of these fields has been made apparent through the crises of the 1970's and much of the continuing work which that period inspired. Depleting fossil fuel supplies, continuing erosion and increasing atmospheric CO_2 levels in the future will certainly reinforce our awareness of those connections. All economic activity requires some form of energy input and much of that activity relys on un-valued [but invaluable] environmental processes such as the neutralization of many residual materials, the delivery of rainwater to crops and the natural production of topsoil. In spite of the huge fossil fuel input, U.S. agriculture is still over 90% dependent on solar energy (Hall, 1984).

Economics is certainly an interesting field of study and has much to offer in understanding human interaction. However, although it is only one aspect of life--one branch of the social sciences--economics seems to have become the overwhemingly predominant consideration for determining the direction of much human endeavor. Unfortunately, through the laws of supply and demand, "there is no means to provide for the long-term maintenance of the resource base upon which the economy depends" (Perelman, 1975, p.133).

It often seems as though we can, through the "laws" of economics, change some of the scientifically accepted laws of the universe, e.g. thermodynamics. More recently, there have been some efforts directed toward valuation of biological and environmental capital expended in human activities. However, data collection difficulties and, often basic-assumption-based, controversies over such economic valuation still severely limit application. While there is some continuing effort along these lines, the current general environmental deterioration would seem to dictate considerably more attention.

Pimentel, et al.(1976), concluded that about 200 million acres (81 million hectares) of U.S. farmland was ruined or seriously impoverished before 1940; that erosion from cropland accounted for 3/4 of the 3 billion tons (2.72 billion Mg) of yearly soil erosion in the U.S.; and that the total estimated cost of erosion was about $5 million/year. They also concluded that the cost of soil loss per year from cropland ($50/acre, $124/hectare) was higher than the cost of control of weeds and the production lost to them ($40/acre, $99/hectare).

As discussed in Section I, soil organic levels are inversely related to erosion rates. A major tenet of organic farming is the buildup of soil through application of organic materials. Commoner, et al.(Cited in Cox, 1975), found that organic farmers generally obtain about the same net profits as chemical farmers; they use smaller tractors which take less fuel; and they use about 1/3 as much energy while getting about the same yields per acre. Cullinery, et al.(1986), found that late season population densities of flea beetles, alate aphids and caterpillars were significantly lower on collards fertilized with sewage sludge and manure than on chemically fertilizied or untreated fields. Thus the energy expenditures and financial and environmental costs of pesticides could be reduced by greater reliance of recycling of organics. Although organic farming's more extensive use of winter cover crops does have its various production costs, these are more than compensated for by the holding of nutrients which might otherwise be leached deeply and by the extra addition of OM when tilled into the soil. Parr, et al.(1983), when considering less developed country situations, suggest that the commercial necessity of strict weed control with the "Green Revolution", high-[seed]-yielding varieties results in less overall photosynthetic fixation and therefore less biomass to be returned to the soil.

The energy contained in OM recycled to the soil supports a huge population of microbes and macrobes. These organisms breakdown the OM, thus releasing nutrients, and hold large quantities of nutrients in crop rooting zones. The overall energy value of OM in the soil is quite difficult to determine. Brady (1984) suggests that 20 Mg (22 tons) of farm manure, containing about 5000 kg (11000 lb) of dry matter, contains 25 million kcal of latent energy, and that a hectare furrow slice of soil with 4% OM contains about 400 million kcal of potential energy. Although it is unclear just what is meant by these figures, they may well refer to the theoretical heat produced by the oxidation of the materials. This author would suggest that a useful approach would be to determine the energy manifested by resistance to erosion, friability, water holding capacity, CEC, reduced acidity, etc. [To apply economic values to these figures would then likely be quite informative.]

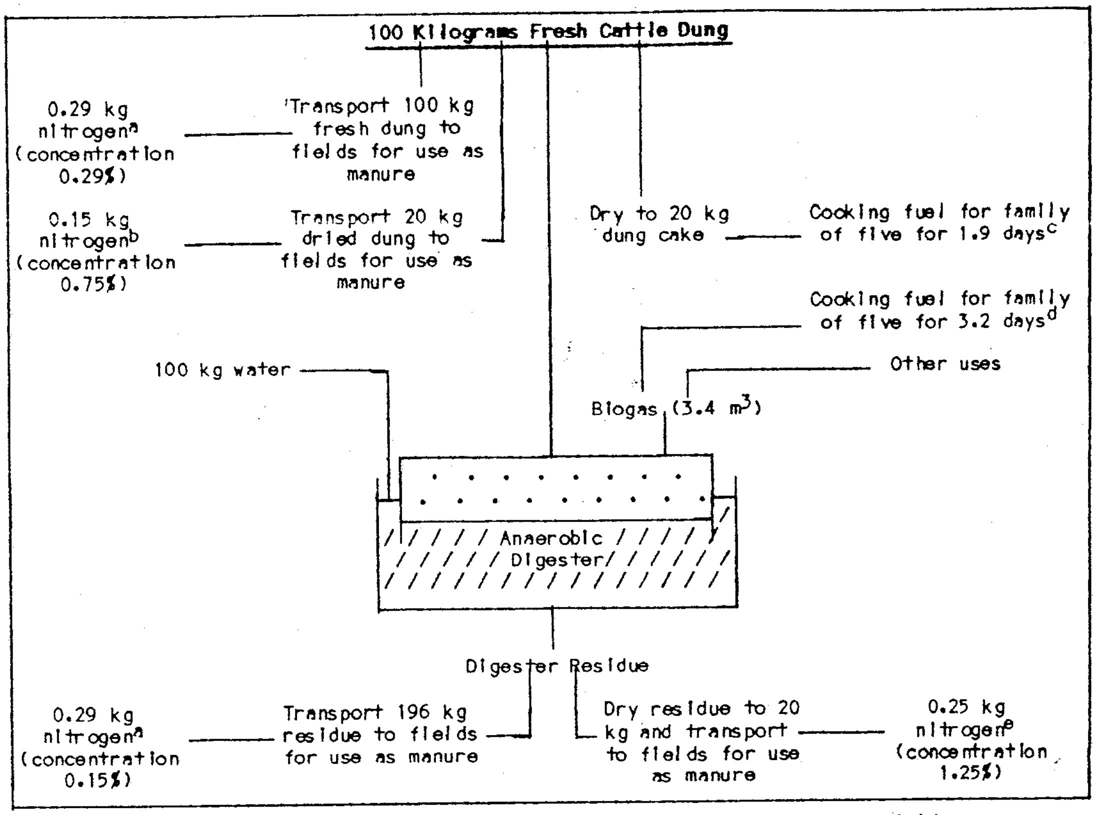
As discussed in Section II, compost and digester effluent would generally be equally useful for building up soil OM [although slightly higher yields with the effluent may give a slightly faster increase]. Proper composting can destroy all weed seeds thus reducing control costs. While digestion does not give complete destruction of weed viability, the higher levels of NH_3 within the digester do result in a significant reduction in viability.

The average amount of free energy from the aerobic reaction is 3.27 kcal/g of chemical oxygen demand (COD) oxidized, while the anaerobic reaction realeases only 0.215 (Jewell, 1981). However, the thermal effeciency of digestion, in terms of heat content of the gas produced per heat content of the organic matter converted, is 90-95% (Augustein, 1977), and the gas is more convenient to use. Utilization of the heat from compost requires a bit more ingenuity, e.g. integration with a greenhouse (Hamburg, 1983) or further drying of the compost (Gould, 1982). The energy in both cases has no net effect on atmospheric CO_2 levels since the CO_2 released by oxidation is CO_2 incorperated through photosynthesis. When considering the situation in an increasing number of less developed countries, Gunnerson and Stuckey (1986) developed Figure VII.1 which illustrates the energy an N value of dung digestion compared to direct combustion.

While simple, small composting systems are certainly cheaper than digestion systems, more elaborate, highly controlled and efficient composting systems may approach or exceed digestion costs (Panel, 1981). The land required for digesters varies greatly since they may be built above or below ground. Composting windrows and especially aerobic lagoons have notable surface requirements (Miner, 1971). The Ecotope Group (1975) developed Table VII.1 giving the relative values for various residue handling alternatives. In spite of all the work done inn this field since then, it is really not possible to improve greatly upon the quantification of these figures due to the numerous variables involved. The only really notable disagreements that this author would have with the table involve the last two items under "Anaerobic Liquid." Since well digested effluents contain quite low levels of volatile solids, the possibility for air pollution should actually be quite low, and a "1" or "2" would be more appropriate. Investment costs for digestion are quite significant and, due to the increased costs of solving some of the problems discovered in early systems, have actually increased since this study. Thus a value of "4" would be more appropriate in this spot. Since these two changes would counteract each other, the final totals would remain much the same.

While the utilization of large quantities of organic residues does have its energy and labor requirements, the energy requirements for production of

Figure VII.1 **Some Alternative Options for Utilization of 100 Kilograms of Fresh Cattle Dung.** Values are approximations based on best available information. (After Santerre and Smith, 1980; Rajabapaiah et al., 1979; Bhatia and Niamir, 1979.)



a Assumes nitrogen content of 0.29 kg and no losses between digester and field.

b Assumes nitrogen decreases by storing in open air from 1.7% to 0.9% of total solids. (Note: Change in solids concentration with storage time is not given.)

c
1. Assumes the daily per capita energy requirments for cooking = 578 kilocalories (kcal) of useful energy.
2. Assumes dung cakes thermal value = 2,444 kcal per kg which are used at 11.2% efficiency for cooking, having a useful energy content of 273.7 kcal per kg.
3. Household daily dung requirements for cooking:

$$\frac{(578 \text{ kcal/capita})(5 \text{ persons})}{273.7 \text{ kcal/kg}} = 10.6 \text{ kg dung cakes}$$

4. At assumed manufacturing rate of 20 kg dung cakes per 100 kg fresh dung, 10.6 kg dung cakes = 53 kg fresh dung required by family of 5 per day. 100 kg fresh dung thus provides for 1.9 days of cooking fuel.

d
1. Assumes energy content of biogas = 4,500 kcal per m^3, which is used at 60% efficiency by biogas stove (Srinivasan, 1978), and has a useful energy content of 2,700 kcal/m^3.
2. Household daily biogas requirement for cooking:

$$\frac{(578 \text{ kcal/capita})(5 \text{ persons})}{2{,}700 \text{ kcal/m}^3} = 1.1 \text{ m}^3 \text{ biogas}$$

3. Assuming conversion rate of 28.2 kg fresh dung into one m^3 biogas, then daily household requirement for dung = 1.1 m^3 x 28.2 kg = 31 kg fresh dung. 100 kg fresh dung thus provides for 3.2 days of cooking fuel.

e Assumes nitrogen decreases by storing in open air from 2.2% to 1.9% of total solids. (Note: Change in solids concentration with storage time not given.)

(Gunnerson, 1986, p.62)

primary nutrient chemical fertilizers is quite significant: 14,700 kcal/kg for N, 3000 kcal/kg for P, and 1600 kcal/kg for K.(Pimentel, 1980) Total energy

Table VII.1

Items of Comparison	Fresh	Relative Value for Type of Manure (One is most favorable; Four is least favorable) Fermented	Aerobic Liquid	Anaerobic Liquid
Effect on corn yield	2	1	4	1
Effect on nutrient recovery	3	1	4	2
Effect on labor:				
seasonal distribution	1	3	3	3
total required	2	2	1	1
Flexibility in:				
time of application	3	1	1	1
method of application	3	3	1	1
amount of bedding needed	2	2	1	1
Possibility for least pollution of:				
streams and lakes	3	2	1	1
air	1	3	2	4
Relative investment cost	1	2	4	3
TOTAL	21	20	22	18

(Ecotope Group, 1975, p.69)

requirements for the application of 150-200 kg of N per hectare (134-178 lb/acre) are about 3.6 million kcal, or about the equivalent of 365 liters (94 gal) of gasoline (Lucas, 1977). In India, chemical fertilizers require about one half of the total energy comsumed in crop production (Dahiya, 1984). Since chemical use efficiency is related positively to the level of soil OM, and since there has been a lack of emphasis on the return of OM to the soil, it is not surprising that, in the U.S., the quantity of output per unit of N applied was five times higher in 1950 than in 1971 (Perelman, 1975).

Much of the yield-enhancing technological progress in agriculture has intensified erosion problems rather than mitigating them (Walker, 1986B). U.S. agriculture as an industry, with its chemical fertilizer and biocide usage, is now the leading polluter of streams and groundwater (Jackson, 1980). Pimentel, et al.(1976), figured that erosion from cropland in the U.S. resulted in the loss of 50 million tons/yr (45.4 million Mg/yr) of NPK, and that to replace all the N and P and one fourth of the K would cost $7.75 billion. Jackson (1980) suggested that replacement of only the N and one fourth of the P lost by erosion would cost $18 billion in 1979 dollars.

While the estimated world production of N and P fertilizers in 1980-81 was about 30 million Mg (33 million tons) the potential from organic sources was 80.4 million Mg (88.4 million tons) (Nagar, 1977). However, when crops are fertilized with organic residues, no matter how handled, it is very difficult to quantify what portion of the yield respose is due to the OM fraction and what portion is due to the nutrient content (Parr, 1983). This has lead to the all too common practice of valuing organic residues in terms of only N, P and K which does not give credit for improved yields due to trace nutrients and improved soil structure (Miner, 1975).

The USDA Cooperative Extension Service has suggested that chemical N requirements may be reduced by only five pounds for every ton of manure spread per acre (6.2 kg/Mg/hectare) (Buford, 1976). Thus, the immediate economic gains from using OM as fertilizers do not compare very favorably with chemicals. However, when consideration is given to the slow release nutrients, trace elements, improved soil properties, reduced erosion, increased efficiency of chemical nutrients, and longer-term, sustained yields, the value of OM increases significantly. That value will, unfortunately, not likely be forthcoming until economic methodology progresses from its current concentration on year-to-year profitability to serious consideration of long-term sustainability.

VIII. CONCLUSION

Throughout the last forty years, the value of soil OM has been largely denigrated by "conventional" farming practices in developed countries and the "Green Revolution" in less developed countries. Over the last decade, however, this unfortunate trend seems to have reversed somewhat and there seems to be a growing awareness of the numerous benefits of recycling organic material to croplands. The organic farming tenet of "feeding the soil, not the plant," is receiving some scientific attention and not just a little verification.

While "probably no soil is perfect for waste disposal,"(Flach, 1974, p.1) quite large quantities of agricultural residues--more than 30 Mg/hectare/year (13.4 tons/acre/year)--can be utilized with no ill effects and constantly increasing, long-term benefits. Municipal wastes can also be placed heavily on agricultural lands when care is taken to limit heavy metal. The heavier use of these materials on energy crops is another available alternative.

Since fresh manure will still decompose over time, the various methods of handling livestock residues ultimately have little effect on the quantity of carbonaceous material added to the soil. Handling methods can, however, have a significant effect on the quantities of plant nutrients, especially nitrogen, returned to the soil. While aerobic decomposition can result in significant losses of N during the process itself, the N transformations which occur during anaerobic decomposition can result in similar losses when the effluents are spread.

Perhaps the most important consideration is sustainable crop yield from various handling procedures. Long-term studies of this are most notable by their absence. It is notable, however, that, while there has been some work showing equal or higher production with digester effluent, none of the studies reviewed for this discussion have shown higher production with compost.

Perhaps the main conclusion from this presentation is that, due to the enormous number of variables involved, a huge amount of research remains to be done. Until considerably more information is available, the much more easily usable energy from anaerobic digestion makes this option more attractive when one is interested in maximizing utilization of natural material cycles and solar energy flow.

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