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Chapter 4

Organic Materials as Alternative Nutrient Sources

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1. INTRODUCTION

Developing countries have traditionally utilized organic materials, such as animal manures, crop residues, green manures, and composts, to maintain or improve the productivity, tilth, and fertility of their agricultural soils. These materials also served as the principal sources of plant nutrients in U.S. agriculture up until the early 1950's when farmers began to replace them with chemical fertilizers. With the advent of the Green Revolution in the early 1960's, organic recycling practices in developing countries were subsequently replaced with chemical fertilizers which were applied to high yielding cereal grains that responded best to increased levels of production inputs, including chemical fertilizers, pesticides, and water. Chemical fertilizers gained rapidly in popularity because they were relatively inexpensive, easily available, and often produced dramatic yield increases. Unlike organic fertilizer sources, they were less bulky and, therefore, easier to store, transport, and apply. Consequently, the importance of organic matter in crop production received less emphasis, and its proper use in maintaining soil productivity was neglected. As a result of this and with failure to implement effective soil conservation practices, the agricultural soils in many developing countries have undergone extensive degradation and have declined in productivity because of excessive soil erosion and nutrient runoff losses, and a decrease in stable soil organic matter levels. Moreover, with increased soil degradation, crop use efficiency of applied chemical fertilizers decreases accordingly.

When the first world energy crisis began in the early 1970's, chemical fertilizers had largely replaced organic sources of plant nutrients in many developing countries (FAO, 1975). Because of steadily rising energy costs and the uncertain availability of chemical fertilizers in developing countries, a strong resolution was passed at the 1974 World Food Conference in Rome, urging greater utilization of organic materials as fertilizers and amendments for improving the fertility and productivity of agricultural soils. Subsequently, the Food and Agricultural Organization (FAO) of the United Nations convened a series of regional workshops to emphasize the value and importance of organic wastes as fertilizers and soil amendments, and to reintroduce both established techniques and new practices for their successful utilization on agricultural lands (Hauck, 1978).

Hauck (1981) estimated that the reintroduction and utilization of organic wastes and residues to improve soil productivity in developing countries could contribute more than 50 percent of the increased food production that is currently needed worldwide. Proper management and use of agricultural and municipal organic wastes on land provides the best means we have for protect-

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ing soils from wind and water erosion, preventing nutrient losses through runoff and leaching, and for maintaining and restoring soil productivity. Organic materials serve not only as sources of plant nutrients (i.e. as fertilizers), but also as soil conditioners by improving soil physical properties, as evidenced by increased water infiltration, water-holding capacity, water content, aeration and permeability, soil aggregation and rooting depth, and by decreased soil crusting, bulk density, and runoff and erosion (Allison, 1973; USDA, 1978).

This chapter presents some new perspectives and strategies for efficient and effective use of organic materials as alternative fertilizer sources and as amendments to improve soil productivity and tilth. The value of some organic materials and their energy relationships, in view of certain competitive uses, is also discussed.

2. INVENTORIES OF ORGANIC MATERIALS

Generally, most developing countries lack reliable data on the types, amounts, and availability of organic materials that could be utilized as fertilizers and soil amendments. Such information should be included in all resource inventories as an essential prerequisite for the planning and design of organic recycling programs to improve the productivity of agricultural soils (Conant et al., 1983).

Often, such information is not readily available in developed countries as well. For example, the Food and Agriculture Act of 1977 (PL 95-113) required that the United States Department of Agriculture (USDA) submit a report to the Congress on the "practicability, desirability, and feasibility of collecting, transporting, and placing of organic wastes on land to improve soil tilth and fertility." Information was urgently needed on the kinds, amounts, and availability of organic materials as possible alternative fertilizer sources, because of the increasing cost of chemical fertilizers and the loss of crop productivity resulting from excessive soil erosion associated with intensive farming systems (USDA, 1978). There was also a growing concern in the urban sector of our society for the impact of farm chemicals, both fertilizers and pesticides, and soil erosion on environmental quality.

A summary of the USDA report is presented in Table 4.1. A total of about 730 million dry metric tons of organic wastes are produced annually (1978 esti-

TABLE 4.1

Annual production of organic wastes in the United States, current use of land, and probability of increased use (Source: USDA, 1978)

Organic wastes	Total production		Current use on land[a]	Probability of increased use[b] on land
	Dry metric tons (× 1000)	% of total		
Animal manure	158730	21.8	90	Low
Crop residues	391009	53.7	68	Low
Sewage sludge and septage	3963	0.5	23	Medium
Food processing	2902	0.4	(13)	Low
Industrial organic	7452	1.0	3	Low
Logging and wood manufacturing	32394	4.5	(5)	Very low
Municipal refuse	131519	18.1	(1)	Low
Total	727969	100.0	–	–

[a] Values in parentheses are estimates because of insufficient data.
[b] Medium indicates a likely increase of 20 to 50%, low indicates a 5 to 20% increase, and very low indicates less than 5% increase.

mate). This represents a national resource of significant economic and energy value, and its proper and efficient use should be emphasized. About 50% of this total is comprised of crop residues, while about 22% is made up of animal manures. Thus, nearly 3/4 of the total annual production of organic wastes in the U.S. is associated with crop residues and animal manures. The USDA report established that about 75% of these two wastes are currently being applied to land for improving soil productivity.

Sewage sludge and septage make up about 0.5% of the total organic waste produced in the United States. Since these data were compiled the amount of this material that is currently applied to land has increased from 23 to more than 40%.

The other four wastes listed in Table 4.1 have not been used extensively on land because of certain competitive uses, high costs of collection, processing transportation, and application; and because of constraints on usage related to certain chemical and physical properties. For example, (a) cotton gin trash and sugarcane bagasse are now increasingly sought as sources of fuel for burning, (b) some food processing wastes may have extremely high acidity or alkalinity that can adversely affect soil pH, (c) shredded municipal refuse may contain considerable amounts of solid fragments (glass, plastic, and metal) that do not readily biodegrade and detract aesthetically when applied to land (see Table 4.12), and (d) some sewage sludges contain excessive amounts of heavy metals and organic chemicals that may be toxic to plants or endanger the food chain after absorption and accumulation. Table 4.2 reports the ranges and median concentrations of trace elements in dry digested sewage sludges, and the recommended maximum level of heavy metals that are acceptable for land application. Heavy metals of greatest concern include cadmium, zinc, copper, nickel, and sometimes lead.

The potential for increased use of organic wastes on land to improve the productivity of soils in the U.S.A. is low (Table 4.1). While the use of sewage sludge and septage on land has increased appreciably, it actually involves a rather small amount of material when compared with crop residues, animal manures, and municipal refuse. It should be remembered also that some animal manures, for example, are deposited directly by the animal on grazing land and

TABLE 4.2

Ranges and median concentration of trace elements in dry digested sewage sludges and a typical agricultural soil, and the maximum recommended level of sludge-borne metals for land application (Source: Chaney, 1983)

Element	Reported range		Median	Typical soil	Maximum recommended level
	Minimum	Maximum			
Arsenic (As)	1.1	230	10	-	-
Cadmium (Cd)	1	3410	10	0.1	25
Chromium (Cr)	10	99000	500	25	1000
Cobalt (Co)	11.3	2490	30	-	200
Copper (Cu)	84	17000	800	15	1000
Fluorine (F)	80	33500	260	200	1000
Iron (Fe)	1000	150000	17000	2	4
Lead (Pb)	13	26000	500	25	1000
Manganese (Mn)	32	9870	260	500	-
Mercury (Hg)	0.6	56	6	-	10
Molybdenum (Mo)	0.1	214	4	-	25
Nickel (Ni)	2	5300	80	25	200
Selenium (Se)	1.7	17	5	-	-
Tin (Sn)	2.6	329	14	-	-
Zinc (Zn)	101	49000	1700	50	2500
Cadmium/zinc (Cd/Zn)	0.1	110	0.8	-	1.5

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TABLE 4.3

Annual organic nitrogen supply (kg) in case-study villages (source: Makhijani and Poole, 1975)

	Hectares of cultivated land	Excluding human excrement			Nitrogen collectable in solid and liquid human excrement[b]	Total nitrogen collectable in solid and liquid wastes	Nitrogen available per hectare cultivated land
		Nitrogen available in net residues[a]	Nitrogen in collectable solid wastes	Nitrogen in collectable solid and liquid wastes			
Mangaon, India	300	10 000	4 000	7 000	3 000	10 000	33
Peipan, China[c]	200	13 000	7 000	9 000	4 000	13 000	65
Kilombero, Tanzania	60	1 000	500	800	300	1 100	18
Batagawara, Nigeria	530	13 000	6 000	9 000	4 200	13 200	25
Arango, Mexico[c]	380	7 000	5 000	6 000	1 700	7 700	20
Quebrada, Bolivia (one *parcela*)	1	70	40	50	18	68	68

[a] Assuming a nitrogen content of 0.2% for crop residues. [b] Assuming that a maximum of 80% of the nitrogen in human excrement can be collected. For Arango and Peipan, intermediate values for the total nitrogen excreted per person per year have been used, and for the other villages, lower figures have been used. The rationale is that people in Arango and Peipan have more adequate diets, which produce excrement with a higher nitrogen (protein) content. [c] The nitrogen figures for Peipan and Arango are probably underestimates as crops there are well fertilized. The nitrogen content of crop residues is probably considerably higher, especially because maize, which has a higher nitrogen content in the residue, is a major crop in both areas.

therefore not available to replace fertilizer nutrients on row crop land. Lauer (1975) estimates that only 43% of manures come from animals in confinement. Furthermore they are not necessarily produced in locations of need. In the USA 42% of the N, 29% of the P_2O_5, and 57% of the K_2O fertilizers used could be replaced by confinement manures, but only at maximal usage with no loss (Lauer, 1975).

The USDA (1978) report pointed out that there is a growing shortage of good quality organic wastes for use in maintaining and improving the productivity of our agricultural soils. The report cited a number of ways in which our limited amounts of organic wastes might be used more effectively as soil amendments. These include:

(1) Improving methods of collection, storage, and processing (e.g., composting) of animal manures to minimize the loss of nitrogen that often occurs in these operations.
(2) Applying manures to land that are presently being wasted.
(3) Applying crop residues to land that are not being fully utilized.
(4) Increasing the use of sewage sludge on land.
(5) Increasing the use of the organic/compostable fraction of municipal refuse.

Some limited estimates have been made for various organic materials as nutrient sources for developing countries (Makhijani and Poole, 1975; Van Voorhoeve, 1974) (See Tables 4.3 and 4.4). While not as detailed as studies in the USA they present some information as to the range and potential amounts in some areas of the world.

3. NUTRIENT CONTENT OF ORGANIC MATERIALS

Most organic wastes originate from the soil as plants, some of which are consumed directly as primary production and some of which are cycled through animals in livestock production. When these wastes are totally removed from the soil, the basic fertility and productivity of the system is diminished. This may have serious consequences over the long-term which can be manifested in accelerated soil erosion and nutrient runoff losses which, in turn, can adversely affect soil productivity (See Chapter 5).

When organic wastes of acceptable quality are returned to agricultural soils on a regular basis they contribute greatly to the overall maintenance of soil tilth, fertility, and productivity, and reduce the need for mineral fertilizers. Certainly, the fact that organic wastes have great potential as a production resource is well established. The energy savings in the use of these organic materials as an alternative to the energy necessary to manufacture chemical fertilizers is obvious. Not so evident is that the increased productivity factor reduces energy inputs per unit of plant production. Today, when there is deep concern about the effects of soil erosion on the loss of productivity there are opportunities to improve on the use of these materials as we seek to minimize our use of energy; minimize the pollution of air, water and soil; and maintain (and restore) the productivity of our agricultural soils.

The range and mean composition of nutrients and the carbon/nitrogen ratio (C/N) of some selected crop residues, animal manures, animal by-products, sewage sludges, composts, municipal solid waste, and human wastes are shown in Tables 4.5–4.14. Such values are often highly variable depending on the origin of the material and the mode/method of processing and storage. For example, the composition of sewage sludge (Table 4.8) can vary greatly according to the treatment process imposed. The nutrient content of animal manures can vary according to the type of animal (Table 4.6) whether bedding is involved (Table 4.9), and the waste handling system employed (Table 4.10). The

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TABLE 4.4

Total annual production of soil nutrients through organic wastes in the developing world, 1971 (actual) and 1980 (estimated) (Source: Van Voorhoeve, 1974)

Source		Quantity of nutrient (10^6 mt)[a]		
		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	0.48	0.38	0.57
	1980	0.60	0.48	0.71
Urban sewage	1971	1.43	0.29	0.6
	1980	1.79	0.36	1.08
Other[b]	1971	6.63	4.44	11.35
	1980	8.29	5.55	14.19

[a] Excludes Central America and Oceania, includes Socialist Asia.
[b] 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.)

composition of composts can vary over a wide range depending on the starting materials and the process technology used (Table 4.11).

4. VALUE OF ORGANIC MATERIALS AS FERTILIZERS AND SOIL CONDITIONERS

The "value" of organic materials as fertilizers and soil conditioners is often misunderstood and has been the source of some controversy. The simplest and most common means of estimating the value of organic materials is to consider them as substitutes for commerical fertilizers that would otherwise have to be purchased. This is done by assessing the current market value of the plant nutrients they contain, especially in terms of their macronutrient content, i.e., nitrogen, phosphorus, and potassium. Beef manure, crop residues, sewage sludge and municipal refuse are valued by this method in Table 4.15. Sewage sludge has the highest nutrient content and is worth about $40/ton. Beef manure has a similar nutrient content and is similarly valued. Crop residues and municipal refuse have a much smaller nutrient content and are worth only 15 to 25% of the faecal wastes.

The energy value of the nutrients in these organic materials relative to fertilizers is also represented in Table 4.15. These values follow the trend of the dollar values. The energy and economic value of all these materials relative to chemical fertilizers can be calculated by using energy data from Chapter 1 for equal amounts of fertilizer nutrients compared to those in organic materials listed in Tables 4.5–4.14.

Many organic materials contain other components in addition to organic matter and macronutrients (N, P, K) which can contribute significantly to higher crop yields. These include secondary nutrients (S, Fe, Mg), micronutrients (Cu, B, Zn, Mn, Mo), and sometimes lime. When these constituents can substitute for essential production inputs the value of the organic material would increase accordingly. On the other hand, some organic materials may contain such constituents as soluble salts, heavy metals, and hazardous organ-

TABLE 4.5

Range and mean composition of some selected crop residues (% dry weight basis) (Source: Misra and Hesse, 1983)

Material		C/N	Nitrogen	Phosphorus	Potassium
Wheat straw	range	80–130	0.21–0.94	0.04–0.22	0.48–1.72
	mean	105	0.49	0.11	1.06
Rice straw	range	80–130	0.36–1.10	0.02–0.17	0.40–3.70
	mean	105	0.58	0.10	1.38
Cotton[a]	range	–	0.44–1.33	0.04–0.27	0.55–2.35
	mean	–	0.88	0.15	1.45
Water hyacinth	range	–	1.03–3.70	0.10–0.63	1.81–4.40
	mean	18	2.04	0.37	3.40
Algae	range	–	1.34–3.60	0.08–0.17	0.06–0.69
	mean	–	2.47	0.12	0.37
Maize straw	range	50–60	0.42–0.75	0.06–0.69	0.19–1.37
	mean	55	0.59	0.31	1.31
Soybean straw		32	1.30	–	–
Bean straw			1.57	0.32	1.34
Sugarcane trash		112–120	0.35	0.04	0.50
Oil palm					
bunch ash				1.71	32.50
pressed fiber			1.24	0.10	0.36
sludge cake			4.30	1.19	1.15
Jute[b]			1.75	0.58	4.12
Cowpeas[b]			1.99	0.19	2.20
Groundnut[b]			2.56	0.17	2.11
Spent tea[b]			4.20	0.23	0.21
Trees/general[b]		40–80	0.50–1.51	0.17–0.43	0.57
Fruit waste		35	0.70–1.90	0.11–0.18	0.01–0.66
Vegetable residues:					
potato tops		27	1.6		
amaranthus		11	3.6		
cabbage		12	3.6		
lettuce			3.7		
onion		15	2.6		
pepper		15	2.6		
tomato		12	1.84–2.33	0.29–0.31	0.01–0.28
carrot (whole)		27	1.6		
turnip tops		19	2.3		
Wood ash			–	0.44–0.88	1.70–8.30

[a] Stalk and leaves.
[b] Leaves.

ic chemicals that could adversely affect soils, plants, animals, and the human food chain. Some materials may have especially high C/N ratios, or unusually high levels of acidity or alkalinity. All of these would, of course, reduce the value of the material for use as fertilizers and soil conditioners.

In some cases, the organic component of a particular material may have a higher monetary value than that of its total nutrient content because of the beneficial effect of organic matter on soil physical properties and improvement of soil productivity. This is especially true when certain organic materials are used to restore the productivity of severely eroded agricultural soils, or to reclaim marginal soils (Hornick, 1982).

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TABLE 4.6

Range and mean composition of some selected animal manures (% dry weight basis) (Source: Misra and Hesse, 1983)

Material		C/N	N	P	K
Cattle manure	Range	-	1.14–2.99	0.27–1.00	0.75–2.00
	Mean	19	1.91	0.56	1.40
Sheep manure	Range	-	1.21–2.71	0.21–1.35	0.32–1.94
	Mean	29	1.87	0.79	0.92
Swine manure	Range	-	1.92–3.98	0.52–2.02	0.31–1.60
	Mean	13	2.80	1.36	1.18
Swine urine	Range	-	8.82–11.76	1.18–1.47	10.88–24.11
	Mean	-	10.88	1.25	17.86
Poultry manure	Range	-	1.35–5.14	0.49–4.73	0.51–2.32
	Mean	-	3.77	1.89	1.76

TABLE 4.7

Range and mean composition of some selected animal wastes other than excreta (% dry weight basis) (Source: Misra and Hesse, 1983)

Material		C/N	N	P	K
Blood meal	Range	3–4	7.0–14.0	0.44–0.88	-
	Mean	3.5	11.12	0.66	-
Bone meal	Range	-	1.0–4.0	8.8–12.3	-
	Mean	-	3.36	10.81	-
Slaughterhouse wastes		-	10.00	0.66	1.77
Fish manure	Range	4–5	4.0–10.0	1.3–3.9	0.8
	Mean	4.5	7.5	2.82	0.8

TABLE 4.8

Approximate quantity and composition of sewage and sewage sludge (Source: Gotaas, 1956)

Sewage sludge and treatment process	Liquid sludge (% solids)	Drying-bed cake (% solids)	Composition on dry basis (%)				
			organic	mineral	nitrogen (N)	phosphate[a] (P_2O_5)	potash[b] (K_2O)
Fresh domestic sewage	0.04–0.15	-	60–85	15–40	5.0–10.0	2.5–4.5	3.0–4.5
Imhoff tank, well digested	8.0–12.0	35–50	30–45	55–70	2.0–3.0	1.2–3.5	0.1–0.5
Primary, fresh	2.5–5.0	28–45	60–80	20–35	1.5–4.0	0.8–4.0	0.1–0.5
Primary, digested	5.0–12.0	35–50	35–60	40–65	1.0–3.5	1.2–4.0	0.1–0.5
Primary and trickling-filter humus, fresh	3.5–6.5	26–40	50–75	25–50	2.0–4.5	0.8–3.6	0.1–0.5
Primary and tricklying-filter humus, digested	5.0–12.0	35–50	35–60	40–65	1.0–3.5	1.0–3.8	0.1–0.5
Primary and activated sludge, fresh	3.0–6.0	26–40	50–80	20–50	2.3–5.2	1.2–4.0	0.2–0.6
Primary and activated sludge, digested	4.5–8.5	28–50	35–55	45–65	2.0–4.8	1.3–4.0	0.2–0.6
Primary sludge, digested, and fresh activated sludge	2.5–4.5	28–45	40–60	40–60	2.2–5.0	1.3–4.0	0.3–0.8

[a] $P_2O_5 \times 0.44 = P$.
[b] $K_2O \times 0.83 = K$.

TABLE 4.9

Dry matter and major nutrient content of solid manure at time of soil applicaiton (Source: Sutton et al., 1975)

Domestic animal	Waste handling system	Dry matter (%)	Nitrogen (N) (%)		Phosphate (P_2O_5) (%)[c]	Potash (K_2O) (%)[d]
			Available[a]	Total[b]		
Beef cattle	Without bedding	15	0.20	0.55	0.35	0.50
	With bedding	50	0.40	1.05	0.90	1.30
Dairy cattle	Without bedding	18	0.20	0.45	0.20	0.50
	With bedding	21	0.25	0.45	0.20	0.50
Poultry	Without litter	45	1.30	1.65	2.40	1.70
	With litter	75	1.80	2.80	2.25	1.70
Swine	Without bedding	18	0.30	0.50	0.45	0.40
	With bedding	18	0.25	0.40	0.35	0.35

[a] Primarily ammonium nitrogen, which is available to plants the first year.
[b] Ammonium nitrogen plus organic nitrogen, available over several years.
[c] $P_2O_5 \times 0.44 = P$.
[d] $K_2O \times 0.83 = K$.

TABLE 4.10

Dry matter (%) and major nutrient content of liquid manure wastes (kg/100 l of raw waste) at time of soil application (Source: Sutton et al., 1975)

Domestic animal	Waste handling system	Dry matter (%)	Nitrogen (N)		Phosphate (P_2O_5)[c]	Potash (K_2O)[d]
			Available[a]	Total[b]		
Beef cattle	Liquid pit (anaerobic)	11	2.9	4.8	3.2	4.1
	Oxidation ditch	3	1.9	3.4	2.2	3.5
	Lagoon	1	0.2	0.5	1.1	0.6
Dairy cattle	Liquid pit (anaerobic)	8	1.4	2.9	2.2	3.5
	Lagoon	1	0.3	0.5	0.5	0.6
Poultry	Liquid pit (anaerobic)	13	7.7	9.6	4.3	11.5
Swine	Liquid pit (anaerobic)	4	2.4	4.3	3.2	2.3
	Oxidation ditch	2.5	1.4	2.9	3.2	2.3
	Lagoon	1	0.4	0.5	0.2	0.5

[a] Primarily ammonium nitrogen, which is available to plants the first year.
[b] Ammonium nitrogen plus organic nitrogen, available over several years.
[c] $P_2O_5 \times 0.44 = P$.
[d] $K_2O \times 0.83 = K$.

TABLE 4.11

Range and mean composition of farmyard manures, rural composts, and urban refuse compost (% dry weight) (Source: Misra and Hesse, 1983)

Material		N	P[a]	K[b]
Farmyard manure	Range	0.33–2.30	0.04–1.05	0.14–2.80
	Mean	0.80	0.21	0.68
Rural composts	Range	0.30–3.88	0.03–2.7	0.15–7.81
	Mean	1.10	0.29	1.37
Urban composts	Range	0.36–2.52	0.03–2.25	0.41–2.60
	Mean	1.29	0.50	0.94
Developed countries	Mean	1.37	0.51	0.71
Undeveloped countries	Mean	0.99	0.49	0.97

[a] $P_2O_5 \times 0.44 = P$.
[b] $K_2O \times 0.83 = K$.

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TABLE 4.12

Bulk composition (wt %) of municipal refuse in two selected cities (Source: Winkler and Wilson, 1983)

Refuse	Cambridge, MA	Middlesbury, VT	Average
Paper	35.8	48.9	42
Metals	9.2	9.1	9
Glass	18.6	16.6	18
Plastics	4.1	2.4	3
Food waste	5.9	4.7	5
Wood	1.1	0.4	1
Other (cloth, rubber, yard, garden, and miscellaneous)	25.3	17.9	22

TABLE 4.13

Composition (%) of major plant nutrients in municipal refuse, from three sources

Source	Nitrogen	Phosphorus	Potassium
Garner (1966)	0.83	0.25	0.31
King et al. (1974)	0.57	0.08	0.31
Volk (1976)	0.60	0.15	0.25
Average	0.67	0.16	0.29

TABLE 4.14

Approximate composition (% dry weight) of human faeces and urine (Source: Gotaas, 1956)

Composition	Faeces[a]	Urine[a]
Organic matter	88–97	65–85
Nitrogen	5.0–7.0	15–19
Phosphorus (P_2O_5)	3.0–5.4	2.5–5.0
Potassium (K_2O)	1.0–2.5	3.0–4.5
Carbon	40–55	11–17
Calcium (CaO)	4–5	4.5–6.0
C/N ratio	5–10	-

[a] Per capita production. Faeces: 135–270 g per capita per day moist weight, 35–70 g per capita per day, dry weight. Urine: Volume: 1.0–1.3 l per capita per day, dry solids: 50–70 g per capita per day.

TABLE 4.15

Content and value of nutrients per dry metric ton of organic waste (Source: Sherff, 1975; USDA, 1978)

Organic material	Nutrients (%)			Value[a] ($/mt)	Energy[b] (GJ/mt of waste)
	N	P_2O_5	K_2O		
Beef manure	4.4	2.5	2.9	40.0	3.5
Crop residues	1.1	0.5	2.4	13.4	1.0
Sewage sludge	4.0	4.6	0.5	43.0	3.2
Municipal refuse	0.70	0.5	0.4	6.7	0.6

[a] Value per kg of N, P_2O_5, and K_2O was set at $0.46, 0.51, and 0.24, respectively.
[b] Energy value of nutrients figured as a replacement for production energy, for fertilizer (Assumed: N, 70 GJ/mt; P_2O_5, 8 GJ/mt and K_2O, 6 GJ/mt).

Further clarification of the agronomic and economic values of organic materials as fertilizers and soil conditioners follows.

The agronomic value

The agronomic value of an organic material is the increased crop yield or quality derived from its application. There is a considerable amount of data in the literature which demonstrates the effect of organic materials on crop yield, but very little on crop quality. Crop yield response to additions of organic materials is highly variable and is dependent upon the crop, soil type, climatic conditions, management system, and the organic material used. In most cases, crop yield response to the addition of organic materials is non-linear. The greatest yield response is obtained with the first few increments of organic material, followed by progressively smaller yield increases with additional increments. Thus, as with chemical fertilizers and other production inputs, crop yield response to an organic amendment follows the law of diminishing returns, and is responsible for the decreased value per unit of the material with increased application rates. Obviously, both the agronomic and economic value per unit of organic material to the farmer are correspondingly higher at low, rather than high, application rates. Reliable estimates of the economic value of organic materials depends upon the accurate assessment of agronomic data relating the crop yield response to the application of a particular material.

One of the problems in determining the agronomic value is dealing with the potential loss of N by ammonia volatilization and other means. Lauer (1975) has estimated between 10–50% of the N in animal manures is lost after application to the land (see Chapter 5).

The assumption that the plant nutrients in organic materials are merely substitutes for those supplied by commercial fertilizers may be somewhat invalid because of data which strongly suggest that some organic materials may actually serve as complements to fertilizer N (Sikora et al., 1980). Others have also reported that crop yields were highest when organic amendments and chemical fertilizers were applied in combination than when they were applied separately.

The economic value

The economic value of an organic waste or residue to a farmer is the value of the increase in crop yield and/or crop quality that is derived from its use. The actual profitability of using organic materials will vary with the quality of the organic materials, the price of the organic materials including the cost of transportation and application, as compared with its substitutes, the value of the crop, and other variables. However, there are two important considerations when analyzing their economic value, and hence profitability, when they are used as fertilizer sources and soil amendments.

Firstly, because the crop yield response to an organic amendment follows the laws of diminishing returns, the average yield increase is always larger than the yield increase attributable to the incremental unit of organic material. If the price of the farmer's product is the same regardless of the quantity produced, which is usually the case, then the revenue derived from the average unit of organic material will be greater than the revenue from the incremental unit. Thus, the value of the average unit of organic material will be higher than the value of the incremental unit of organic material.

Farmers can be expected to utilize organic materials to the point where the revenue from the incremental unit is equal to its price, assuming that the application cost is included in the price. They would certainly use no more than

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that quantity since additional application of the organic material would produce a loss. Likewise, they would not wish to use less since total profits would decline. Thus, an estimate of the value of the incremental unit of organic material would be useful to farmers as well as public waste management agencies analyzing the marketability of a recycled product. However, public decision-makers should also be interested in estimates of the total economic benefits from resource recycling alternatives, such as composting, to compare them to destructive alternatives such as landfilling or incineration. Thus, an estimate of the value of the average unit of organic material would be the appropriate figure to use in public project analyses.

Secondly, the rate at which organic materials decompose or mineralize in soil is highly variable. However, they do have a greater residual effect on soil fertility than most chemical fertilizers because of the slow-release character of the nitrogen and phosphorus components. Thus, a significant portion of the economic value of organic materials as fertilizers is their capacity to elicit yield respones from succeeding crops. This response must be accounted for to assess the true value of the material. Barbarika et al. (1980) and Colacicco (1982) estimated that the cumulative economic value of some organic materials applied to agricultural soils could be as much as five times greater in succeeding years than the value realized during the application year.

A better method (than the plant nutrient/market value approach) for estimating the value of organic materials is derived from yield response experiments that are designed to determine how much of a particular material, such as sewage sludge compost, is needed to substitute for another production input, e.g. peat or fertilizer, to achieve a desired plant growth response. Some organic materials, including sewage sludge compost, have been utilized as acceptable substitutes for topsoil and peat in certain horticultural applications. As a peat substitute these materials would have a value of $35 to $50 per metric ton. A metric ton of digested sewage sludge was found to provide the same yield response as $16 of mineral fertilizer in corn production in Maryland, U.S.A. (Barbarika et al. 1980).

5. USE AS FERTILIZERS AND SOIL CONDITIONERS

Some organic materials are known to mineralize and release available plant nutrients rapidly as a result of microbial attack. In some cases this is desirable, particularly on soils that are already in a high state of fertility and productivity. On the other hand, marginal, erodible, sloping, and generally less productive soils would benefit, at least initially, from application of organic materials having a degree of microbial stability in soil. Such materials would release their plant nutrients at a relatively slower rate. Farmers in developing countries often have occasion to use both types of materials in their farming operations depending on whether there is a need to release nutrients rapidly, or to improve the productivity of marginal soils. Table 4.16 lists some organic materials that would be expected to differ considerably in these two properties. Although these are hypothetical values and would have to be verified experimentally, the concept introduced here is the important consideration. A high nutrient availability index (NAI) indicates materials that would release nutrients relatively rapidly, while a high organic stability index (OSI) would be associated with more stable forms of organic matter. Materials with the high NAI value usually would be expected to have a low OSI value, and conversely. Research is needed to develop reliable numerical indexes such as those shown in Table 4.16. This would allow a realistic basis for predicting the nutrient

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TABLE 4.16

Hypothetical nutrient availability indexes (NAI) and organic stability indexes (OSI) for composted and uncomposted organic materials (Source: Parr and Papendick, 1978)

Product	Nutrient availability index[a]	Organic stability index[a]
Beef manure	70	30
Rice straw	15	85
Sewage sludge	80	20
Sewage sludge woodchip compost	35	65
Refuse compost	25	75
Refuse - pit latrine compost	40	60
Poultry manure rice straw compost	65	35

[a] Values are hypothetical, but are based mainly on what is known of the C/N ratio of organic materials cited, and the decomposability of the various components (i.e. cellulose, hemicellulose, lignin, sugars, proteins, etc.) that comprise them.

availability and organic stability of different wastes under different soil, climatic, and cropping conditions.

Figure 4.1 shows the dollar benefits per ton of chicken manure and sewage sludge from two agronomic experiments (Colacicco, 1982). The high nutrient content of chicken manure makes it more valuable at low application rates (< 20 mt/ha) than the sewage sludge. The soil conditioning properties of the wastes are more important in eliciting a yield response at the higher application rates.

The profit maximizing rate of application for organic wastes is often less than the amount required to meet the recommended nitrogen rate. The common recommendation of applying organic wastes at fertilizer rates may result in application rates that do not maximize the organic materials ability to improve soil physical properties. The relative proportion of nutrients contained in some organic materials may not be in optimum balance for some crops. For example, when sewage sludge compost is applied at N fertilizer recommendations to sustain a corn crop, it is likely that P will be applied in excess of that needed by the crop. Thus, the excess P is wasted or might even become an environmental pollutant. One study involving sewage sludge compost showed a 20% loss in potential profits when it was applied to furnish all of the crop's N requirement.

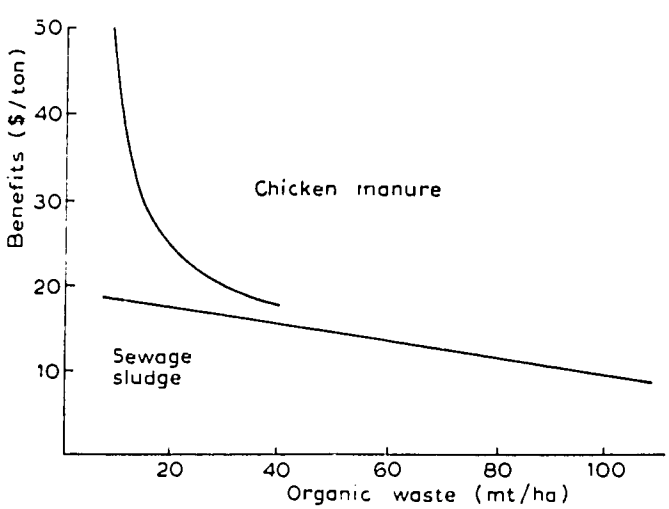

Fig. 4.1. The benefits of sewage sludge and chicken manure in corn production.

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Certainly, the most acceptable strategy for maximizing the agronomic and economic benefits from organic wastes and residues would be to (1) determine exactly what a farmer is trying to achieve, e.g. restoration of the productivity of an eroded soil or to provide supplemental N to a high value crop, (2) determine the approximate organic stability index (OSI) and nutrient availability index (NAI) of the organic materials to be used, and (3) determine what practical and workable combinations of organic materials and mineral fertilizers are most appropriate to accomplish the proposed task.

6. SPECIAL MANAGEMENT PRACTICES FOR UTILIZATION OF ORGANIC WASTES ON LAND

Special management practices may be needed to obtain the full value of organic wastes as soil amendments and as sources of plant nutrients. For example, the value of organic materials as fertilizers is increased if nutrient release through decomposition and mineralizaton coincides with the crop's nutrient requirement curve. The nutrient release pattern of organic materials can be controlled to some extent by proper timing of application, pretreatment methods such as composting, and by the method of application. For example, certain organic materials may decompose more slowly if left on the soil surface or concentrated in the soil than if thoroughly mixed in the tillage layer (Parr and Papendick, 1978).

Many farmers in developing countries have shifted toward intensive row cropping for short-term economic gain, and have thus neglected soil and water conservation practices. This has resulted in markedly increased soil erosion, extensive damage to cropland, sedimentation, and nutrient runoff and enrichment of surface waters. With increasing public concern for environmental pollution and agriculture's contribution to it, there is an urgent need to reintroduce those soil and crop management practices which have been cited as best management practices for controlling soil erosion and water pollution from cropland (USDA/EPA, 1975, 1976). These include the use of agricultural and municipal organic wastes and residues, sod-based rotation, contouring, conservation tillage, cover crops, grassed waterways, and possibly others such as divided slope farming (USDA, 1980). Research and extension programs should be formulated and implemented, in both developed and developing countries, to demonstrate the cost/benefit relationships of conservation management practices. Aspects of multiple cropping systems such as double cropping, sequential cropping, and intercropping may also provide special means for controlling wind and water erosion, and for effective recycling of nutrients from organic materials (ASA, 1976). Chapter 5 presents a more detailed discussion on conservation of nutrients.

Environmental pollution has also become an international concern. Thus, proper processing and recycling of organic wastes as resources for agriculture can greatly reduce environmental pollution. Additional benefits include improved public health, conservation of resources, and better appearance of both urban and rural communities.

7. COMPOSTING TO ENHANCE THE USEFULNESS AND ACCEPTABILITY OF ORGANIC WASTES

Some of the problems associated with the utilization of various organic wastes (e.g. odors, human pathogens, and storage and handling constraints) can be resolved by composting. Composting is an ancient practice whereby

farmers have converted organic wastes into resources that provide nutrients to crops and enhance the tilth, fertility, and productivity of soils. Through composting, organic wastes are decomposed, nutrients are made available to plants, pathogens are destroyed, and maloders are abated. The historical aspects of composting have been thoroughly discussed in reviews by Gotaas, 1956; and Golueke, 1972.

Composting can be conducted under either aerobic or anaerobic conditions. In either case, mixed populations of microorganisms utilize available carbon and nitrogen sources in their growth and metabolism, thereby transforming the organic waste into a more stabilized organic material which decomposes at a much slower rate than the original waste when applied to soil. Most of the inorganic nitrogen is converted into an organic configuration during the process.

Recently, the USDA at Beltsville, Maryland, developed the highly successful Beltsville Aerated Rapid Composting (BARC) Method for composting sewage sludges, animal manures, municipal refuse, and pit latrine wastes (Willson et al., 1980). This method has been widely adopted by both large and small municipalities throughout the United States for composting sewage sludge and solid waste. A number of developing countries have also adopted this technology. The method is simple and relatively inexpensive, yet effective, and allows considerable trade-off between labor and capital.

In the BARC Method (Fig. 4.2) sewage sludges ranging from 15 to 25% solids are mixed with woodchips as a bulking material and then composted in a stationary aerated pile for 3 to 4 weeks. Sludges in this high moisture range will not readily compost aerobically because sufficient air cannot penetrate the biomass, either naturally or through forced aeration. Thus, it is essential to mix the sludge with a bulking material to provide the necessary structure and porosity to facilitate forced aeration. The bulking material also lowers the moisture content of the sludge thereby ensuring rapid aerobic/thermophilic composting. Aerobic conditions are maintained by drawing air through the pile with a blower connected to a loop of perforated pipe in the pile base. Other bulking materials that could be used include leaves, refuse, paper, peanut hulls, straw, corn cobs, and wood bark.

As shown in Fig. 4.2 air is drawn into and through the composting biomass and finally exhausted into a small pile of screened, cured compost where odorous gasses are effectively absorbed. The pile is blanketed with a 30 to 40 cm layer of screened compost for insulation and odor control. Uniform tem-

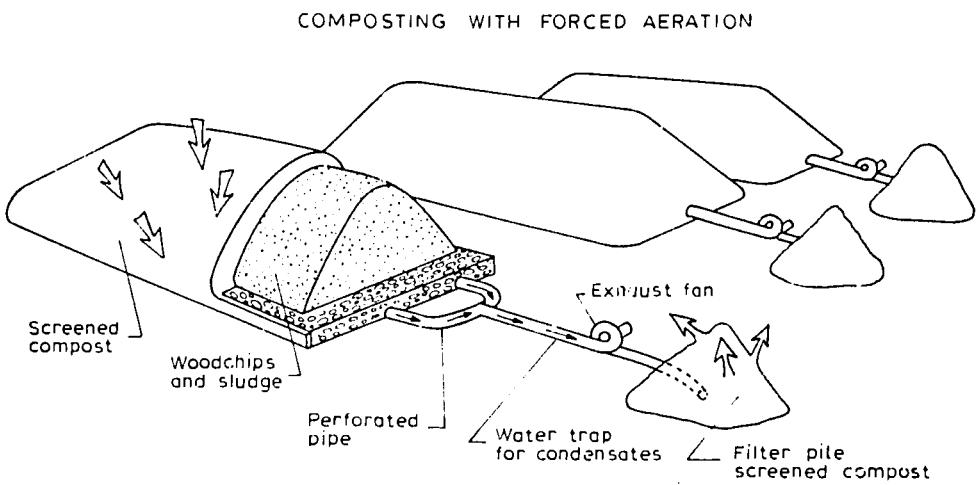

Fig. 4.2. A schematic diagram of the Beltsville Aerated Rapid Composting Method for composting sewage sludge and other organic wastes.

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peratures are maintained throughout the pile with a timer programmed to operate the exhaust fan on a predetermined intermittent cycle. Within three days after composting begins temperatures are well into the thermophilic range (60 to 70°C) and remain there for several weeks. This ensures complete destruction of enteric pathogens. There are now more than 50 BARC-type composting facilities operating in U.S. cities and municipalities with 25 others in various stages of construction and development (Goldstein, 1985).

Interestingly, the BARC Method is quite similar to high temperature compost heaps developed in China and described in an earlier publication (FAO, 1977). The principal difference is that static rather than forced aeration is used in the Chinese system, and is facilitated by bamboo "piping" or by installing bundles of mature maize stalks. In China the composting biomass usually consists of mixtures of dried silt, animal manures, and human waste (i.e. nightsoil including urine). The compost heap (i.e. pile) is sealed with mud for insulation to ensure that sufficiently high temperatures are achieved to kill human pathogens.

Recent reports by Hornick et al. (1979, 1984) discuss the uses of sewage sludge compost for soil improvement and plant growth including (a) establishment, maintenance, and production of turfgrass and sod, (b) use in vegetable gardens, (c) production of field crops and forage grasses, (d) use on nursery crops and ornamentals, (e) use in potting mixes, and (f) reclamation and revegetation of disturbed lands. Recommendations are provided as to time, methods, and rates of compost application for different soils, and management practices.

Some organic wastes may have chemical, physical, and/or microbiological properties that would greatly limit the extent to which they could be composted alone. Some wastes may have an extremely acidic or alkaline pH, others may have an unusually high or low C/N ratio, and still others may vary widely in their solids content. In such cases, selective co-composting of these wastes with sewage sludges, pit latrine waste or nightsoil, municipal solid waste (i.e., garbage or refuse), crop residues, animal manures, food processing wastes and certain industrial wastes, may alleviate these deficiencies and provide a readily compostable mixture and higher quality product. For example, rice straw has a very high C/N ratio and would compost slowly alone. If combined with a low C/N material such as poultry manure (see Table 4.5 and 4.6) a more favorable ratio is achieved for rapid composting, and a compost is produced that has a higher nutrient content. The ideal C/N ratio for composting is about 25 to 30. At higher C/N ratios, composting will be slow, and at lower ratios ammonia can be lost through volatilization. Dalmat et al. (1982) reported that pit latrine waste (nightsoil) was successfully co-composted with municipal refuse in Haiti. Haiti.

8. ORGANIC MATERIALS AND ENERGY RELATIONSHIPS

There is an increasing awareness that excess crop residues are potential resources that could be utilized as fuel, fiber, and livestock feed (Atchison, 1976). One of our highest priorities in agricultural research is to determine how much residue (and biomass) could be removed from soils under different tillage and cropping practices, and for different soil, topographic, and climatic conditions without causing increased soil erosion, plant nutrient and organic matter losses, and decreased soil productivity (Larson et al., 1977). Unfortunately, we do not yet have this information in sufficient detail.

Larson et al. (1977) estimated that approximately 3150 kg/ha of crop residue is needed for adequate control of both wind and water erosion under most Corn

Belt conditions. They also concluded that crop residues, in varying amounts, could be removed from up to 50 percent of the area cropped. Crop residues and biomass can potentially supplant some of the energy that is now provided by fossil fuels. However, the utility of these alternative energy sources will depend upon the amount of energy required to produce biomass crops, the cost of collecting and transporting crop residues and biomass to processing centers, and the cost of conversion, depending on the particular process selected, e.g. direct combustion, pyrolysis, hydrogasification, or anaerobic digestion.

The utilization of crop residues for energy is particularly attractive to those rural areas where residues are produced in abundance and in close proximity to industries and municipalities (Epstein et al., 1978). Organic wastes such as sewage sludge and composted garbage could be used to replace organic matter lost by residue removal (Epstein, 1976; Epstein and Parr, 1977). The composting process developed by USDA at Beltsville, Maryland represents a method of converting sewage sludge into an organic resource that can be used beneficially as a fertilizer and soil conditioner to increase the production of biomass, while maintaining soil productivity and minimizing runoff and erosion (Willson et al., 1980). The effects of erosion on soil productivity is discussed in greater length in Chapter 5. The energy relationships of agricultural and municipal wastes and residues are covered in much greater detail in a later volume.

9. SUMMARY AND CONCLUSIONS

The 1978 USDA report on "Improving Soils with Organic Wastes" concluded that there is a growing shortage of good quality organic wastes for use in maintaining and restoring the tilth, fertility, and productivity of our agricultural soils. Indeed, most (> 75%) of our traditional agricultural wastes, i.e. animal manures and crop residues are currently being recycled on agricultural land. These wastes are often of limited availability in developing countries because of such competitive uses as fodder, fuel, and fiber.

Both developed and developing countries need to conduct periodic inventories on the kinds, amounts, and availability of organic materials that could be utilized as fertilizers and soil amendments, and especially municipal wastes such as garbage (refuse), sewage, and nightsoil. Composting techniques are available to minimize environmental hazards and health risks, and to overcome certain chemical, and physical contraints that would limit their use on agricultural lands. Because these materials represent a potential source of considerable agronomic, energy and economic value, their proper and efficient use as fertilizers should be emphasized by national governments in developing strategies for increasing agricultural productivity and stability.

Most organic wastes and residues are low in their content of macro- and micronutrients compared with most chemical fertilizers. However, research has shown that crop yields are consistently higher when organic materials are applied in combination with chemical fertilizers than when either [illegible] is applied alone. This would suggest that organic materials can increase the efficiency of chemical fertilizers and, if so, farmers might be able to reduce their fertilizer (and energy) inputs accordingly. Research is needed to evaluate crop yield response to various combinations of organic and chemical fertilizers and to determine what agronomic, energy, and economic trade-offs are possible.

Research is also needed to improve the efficient and effective use of organic materials in cropping systems. Studies should be conducted to establish the best mode/method of application to soil (i.e. surface mulched,plowed down, disked in, or sidedressed), proper rate and time of application, best sequence of

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crops to be grown, and the rate of release of nutrients. A better understanding of the interaction of these factors would provide a more reliable basis for developing effective application/utilization strategies for organic wastes in agriculture.

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