This is to certify that the

dissertation entitled

Effects of organic amendments (manures /plant residues) on nutrient leaching in soils

presented by

Joseph Sedgo

has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Soil Fertility

Major professor

Date May 19, 1989

EFFECTS OF ORGANIC AMENDMENTS (MANURES /PLANT RESIDUES) ON NUTRIENT LEACHING IN SOILS

By

Joseph SEDGO

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Sciences

1989

604627

ABSTRACT

EFFECTS OF ORGANIC AMENDMENTS (MANURES/PLANT RESIDUES) ON NUTRIENT LEACHING IN SOILS

By

Joseph SEDGO

This research was conducted to investigate the mobilization and leaching of essential nutrients in relation to applied fertilizer and organic manure treatments in soils. To realize such objectives, two main experiments were established as follows:

1) Soil samples were taken at 15 cm increments down to 105 cm from field plots that were previously treated for 20 years (1963-1982) with inorganic fertilizer (0.168-0.168-0.168 Mg/ha/year $N-P_2O_5-K_2O$) and cattle manure applied at 22.4, 44.8, 67.2 Mg/ha/year, respectively. Nutrients of interest included: P, K, Ca, Mg, Fe, Mn, Zn, and Cu.
2) A column leaching study was conducted under lab conditions in order to ascertain the influence of incubation, texture, and pH on nutrient leaching from fertilizer and organic treatments which consisted of 60 mg/ha for plant residues (barley; soybean) and animal manures (cattle; poultry), and of equivalent amounts of N-P-K for inorganic fertilizer, respectively. After sequential leaching respective treatment results were compared.

The major conclusions reached in this research were :

a) <u>Field Study</u> : For most nutrients the potential for excessive downward movement into lower soil zones reflected very much the amounts of manure applied. There was, however, no evidence of any significant nutrient movement beyond the 75 cm depth. This indicates that long term soil treatments with animal manure can be very beneficial in building up complementary nutrient levels for crop production.

b) <u>Lab Leaching Study</u> : Incubation of amended soils generally increased nutrient leaching except under the barley and inorganic fertilizer treatments. With respect to texture 1.7 to 2.0 times more leaching occurred in a sandy loam compared to a clay loam soil. Compared pH effects suggested in addition that essential nutrient leaching in soils would be greater at lower pH values.

This dissertation is lovely
dedicated to my parents and to
my wife for their love, support,
and prayers without which very
little would have been
accomplished.

A C K N O W L E D G E M E N T S

I'd like to take this opportunity to express my sincere gratitude to all those who contributed towards the successful completion of this program.

First of all I am very much indebted to Dr. D. D. Warncke, my major professor and committee chairman, for his patience and guidance as well as for the valuable suggestions he provided all along during the completion of this project.

I am equally grateful to the committee members, i.e. Dr. D. R. Christenson (second reader), Dr. B. G. Ellis and Dr. M. L. Esmay, for their respective advice and contributions which no doubt added a lot substance to the content of this dissertation.

Special thanks are extended to Calvin Bricker for the key role he played during the setting up of the leaching experiment and for his kind assistance in developing some of the data slides. I am fully grateful to William Berti alias "Bill" and to the MSU soil testing lab crew, notably Jon, Rosie and Roger for their friendly cooperation and help during the analytical phase of this project.

Special thanks are also due to Drs. C. Cress and S. Eisensmith for their kind advice and suggestions which facilitated the statistical analysis of the data.

Consulting with Dr. R. Kunze has proved to be very helpful and indispensable, especially with respect to understanding critical aspects in the leaching experiment.

Dr. Y. Segun was the one who kindly initiated me to the MSTAT program without which it would have been virtually impossible for me to process all the data within the required time frame. Thank you then for this assistance and also for being one of the nicest colleagues and office mates I ever met.

I am particularly grateful to Ms. E. Keaton and Dr. K. Ebert (Office of International Scholar and Student Programs) for bailing me out each time that administrative difficulties appeared seriously to be in interference with my academic performance. I am also very grateful to Drs. J. Jay and E. Foster who ultimately became my "listening ear" and personal counsel in many difficult situations. Thank you then so much for being so concerned and caring for me in all these years I've come to know you.

As a student worker I made a lot of friends at the USDA Regional Poultry Research Lab (RPRL) on Mt Hope Road (E.L.) and at the Institute of International Agriculture (IIA) at MSU. Thank you all for your support and encouragements.

Spiritually, I am infinitely grateful to Alain Koné, G.P. Rao and family, and to the numerous friends at the First Assembly of God (Lansing Road) for their constant encouragements and prayers. Without God's help nothing would have been accomplished, especially under those very difficult circumstances my wife and I have unjustifiably been subjected to for years while this project was taking place.

Special thanks are also in order for many friends, notably Ousmane Coulibaly, Honoré and Françoise Diendéré, Drs. Mike and Ngozi Okoroafor, Benjamin and Nosa Egiebor, Klengolo Traoré, Djibo Hamidou, Abdoul Barry, Emil Mmbaga, Pauline Zekeng, Wilbert Jenkins, Dave Edmond, Kevin Hendricksen, Michele Green and Robert Ndondole, and Prince Nimako and family, for their respective support and encouragements.

Last, but not least I'd like to take this special moment to express my heartfelt respects and gratitude to everyone in my family. I am mostly thankful to my Mom (Marie), my Dad (Jean-Pierre) and to my Godfather (Emile) and his family for their love, support, prayers as well as for all God's inspiring values they instilled in me since my younger days. Despite these many years of separation you've always been on my side and never complained of anything even when I had, due to very demanding circumstances, to remain silent for months without responding to your letters. May God bless you and reward you abundantly for everything you've done for me.

Special thanks are also due to my brother Alphonse, my sisters Scholastique and Perpétue, and to all my in-laws including notably my late mother in-law Aissa (God bless her soul), "papa" Yamba, Maxime, Albert, Djibril, Sambo, Prosper and André, for their continued support and encouragements.

Finally, I'd like to pay a very special tribute of gratitude to my beloved wife Rachel for her love, constant support and encouragements, prayers as well as for all the endless sacrifices she had to endure so that I could realize such an important dream in my life. In recognition for such contribution and support, I dedicate then this dissertation in her honor.

TABLE OF CONTENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The intensification of agricultural activities (i.e. cropping, livestock production, and processing of agricultural products) over the past few decades has contributed to the disposal of increasingly higher rates of organic wastes onto croplands. The heavier loads of manures to be disposed are currently believed to have increased the potential for harmful effects on the soil environment, growing plants, and ultimately on both animals and humans. In many countries, especially in the northern hemisphere excessive soil nutrient build-up, salinity, surface water and ground water pollution, phytotoxicity, reduced crop yields, etc... have been reported as a result of application of organic wastes (Tunney, 1980; Sutton, 1986). Given this situation, there is little doubt that proper research ought to be carried out not only to increase our understanding on these issues, but to attempt to provide viable solutions as well. With such considerations in view the objectives then in this research were as follows :

1) To ascertain the effects of long term manure applications on the distribution of P, K, Ca, Mg, Fe, Mn, Zn and Cu in the soil profile.

2) To compare the effects of manuring rates on nutrient leaching over a 20 year period.

3) To investigate the influence of incubation, pH, and texture with applied manure or crop residues on nutrient leaching under controlled laboratory conditions.

TERMINOLOGY:

DEFINITION OF KEY TERMS

Due to the great diversity of today's agricultural activities, confusion and miscalling of one by-product for another are often common. To forestall such a misunderstanding a definition of certain key terminologies has been included.

a) Organic fertilizers, amendments, manures, biofertilizers

Often used interchangeably, these terms normally refer to organic materials applied to land for agricultural production (Egawa, 1975). Such a definition appears to include most of the so-called farm yard manure, green manure, night soil, sewage sludge as well as various agro-industrial by-products such as blood meals, meat meals, fish meal, bone meals, oil cakes, sugarcane molasse, sawdust, etc...

b) Farm yard manure

Farm yard manure is composed of partially rotted straw mixed with urine and/or feces from domestic animals (cattle, horse, goat, sheep, pig, poultry, etc...). Farm yard manure rendered liquid through dilution of water is called liquid manure or gülle (Cooke, 1982). The term liquid manure may sometimes be used, however, for other liquid forms of organic fertilizers, such as liquid sewage sludge, waste waters, etc...

c) Green manure

The term manure is used for plants or parts of plants plowed in fresh in order to improve both (or either) soil conditions (Thorne,1913) and crop yields (Follett et al.,1981). Such plants can be either cropped or uncropped, legumes or grasses.

d) Plant residues

Post harvest plant remains returned to soils, incorporated or laid over as mulch, constitute what are generally considered as crop/plant residues. Such a definition would still hold, even when the applied plant residues are transferred from one location to another.

e) Composts

This term refers to partially decomposed organic residues (Egawa,1975). Depending on the provenance of the raw materials, these semi-decomposed materials can be further classified as city (urban), garbage, township, rural, etc... " composts".

f) Night soil

This refers to human wastes (urine and /or feces).

g) Sewage sludge

Sewage sludge usually refers to solid wastes removed from polluted waters. When the sludge is laden with microorganisms that promote rapid decomposition it is said to be activated (Turk et al., 1984).

h) Agro-industrial wastes

All wastes generated by food processing industries (rice, sugarcane, coffee, fruit, vegetables, oil cakes, fish meal, slaughter house wastes, i.e. blood, meat, bones, etc...), forest mills (cellulose, sawdust,...), tanneries, wool plants, etc..., constitute another important class of organic materials likely to be disposed of on croplands.

LITERATURE REVIEW PART I : MAJOR CHARACTERISTICS OF FARM YARD MANURES

A) HISTORICAL OVERVIEW

About 800 B.C. the use of farm yard manures for agricultural purposes was already quite common among the early farmers. Evidence is given through the prevalence of early records :

-Homer (900-700 B.C.) : manuring of vineyards by the father of Odyssey (Tisdale et al., 1975).

-Theophrastus (372-287 B.C.) : soil enrichment with bedding from stall; recognized value of human, swine, goat, sheep, cow, oxen, and horse manures (ibid.).

-Varro (ca 600 B.C.) : bird and fowl manures (ibid.).

-Archilochus (700 B.C.) : increased crop growth from dead bodies (ibid.).

-Bible (Deuteronomy) : animal blood spread over the ground (ibid.).

-Mahamuni Passara (3000 years ago) : cow manure utilized during sowing time in Asia (Fahm, 1980).

It was not until the 1800s, however, that scientists had begun to discover more precisely the real "how and why" of certain agricultural benefits and limitations due to the application of farm yard manures. Aikman (1894) indicated that the beneficial effects of farm yard manures to crop production were essentially related to the following major attributes :

-Supply of nutrients mostly N and P

-Improvement of soil physical conditions (texture, porosity, water holding, tilth) for both fine and coarse texture soils

-Beneficial lasting effects throughout a whole crop rotation or even longer

Despite such effects, Aikman cautioned that exclusive use of farm yard manures may lead to the following limitations :

-Inadequate nutrient contents for plant needs

-Inappropriate forms of nutrients, especially in case of N and P

-Doubtful or questioned economic returns

-Additional needs for "artificial" or mineral fertilizers (i.e. more expenses) for satisfactory results

Later, Thorne (1914), a scientist working at the Ohio experimental station (USA), took stock of the long term results from manure studies both in England at Rothamasted Institute and in the United States at Ohio, Pennsylvania, New Jersey and Illinois agricultural stations. From such an appraisal, he found that :

-The effect of manure was not as immediate as that of chemical fertilizers and therefore crop responses from manures were not as effective as with chemical fertilizers, at least during the first 10 years.

-Continuous cropping (wheat and barley) reduced crop yields, but to a much greater extent on continuously fertilized plots than on the ones similarly treated with manures.

-Manured crops showed a net superiority in yields over unmanured crops without a supply of supplemental chemical fertilizers.

-Chemical fertilizers indicated very little residual effects on crops yields as compared with manures.

-Fresh stall manure added more value in crop yields over the exposed yard manure at comparable rates.

-No significant differences were obtained in yields between fresh and rotten manure.

-Responsive crops to manuring were corn, potato, wheat, grass crops (meadows and pastures), and orchards

-Manure conserved its value best when not exposed to air, snow, heat, or excessive rains.

-To enhance its beneficial effects manure could be reinforced with certain materials, such as crude phosphate, sulfate lime (gypsum), dilute sulfuric acid (most effective, but dangerous), table salt, and crude potash (kainit).

-Manure had certain limitations one should be aware of; among other things the fact that it was neither a complete fertilizer, nor the most economical way for building up soil fertility (Aikman, 1894), and the relatively greater chances for nutrient losses (especially N) from leaching.

B) COMPOSITION

Organic manures have been generally characterized by their great spatial and time variabilities in terms of chemical compositions. Despite such a feature, typical values derived from extensive studies and reviews have been recently made available by a number of authors. To provide the reader with a quick overview, selected references are summarized in Tables I through VII.

Table I. Analyses of various animal manures, sewage sludge and municipal refuse.

	MOISTURE	N	P	K
<u>BRITISH ANALYSES</u>	------------------	------------------	%	-----------
POULTRY MANURES				
Deep litter	6-71	.3-3.5	.04-2.3	.17-2.1
Broiler litters	9-75	.4-3.6	.09-1.7	.25-2.0
Battery	12-88	.5-4.5	.13-2.1	.17-3.3
Turkey Manures	10-81	.4-5.7	.22-1.9	.08-1.4
CATTLE MANURES				
Farm Yard Manures	8-86	.3-2.2	.04-.9	.40-1.2
Feces (fresh)	-	-	-	-
Feces + Urine	86-93	.2-1.7	.04-1.0	.08-1.9
Pig Slurry	85-99	.02-1.0	.01-.35	.08-.33
Sewage Sludge	5-94	.10-2.7	.04-2.1	.01-.07
TOWN REFUSE				
Municipal	4-78	.30-10	.04-.90	.17-1.3

SOURCE : G.W.Cooke, " Fertilizing for Maximum Yield", 3rd Edition, pp 96-97, Macmillan Publishing Co., Inc., New York, 1982.

Table II. Composition of Organic Manures from Various Animals in West Africa (Nigeria).

SOURCE	MOISTURE	TOTAL ASH	SOLUBLE ASH	P_2O_5	K_2O	N_2
	COMPOSITION					
	%					
Dairy cow, Pig, with Sweepings, Grass, etc...	52.38	-	-	1.07	3.44	1.14
Pen manure (cattle rotted)	56.77	-	-	0.82	5.54	1.57
Pig manure as above	70.77	-	-	1.06	4.76	1.63
Pig manure (dry)	15.40	88.1	-	0.19	0.07	0.37
Sheep manure (dry)	10.60	79.2	-	0.30	0.34	0.48
Pen manure	24.24	62.55	9.55	0.49	2.33	1.03
Pen manure	45.65	54.40	16.41	1.16	2.47	1.87

Source : Philips, T.A. (1964), "An Agricultural Notebook Ikeja : Longman Nigeria Ltd" reported in Okigbo (1980).

Table III. Dry Matter and Major Fertilizer Nutrient Composition at Time of Soil Application : Solid Waste Systems of Managing Animal Manures.

Domestic Animal	Waste Handling System	Dry Matter	Nitrogen (N) Available[a]	Nitrogen (N) Total[b]	P_2O_5	K_2O
		%				
Beef Cattle	W/bedding	15	.20	.55	.35	.50
	W/out bedding	50	.40	1.05	.90	1.30
Dairy Cattle	W/bedding	18	.20	.45	.20	.50
	W/out bedding	21	.25	.45	.20	.50
Poultry	W/bedding	45	1.30	1.65	2.4	1.7
	W/out bedding	75	1.80	2.80	2.25	1.7
Swine	W/bedding	18	0.30	.50	.45	.40
	W/out bedding	18	0.25	.40	.35	.35

[a] Primary ammonium nitrogen, which is available to plants the first year.
[b] Ammonium nitrogen plus organic, available over several years.

NOTES:

lb/ton : 1/2 kg/metric ton
P_2O_5 x 0.44 = P
K_2O_5 X 0.83 = K

SOURCES : A.L.Sutton, J.V.Mannering, D.H.Bache, J.F. Marten, and D.D. Jones, "Utilization of Animal Waste as Fertilizer", Purdue University, 1D-101, 1975.

Table IV. Dry Matter and Fertilizer Nutrient Composition At Time of Soil Application : Liquid Waste Systems of Managing Animal Manures.

Domestic Animal	Waste Handling System	Dry Matter (%)	Nitrogen (N %) Available[a]	Total[b]	P_2O_5 (%)	K_2O (%)
			lb/1000 gal of Raw Waste			
Beef Cattle						
Liquid Pit	(anaerobic)	11	24	40	27	34
	Oxidation Ditch	3	16	28	18	29
	Lagoon	1	2	4	9	5
Dairy Cattle						
Liquid Pit	(anaerobic)	8	12	24	18	29
	Lagoon	1	2.5	4	4	5
Poultry						
Liquid Pit	(anaerobic)	13	64	80	36	96
Swine						
Liquid Pit	(anaerobic)	4	20	36	27	19
	Oxidation Ditch	2.5	12	24	27	19
	Lagoon	1	3	4	2	4

[a] Primary ammonium nitrogen, which is available to plants the first year.
[b] Ammonium nitrogen plus organic, available over several years.

NOTES:

1000 gal = 4.4 metric tons (tons)
27,154 gal (102,778 l) = A-in. (0.973 ha-cm)
P_2O_5 x 0.44 = P
K_2O_5 X 0.83 = K

SOURCES : A.L.Sutton, J.V.Mannering, D.H.Bache, J.F.Marten, and D.D. Jones, "Utilization of Animal Waste as Fertilizer", Purdue University, ID-101, 1975.

Table V. Summary of Cattle and Pig Slurry. Adapted from Tunney (1977a).

	DRY MATTER	N	P	K	Mg
		NUTRIENTS			
	%	kg per 10 mt manure			
		Cattle Slurry (33 farms)			
MEAN	8	28	6	42	4
RANGE	1-14	8-56	1-12	8-64	1-11
		Pig Slurry (25 farms)			
MEAN	4	30	9	15	4
RANGE	1-13	4-70	1-34	2-33	1-20

Table VI. Range of Values from Literature on Composition of Cattle, Pig, and Poultry Manures. Adapted from Tunney (1977).

		NUTRIENTS			
SOURCE	DRY MATTER	N	P	K	Mg
	%	-------kg/10 mt fresh manure----			
Cattle Manure	4-23	24-65	4-18	20-58	2-6
Pig Manure	5-25	16-68	6-21	17-36	3-7
Poultry Manure	23-68	96-230	24-120	38-116	12-22

Table VII. Inorganic Nutrient Contents Of Animal Excreta.

Animal	Item	N	P_2O_5	K_2O
		(Fresh Matter Basis)		
		------- % ---------		
Dairy Cattle	Feces	0.30	0.25	0.10
	Urine	0.80	-	1.40
Beef Cattle	Feces	0.30	0.25	0.10
	Urine	0.80	-	1.40
Hog	Feces	0.60	0.45	0.45
	Urine	0.30	0.12	0.20
Laying Hen	Feces	1.60	1.70	0.80
	Urine	-	-	-
Broiler	Feces	1.60	1.70	0.80
	Urine	-	-	-

SOURCE : Inoko, 1983

C) <u>EFFECTS ON SOIL PROPERTIES</u>

General work in Africa (Balasubramanian et al., 1980) has shown that depletion of organic matter has very often resulted in increased erosion, run-off nutrient loss, reduced soil moisture retention (Charreau, 1974) and increased soil compaction (Greenland, 1972). It has been reported that soil organic matter represents about 60 to 80 % of the cation exchange capacity, particularly in the savanna soils (Kadeba et al., 1976). The application of organic materials, such as farm yard manure, in order to improve both the physical and biochemical properties of the soils needs to be considered as a priority by the African farmer. Studies by Jones (1971) indicated that application of 12.5 mt /ha/year of farm yard manure for nearly 20 years resulted in four times as much increase in the mean carbon content of the treated plots (0.82 %) over controls (0.22 %). Bache and Heathcote (1969) found likewise that application of cattle manure increased not only soil C and N, but also its CEC, pH, and exchangeable Ca and Mg. However soluble Al and Mn were decreased. In addition to these findings, studies by Olsen et al., (1970), Ofori (1980), and Mokwunye (1980) suggested that application of farm yard manure could increase the availability of P in soils.

In Asia, Singh et al. (1980) observed that most organic materials, with the exception of green manure, have always been utilized to build up soil fertility. In India, Gaur (1983) found that application of farm yard manure contributed to increases in both total soil N and available P. In addition, Gaur (1983) obtained increases in total carbon, humin carbon, and humus contents of the soil from the applications of various organic amendments (including farm yard manure).

In China, Nan Rong Su (1983) reported the following changes in soil properties from high level applications of animal manures: increased availability of P, Cu, Zn, Ca, Mg ; large gains in organic matter contents, N, and K with only a slight accumulation of Na. Other beneficial effects, such as solubilization of nutrients by organic acids and buffering role of soil organic matter against deficiencies or excess of pesticides and toxic chemicals, have also been mentioned by Gaur (1983) and Mishara et al., (1983).

In the humid temperate regions, research with respect to the effects of farm yard manure on soil properties has also led to the following findings. In Europe, Keller (1982) indicated that favorable long term results from application of animal manures included among other things, supply of nutrients, improvement of aggregate stability and prevention of the decline of soil organic matter contents. Rixhon (1979), however, with 40 mt/ha of farm yard manure application every four years could not manage to increase the soil organic matter level to more than 1.7 % over a 16 year period. Vez (1979) comparing 40 mt/ha of farm yard manure with straw, sugar beet tops, and controls, reported that regardless of the treatments, he could not prevent the decline in organic matter from 3.5 to 2.6 % over a 16 year period. Cooke (1967) comparing farm yard manure with sewage sludge and composts of straw found that the main value of these organic manures was in the plant nutrient supply and to a lesser extent in the increase of the soil organic matter contents. Tunney (1980) agreed with Cooke in stating that most scientific evidence indicated that normal levels of organic waste application have minimal effects on soil organic matter content. Tunney (1980) also pointed out that under most soil conditions, the physical benefits appeared to be secondary compared to those associated with the nutrient supply. In the United States, literature reviewed by Godz (1972) over the 1927-1972 period has indicated only some occasional changes in soil physical conditions from the applications of farm yard manure. Under certain conditions, improvement in soil structure, root environment, and nutrient up take have been obtained by Flaig et al. (1976).

With respect to liquid manures, Swiss work reported by Cooke (1982) indicates that 'full liquid manure' or 'gülle', i.e. mixture of feces, urine, and litter diluted with water, was only half as effective as urea for the supply of total N, but nearly as effective as ordinary fertilizers when considering the nutrients P and K. Urine tested alone proved to be as good as NPK fertilizers (Cooke,1982). Tunney (1975) studying the influence of liquid manure on soils found that land receiving cattle slurry had high levels of potassium. However in the case of pig manure slurry soil analysis showed high levels of phosphorus. Further studies indicated higher levels of Ca and Mg, but lower contents of available Mn when pig manure slurry treated plots were compared with artificial fertilizer treatments (Tunney, 1977a).

Studies with pig manure slurry reported by Tunney (1980) showed a small, but significant increase in soil pH. British work on the other hand (Cooke, 1967) indicated that liquid manure had no marked effect on soil pH or phosphorus content, but increased only the levels of K. Besides these effects other such as stimulation of root hairs, increases in number of saprophytic microorganisms in the soil and production of certain substances capable of inhibiting pathogens (fungi) and reducing diseases have been found to be associated with the application of farm yard manures (Cooke, 1967).

D) STUDIES ON PLANT GROWTH AND YIELDS

Various studies conducted in Africa have shown very encouraging effects from the application of farm yard manure on crop yields. In Nigeria, Hartley (1937) showed that 2.2 mt/ha of farm yard manure was as effective as N-P-K fertilizer at certain rates in increasing yields of seed cotton and guinea corn. However, a combination N-P-K fertilizer + farm yard manure did not produce better results than with farm yard manure alone. Other studies by Richard (1967), Roch (1970), and Poulain (1976) showed that the application of farm yard manure not only increased yield, but in their cases appeared to produce the best results when it was combined with NPK fertilizers. Ganry et al.(1974) noted that a combination of either straw or farm yard manure with 30 kg N/ha contributed to net fertilizer N savings of about 60 kg / ha. Beneficial long-term effects from twenty annual manure applications on maize have been reported in Nigeria (Samuru) by Abdullahi (1971). In Ghana, as indicated by Cooke (1982), 'kraal manure', i.e. dung at 5-10 t/ha has nearly always given better yields than inorganic fertilizers containing about 25, 25, 35 of N, P_2O_5, K_2O kg/ha, respectively. Stephens (1969) and Heathcote (1970) pointed out that most of these beneficial effects on crop yields in many parts of Africa seemed to be mainly associated with the mineral compositions of the manures.

In India, Gaur (1983) reported that extracted humus substances from manure, especially from farm yard manure at a concentration of 0.05 % were able to increase rice yields by 85 %, when a basal NPK fertilizer dressing was given along. In another experiment the application of 15 metric ton /ha of farm yard manure every season increased the paddy rice yield to a record of 1,844 kg / ha. In a highly sodic soil, rice yields also doubled when 22.2 metric ton of farm yard manure were applied in conjunction with sesbania green manure (Uppal, 1955). At Pusa in India, a long term trial by Agarwal (1965) indicated that farm yard manure plots outyielded the fertilizer plots on an equal nutrient basis in rotations that included maize, oat, pea, wheat, and gram crops.

In China, Nan Rong Su (1983) found that incorporation of 15 mt/ha of fresh hog manure increased rice yield from 4 to 11 % and with a net fertilizer N saving of 50 % compared to the control plots that received 126 kg/ha of fertilizer N. In another trial, the same author in an effort to raise napier grass yields compared hog and cattle manures with chemical fertilizers. But in this case, he observed that no significant differences resulted when all application rates were adjusted to 200 kg N/ha/year. Yet in similar trials, napier grass tested with irrigation of hog effluent showed a yield response of 14 mt of dry matter over the plain water irrigation with conventional NPK fertilizers.

In Hong Kong, Chun-Wai Hui (1983) reported that chicken manure has become so popular for growing flowers, that farmers sometimes have to wait very long after their orders.

In Japan (Inoko,1983), 50 years of continuous applications of organic manure and inorganic fertilizer showed an average increase in rice yield of about 168 and 167 % over the control.

In the Philippines, Marquez et al. (1983) contended that the vegetable industry in Benguet owed a great deal of its success to the use of chicken manure. An experiment set up in this regard showed that 10 mt/ha of chicken manure in combination with mineral fertilizers were able to produce as much as 45 mt / ha of pechay (Brassica chinensis) or 83 % increase over the control (ibid.). According to the same source, the beneficial effects of chicken manure seemed so great that the majority of farmers in Benguet preferred it to the chemical fertilizer.

In Thailand optimum yields have also been obtained in studies where farm yard manure applications were supplemented with chemical fertilizer (Teppolpon et al., 1983).

As evidence has shown the use of farm yard manure, particularly in combination with chemical fertilizers, has resulted not only in reducing the need for fertilizer N, but also in producing the best yields throughout most of the Asian countries.

Despite the tremendous development of chemical fertilizers that has been taking place over the last thirty years, research on manures, especially on farm yard manure has been continued throughout the years in industrial developed countries. Literature reviewed by Godz (1972) from 1927 to 1972 has shown similar results in the United States to that seen in Asia and in Africa. In most cases good crop responses were obtained from manure, but many of the highest yields resulted when farm yard manure was applied in combination with chemical fertilizers. More recent work in the United States by Doss et al (1976) indicated that 22 metric ton / ha (10 ton /A) or more of dairy cattle manure was able to produce better yields of pearl millet and cereal rye compared to either the control or fertilizer treated plots. Bandel et al. (1972) showed that vegetable crops, such as tomatoes and squash responded effectively to poultry manure applications, especially during the warm seasons.

Kofoed (1976) and Debruck et al. (1979) were of the opinion that the combination of farm yard manure and fertilizer should be preferable in most cases for it produced the best yields. In England Cooke (1967;1982) found that for agricultural and horticultural crops farm yard manure gave the largest yields when compared with straw and sludge manures, respectively.

To conclude on this aspect, it appears that in order to produce the best results with crops it would be highly desirable to almost always combine appropriate rates of farm yard manure with mineral fertilizers.

E) MAJOR LIMITATIONS AND RELATED FACTORS

E1) OVERVIEW

Except for the fact that manure contains only small quantities of plant nutrients and that farmers usually do not have the appropriate means to collect, haul, and apply adequate amounts of it in their fields, no further direct limitations to soil or to plant growth have yet been reported in African literature. Conversely in Asia, reduced crop yields and adverse effects on soil properties (salinity, compaction, infiltration, and pollution problems) as a result from the applications of farm yard manure have recently been indicated in some studies. In China particularly, Nan Rong Su (1983) observed the following effects when excessive amounts of animal manures were applied : distinct increases in H+ and electric conductivity, tremendous accumulations of Cl- and Cu, and salinization problems. As in Africa, Nastiti (1983) and Marquez et al., (1983) pointed out that expensive handling and lack of appropriate equipment for deep placement in soils could constitute a serious limitation to manure utilization by farmers, especially in Asia.

Despite these problems it appears as though much of the trouble experienced so far could be identified geographically with the temperate regions of North America and Western Europe. In these regions the development of livestock and cropping activities has become such that heavy rates of manure applications appear to be almost inevitable. This may have been encouraged by the opinion that the soil should be the ultimate repository for all animal wastes (Donahue et al.,1977). Research at Auburn University indicated that crop yields (especially pearl, millet, and cereal rye) begin to decline when the applied farm yard manure rates exceed the 90 mt/ha (i.e. 40 t/A) limit. Tunney (1975) similarly found that 65 mt/ha of pig slurry resulted in higher yields than 110 mt/ha. When heavy rates of manure are applied crop yields may be reduced because of phytotoxicity and/or degradation of soil physical conditions. With respect to the latter, Stevens and Cornforth (1974) found that heavy applications of manures, especially of slurry could lead to following adverse effects : reduced soil porosity, anaerobiosis, and reduced infiltration capacity which in turn are likely to result in increased surface run-off during rainfall (Tunney, 1980). With excessive applications of agricultural wastes risks for toxicity or ground water pollution problems due to accumulated nitrate and copper in soils, plants, and/or animals have been cautioned by Azevedo and Stout (1974), Hartmans (1975), Hann et al. (1976), and Cremer (1976). Excessive levels of Cu can be obtained if copper sulfate is included in the pigs' diet. Other environmental disturbances, such as eutrophication of lakes, fish kills (excessive ammonia reduces the availability of O_2 in waters), groundwater and surface water pollution have also been reported in Europe (Tunney,1980). Several studies in the US (Murphy, 1972; Tunney, 1975; Doss et al., 1976) have indicated that manure application rates of 100 ton or more per acre would be likely to result in excessive soluble salt accumulations in soils, and hence increase the potential for either reducing plant growth or polluting the ground waters. Under such conditions it has been estimated that "nitrates may reach ground water 100 feet deep (30.5 m) in 10 to 50 years when 7 to 10 inches (18-25 cm) of water each year leaches through the soil". Toxic Cu and As accumulations may also be a serious concern when excessive poultry manure is applied to soils (Donahue et al.,1977). In addition to these concerns one should also be aware of other potentially harmful effects that could result, such as odors, toxic gases (particularly hydrogen sulfide from slurry), diseases, pathogens,. rainwater/washwater contamination (with manure), etc... (Tunney, 1980).

E2) FACTORS AFFECTING ESSENTIAL NUTRIENT ACCUMULATIONS AND DOWNWARD MOVEMENT IN SOILS

According to Sutton et al. (1986), most of today's growing concerns about applications of organic manures in soils can be attributed to either :

1) Nutrient build-up and potential imbalance in soils, or

2) Nutrient leaching into groundwaters

Given such premises and in view of the objectives discussed earlier, it appears then appropriate to survey the current state of knowledge regarding the circumstances and factors that could result in essential nutrient accumulations and/or movement in soils from some of the already tested agricultural systems today.

NITROGEN (N)

As far as crop uptake is concerned two main forms of nitrogen notably NO_3^- (nitrate) and NH_4^+ (ammonium) occur in soils. Because of electrostatic attraction the ammonium form (NH_4-N) is generally considered to be well retained by soil colloids. Due to its negative charge the nitrate form (NO_3-N) on the other hand cannot be sorbed by the negatively charged soil colloids, and therefore is subject to loss by leaching in the soil. Research studies have shown no leaching problem associated with NH_4-N. When NH_4-N is highly produced, nutrient N can accumulate in exchangeable forms to increase the soil reserves unless nitrified.

Nitrate-nitrogen (NO_3-N) on the other hand has shown, when present in soils in quantities beyond plant requirements, to be easily leached through drainage waters, especially under persistent and prolonged rainfall conditions (Cunnigham et al., 1958). Studies by English workers (Cooke,1981) have shown particularly that :

-Generally more nitrate leaching occurs from arable lands than from grasslands.

-With respect to texture more nitrate losses generally result under sandy soil compared to fine clay soil conditions.

-There may be at least 5 to 10 mg dm^{-3} per year of nitrates lost under control and fertilizer treated plots, respectively.

In the United States a lot of attention has been focused in recent years on problems related to nitrate leaching. Among the american workers, Hoyt et al.(1977) noted in addition to the English results, that discrepancies in N movement could generally be explained by taking into account differences in soil structure, crusting or clogging of pores by manures, permeability to water or increased microbial activity. In California

Devitt et al. (1976) observed that NO_3-N concentrations and movement were dependent on both the water movement and the amount of NO_3^- available for leaching. In comparing inorganic versus organic N sources, Kissel et al. (1974) in Texas interestingly indicated that the leaching of NO_3^--N resulting from mineralization of organic sources may be greater than that from fertilizer when accumulated drainage water is less than 50 mm subsequent to fertilizer applications. Contrary to Kissel et al. (1974), Kimble et al. (1972) reported that more nitrate was lost from N applied as NH_4NO_3 compared to similar applications with dairy manure.

Screiber et al. (1985) considered that differences in the nutrient contents as well as the susceptibility to leaching of given sources appeared to constitute the most important factors contributing to the leaching of nutrients through soils. In regard to rainfall intensity and loading rate, incorporated wheat residue studies by Schreiber (1985) also showed that the amount of nutrients leached through drainage waters appeared to be increased in the order of organic C > P > N.

From their investigations on irrigated Nebraskan soils Muir et al. (1976) observed that the downward movement of N to water table in that region was directly related to the valley position and the location of sandy soils in uplands. Pratt et al. (1977) pointed out that under irrigated systems, soil water transmissivity constituted an important factor in essential nutrient leaching from applied manures. Despite these views, Karlen et al. (1976) in Michigan and Avnimelech et al. (1976) in Israel considered, based on Cl/NO_3^- ratios obtained under irrigated conditions, that much of the unrecovered N was not due to leaching, but rather due to the denitrification process within the top soil layers. Data from California reported by Devitt et al. (1976) suggested, however, that in coarse textured profiles little denitrification occurred. Calvert (1975) found that deeply incorporated limestone had a tendency to increase NO_3^--N discharge into subsoil layers. This may have been related to improvement of soil pH and microorganism activity.

At the University of Illinois Gentzsch et al. (1974) reported that poorly drained soils or soils with natric horizons at shallow depths showed rather low levels of nitrate leaching compared to all other soils. Tyler et al. (1977) indicated on the other hand that the mobile anions such as NO_3^- and Cl^- may be washed into natural soil cracks therefore causing much deeper leaching than what is normally predicted by current displacement theories.

Besides these circumstantial reports, other studies in the USA seemed to have devoted more time to other factors such as the depths at which nitrate ions could be moved. Wallingford et al. (1974) in Kansas found that with beef feedlot lagoon water NO_3-N could be moved to as far down as 100 cm in the lower soil profile only after a 2 year study period. In North Carolina, King et al. (1985) reported likewise on cases where NO_3-N had been leached in to about 300 cm depth in the soil.

From the quantitative stand point, Adriano et al. (1975) estimated after 20 year long term studies with irrigated cannery and milk wastes that the annual subsurface discharge could amount to as much as 65 to 76 of applied N. Various literature reviewed by Cooke (1981) indicated that on an average basis agricultural land losses of N in the USA may be considered to fall somewhere between none and 50 kg / ha per year. Much higher figures in the order of 93 kg / ha of NO_3-N lost annually have been reported, however, by Baker et al. (1975).

In tropical areas not much is known yet in detail regarding the problems of nutrient leaching in agricultural lands. However recent studies by Roose and Talineau (1973) in the Ivory Coast (West Africa) suggest nonetheless somewhat similar risk effects from applied manures. From their studies, these authors revealed that up to 16 kg / ha per year of N would be attributed to losses through drainage waters under fertilized panicum grass. Under stylosanthes and bananas the observed N leaching losses were found to be in the order of 65 kg /ha per year and 55 % of inputed fertilizer N, respectively.

PHOSPHORUS (P)

Phosphorus is taken up by plants as either the $H_2PO_4^-$ or HPO_4^{2-} form depending on the prevailing pH in soil. Factors affecting phosphorus retention or accumulation in soils can be briefly outlined as follows (Tisdale et al., 1985):

Nature and composition of the soil :

-Hydrous metal oxides of Fe and Al : They are most frequent in weathered soils and are capable of fixing large amounts of phosphorus

-Type of clays : Phosphorus is retained to a greater extent by 1:1 clays compared with 2:1 clays.

-SiO_2 / R_2O_3 ratio : Clays with low ratios have a tendency to fix more P than those with higher ratios.

-Clay contents : In general the greater the clay contents the greater the P fixation.

-Amorphous colloids : Fixation of P tends to be greater as the amounts of Al^{3+} contained by these colloids increase.

-Calcium carbonate : Soils with high Ca^{2+} activity are known to result in relatively more P adsorption and /or formation of calcium phosphate precipitates.

Effect of pH :

The optimum pH for P availability in soils ranges between 6.0 and 6.5 . At lower pH values, P is largely retained by Fe, Al, and their hydrous oxides whereas at pH above 7.0 P is normally precipitated by Ca and Mg.

<u>Cation effects</u> :

Divalent cations (e.g. Ca^{2+}) seem to induce more P sorption compared to monovalent cations (e.g. Na^{+}).

<u>Anion effects</u> :

Due to competition for adsorption sites the presence of both organic and inorganic anions can result in relatively less sorption of added P or desorption of retained P. Weakly adsorbed anions (e.g. nitrate, chloride) seem, however, to be less effective in this regard compared to the specifically sorbed ones, such hydroxyl, silicic acid, and molybdate.

<u>Saturation of the sorption complex</u> :

It is normally considered that the higher saturated the sorption complex the lower the P sorption in the soil and vice versa.

<u>R_2O/P_2O_5 ratio</u> : (sesquioxide over available phosphorus, respectively)

The higher this ratio the more P fixation in the soil due to the increased presence of Fe and Al oxides.

<u>Organic matter</u> :

It is generally considered that organic P tends to be more mobile (4 to 6 times) than inorganic P. The presence of organic matter therefore can result in more P leaching in soils.

Temperature :

High temperatures are known to increase P fixation in soils. However, it is also considered that the mineralization of organic phosphorus, which leads to the release of more mobile P, tends to be induced as well with increased temperatures.

Time of reaction :

Two distinct patterns are normally obtained. First, an initial rapid reaction where P is exchanged for anions and the ligands of metal atoms on the surface of Fe and Al oxides. Second, a slower reaction whereby the loosely held P at colloid surfaces changes to become more tightly bound and less available.

Placement of fertilizer :

Studies have shown that for water soluble P band placement appears to result in less P fixation compared to broadcast application. With water insoluble P, such as rock phosphate broadcasting and mixing in soils tends to result in higher P availability than does band placement. It is fairly well established that only small amounts of P can be moved downward in as much as soil solution contain very low concentrations of phosphate. Notwithstanding, work in England has shown that substantial fertilizer P can be leached into the subsoil layers, especially in soils where the organic matter contents had been increased from either continued farm yard manure applications or permanent pastures. In comparing farm yard manure with inorganic P, it was observed that twice as much P had moved down to 50-60 cm from farm yard manure than from fertilizer P, and with even much greater leaching when P was supplied by both materials together (Cooke, 1981). Under acid sandy soils the same studies contended furthermore to have obtained significantly higher P leaching from the soluble superphosphate compared to water insoluble P sources, such as basic slag and rock phosphate.

Literature reviewed seems to provide only very small values for P losses in drainage waters ranging somewhere between 0.00 and 0.80 mg /dm^3 per year (Cooke, 1981). In the United States, similar studies confirmed the fact that phosphorus could be more leachable in organic soils. However, with all things equal the extent of P leaching seemed to depend, in general, on soil sesquioxide content (Larsen et al.,1958) amount of adsorbed cations (especially Al), and the pH (Fox et al., 1971). According to other studies notably from Dalton et al. (1952) the movement of P along a given soil profile could also be related to other factors, such as application rate of P, type wastes, and nature of P bonding with soil colloids. Reddy et al. (1983) considered that in poorly drained and flooded soils more rapid P movement and hence leaching could result via diffusion and mass flow than otherwise. In highly concentrated solutions they observed in addition that there was much faster P movement under oxidized that reduced conditions.

Calvert (1975) reported on the other hand that deep incorporation of limestone in subsoil appeared to decrease P discharge in those soils. Contrary to the results of Dalton et al. (1952), Reddy et al. (1980) in North Carolina contended that increased rates of beef, dairy, swine, or poultry manures seemed to have resulted in more accumulations rather than leaching for P in both acid and alkaline soils. Similar studies by Sommerfeldt et al. (1973) in Canada (Alberta) also confirmed P build-up in soils, but without any harmful effects.

After applying beef feedlot effluent at 5 cm /week for 2 years, Sukovaty et al. (1974) in Nebraska reported to have obtained a significant P increase in the top 10 cm of the treated soil profiles from 52 to 118 ppm. Sawhney (1977) suggested that excessive leaching of P into groundwaters could likely result during prolonged P applications in those soils with relatively low sorptivity.

From their extensive studies on various crop management systems in Nebraska, Muir et al. (1976) concluded that under non irrigated conditions the chances of P movement into lower soil zones seemed to be rather low. This was apparently in agreement with work by Baker et al. (1975) who likewise reported that in their studies tile drainage losses for P were insignificant compared to those observed in run-off.

In comparison with other essential nutrients, Lund et al. (1980) found the downward movement of P from dairy manure to be among the least. Wallingford et al. (1975) similarly confirmed that with beef feedlot manure the downward movement of P was mostly restricted to the top 30 cm under silty clay loam conditions. With swine effluent King et al. (1985) contended to have obtained evidence of P movement down to 60 cm of soil profile. Long term studies by Adriano et al. (1975) suggest on the other hand that the annual P discharge through drainage waters from cannery and milk wastes could amount to as much as 2 to 27 % of the inputs in the soil, respectively. Overall, the potential for downward movement of P in cultivated soils appears not to be significantly important although research suggests that additions of organic materials could contribute to relatively greater P leaching compared to applications of inorganic fertilizer P.

POTASSIUM (K)

The bioavailable form of potassium in soils is considered to be ion K^+. The factors affecting K availability and movement in the soil can be summarized as follows (Tisdale et al.,1985) :

<u>Kinds of clay minerals</u> :

Clays with high K contents (e.g. vermiculite or montmorillonite) tend to have a greater availability potential than those with lower K contents (e.g. Kaolinite). Fixation/entrapment of K is considered on the other hand to be increased with the amounts of illite type clays present in the soil.

<u>Cation Exchange Capacity (CEC)</u> :

Generally the higher the CEC the more K that is retained, although it may not be always available. In Ohio for instance, sufficiency exchangeable K (SEP) for corn has been related to the CEC as follows : SEP (Sufficiency Exchangeable K in pp2m or lb /acre) = 220 + (5 x CEC). From this relationship it can be clearly observed that soils with higher CEC would be likely to supply more K for plants than those with lower CEC.

<u>Amounts of exchangeable K</u> :

The availability of K in soils tends to be related with K soil test levels which usually represent the amounts of K subject to exchange for NH_4^+.

<u>Capacity to fix potassium</u> :

Fine textured soils tend to result in higher K fixation compared to sandy soils. Studies in Illinois suggested that it would take up about 4 lb/acre of added K before the level of exchangeable K is increased one pound per acre (Tisdale et al., 1985).

Subsoil K and rooting depth :

In Montana it has been reported that crop rooting depth and response to fertilizer K were found to be related to some extent with the amount of available K present in the subsoil zones.

Soil moisture :

K diffusion (availability) is considered to be increased with soil moisture contents, if not excessive however.

Soil aeration :

Excessive moisture and poor aeration conditions are generally considered to have reducing effects on the availability of K in soils.

Soil temperature :

Research studies at Purdue University by Barber et al. (1984) demonstrated that the optimum temperatures for K availability to plants occurred at soil temperatures in the range of 15 to 29 C.

Soil pH or reaction :

Liming acid soils appears to free up blocked binding sites (i.e. held by Al^{3+} and hydroxy aluminum cations) thus contributing to induce more K retention by soil colloids. Raising soil pH from 5.5 to 7.0 was found to bring about the collapse of expanded silicate clay layers (via conversion of Al $(OH)_3$) therefore resulting in the transient entrapment of K^+ by clays (Tisdale et al., 1985). Liming soils with a pH already in the range of 6.0 to 7.5 was found to have an adverse effect on both the exchangeable and water soluble K^+. Overall liming acid soils contributes to significantly reducing the amount of available K susceptible to being leached through the soil. It is worth noting though that the presence of high levels of KCl in acid soils was suspected to produce phytotoxic accumulations of certain elements, such as Al and Mn.

Calcium and Magnesium :

Based on the activity ratio concept, it has been demonstrated that the availability of K in the soil tends to be more dependent on its concentration relative to that of calcium and magnesium than on the total amount of K present. Soils that test high in either calcium or magnesium (or both) are usually considered to result in less available K.

Tillage :

According to various research studies it appears that available K under reduced tillage systems tends to be lower compared to that found under the conventional tillage systems.

Placement of fertilizer :

In soils rich in high fixing clays (i.e. 2:1 types) it is generally recognized that more K availability occurs with band placement than with broadcasting. The same seems to be equally true for those soils that are characterized by relatively low initial K contents. For soils testing high in available K, it is considered that using either placement method would not make much of a difference in terms of available K.

Studies in England (Cooke, 1981) indicated that adding soluble anions, such as nitrate, chloride, or sulfate as soluble fertilizers appeared to increase the downward movement of K^+ in the soil. The leaching effects were most pronounced in sandy soils and in those composed mainly of 1:1 type clay minerals. Similar studies reported by Cooke (1981) indicated that applying farm yard manure at 75 mt /ha for 19 years resulted in the downward movement of K. At the 62 cm depth the K concentration was nearly as high as what was obtained in the topsoil. In comparing farm yard manure and inorganic fertilizer applied for 50 years research studies at Broadbalk found that the downward movement of K had reached the 45-70 cm zone of the soil profile. English studies have suggested about 2 kg K /ha per year as the average K loss although losses amounting to as much as 70 % of input K have been obtained with sandy podzol soils. Studies in New Zealand were for the most part in good agreement with the English results (Cooke, 1981). Under tropical conditions Boyer (1973) inferred also that K leaching losses could be significantly large in soils which have low CEC values. In the Ivory Coast a comparative study with the forage crops, panicum maximum, and stylosanthes guynensis, indicated only small losses of K through leaching due to the fact that the plants in question were removing almost all the applied K. Other tropical studies suggested that important K losses could result as well under the paddy rice soil conditions (Cooke, 1981).

In the United States, various studies summarized by Munson and Nelson (1963) reached essentially the same conclusions as those already discussed above. The only differentiating note that is worth reporting pertained to the somewhat contradictory role of liming acid soils. While in some cases liming was found to be beneficial in reducing K leaching losses there was also evidence in some other instances that the liming of acid soils may have contributed to the increased K losses with drainage waters. Recent studies in Arizona by Amoozegar-Fard et al. (1980) indicated that even under intensive feedlot applications (i.e. in the order of 100 Mg /ha), the resulting downward movement of Na and K would be somewhat delayed, since they can substitute for Ca and Mg on the exchange sites. From their studies with broiler litter in Georgia, Jackson et al. (1975) contended that K and Mg appeared to be more completely leached (in proportions of 99 and 88 %, respectively) in the soil compared to the calcium. In a four year study in California, Pratt et al. (1977) concluded that the percent leaching of cations such as Ca, Mg, and K tended to decrease proportionally with increased rates of applied manures. Reddy et al. (1983) suggested that the release of large amounts of Fe^{2+}, Mn^{2+}, and NH_4^+ under reduced conditions could lead to more K leaching via displacement from the exchange sites. This could be important in flooded soils and /or low in O_2. Wallingford et al. (1975) pointed out that the downward movement of K and P from beef feedlot treatments appeared to be restricted only to the top 50 and 30 cm of corresponding soil profiles, respectively. In Nebraska, Sukovaty et al. (1974) seemed to confirm such a view since they obtained only small increases in Ca, K, and Na 60 cm below the soil surface. Based on field studies Pratt et al. (1977) in California were of the opinion that there is practically no significant downward movement of K beyond 1.5 m, i.e. beyond the lower limits of plant rooting zone.

Information on the amount of K leached seemed to be rather scant and variable in the literature. Data reported by Tisdale et al. (1985) estimates that K leaching losses could range from as little as 1.4 to as much as 126 lb per year, under silt loam and coarse sandy soil conditions, respectively.

CALCIUM (Ca)

Factors of greatest importance in determining the bioavailability of calcium in soils are generally considered to be as follows (Tisdale et al., 1985) :

Total calcium supply : It is normally considered to be very low under sandy soils and those with low CEC.

Soil pH : High H^+ activity are known to reduce the Ca bioavailability in soils.

CEC : The higher the CEC, the better the Ca availability.

Percent calcium saturation of soil colloids : High saturation entails more favorable pH for Ca availability in soils and vice versa.

Type of soil colloids : The 2:1 clays require a high degree of saturation (70 % or more) while with 1:1 clays usually less than 40-50 % is satisfactory. As a result more calcium would likely be available in the soils with relatively higher 2:1 clay contents.

Ratio of calcium to other cations in soil solution :

Tisdale et al. (1985) indicated that the optimum ratios for calcium /total cations (Ca + Mg + K) usually range from 0.10 to 0.15; 0.10 to 0.20; and 0.16 to 0.20 for cotton, soybean, and tomato, respectively.

With respect to leaching losses, British studies reported by Cooke (1981) indicated that ammonium salts, such as ammonium sulfate resulted in relatively increased

Ca leaching in soils via the displacement process. Significant Ca losses were also reported under soils that were very acid, sandy, or rich in $CaCO3$. According to some estimates annual Ca losses from British croplands could amount to as much as 60 kg / ha and 300 kg / ha in very acid sandy and calcareous soils, respectively. In tropical climates, not much information seems to exist regarding this problem of Ca leaching in soils (Cooke, 1981). In the USA, however, various studies performed have suggested that Ca could be the most dominant cation that is annually carried in the drainage waters, springs, streams, and lakes (Tisdale et al., 1985). Reddy and Patrick (1983) reported that the increased mobility of Ca and Mg in soils was in most part related to their displacement by Fe^{2+} and Mn^{2+}, or due to dissolution of $CaCO_3$, especially under poorly drained, flooded, alkaline, low O_2, and/or high CO_2 soil conditions. In California, Pratt et al. (1977) indicated from their manure studies that while they observed substantial losses for Na it appeared as though the downward movement for Ca and K had been rather restricted within the top soil zones. In Arizona, Amoozegar-Fard et al. (1980) predicted relatively high leaching losses for Ca and Mg, given their potential displacement from the exchange sites by Na and K ions. According to Tisdale et al. (1985) current estimates for Ca leaching losses in the USA are considered to be somewhere between 75 and 200 lb /acre per year.

MAGNESIUM (Mg)

General factors regarding Mg availability and/or mobility in soils are considered to be as follows (Tisdale et al., 1985) :

Amount present : Soils are normally considered to be deficient when they have less than 25-50 ppm of exchangeable Mg.

Soil pH : Acid soil conditions (especially when Al saturation is between 65 and 70 %) are known to be antagonistic to Mg availability in soils. Reduced Mg availability due to fixation by soluble silica/aluminum chlorite or co-precipitation with $Al(OH)_3$ has also been reported in Georgia for soils that were treated with additions of magnesium liming materials (Sumner et al., 1978).

Degree of saturation : Mg availability seems to be seriously affected when its saturation in the soil complex measures up to less than 10 % (Tisdale et al., 1985). However, research by Schickluna (1961) showed that in Michigan a percentage of 3 % was adequate.

Presence of other ions : The presence of high calcium, indicating Ca / Mg ratios in the order of 7:1, is considered to be depressive on the availability of Mg in soils (Tisdale et al., 1985). Similar effects are also obtained when high to very high levels of K^+ and NH_4^+ prevail in soils. Mg deficiency can produce grass tetany disease for the ruminants. On an equivalent weight basis, it is generally recommended to maintain in the soil K /Mg ratios of about 1.5 : 1; 1.0 :1; and 0.6 : 1 for the field crops, vegetables /sugar beets, and fruit /greenhousecrops, respectively (Tisdale et al., 1985).

Type of clays : There is usually more Mg retention in soil by the 2:1 compared to the 1:1 clay types.

With respect to leaching losses, literature reviewed (Sukovaty et al., 1974; Wallingford et al., 1974; Jackson et al., 1975; Pratt et al., 1977) suggests an apparent similarity with calcium and to some extent with potassium as well. For supplementary information, the reader therefore is referred to the preceding sections on Ca and K, respectively.

Research studies in England indicated that adding soluble salts, such as superphosphate, potassium sulfate, or potassium chloride to soils appeared to significantly increase Mg losses through the drainage waters. In New Zealand, it was observed that higher Mg leaching was obtained in soils treated with KCl instead of potassium sulfate (Cooke, 1981). Under tropical climates most of the Mg losses recorded seemed to usually be associated with the low cation exchange capacity of the soils. In the USA, various studies performed have resulted in similar conclusions as those obtained in New Zealand. It is worth noting though that not much of the applied Mg could be displaced when equivalent amounts of potassium were applied as carbonate, bicarbonate, or phosphate.

In terms of quantitative figures, the following estimates in Mg leaching losses have been reported in various parts of the world :

-England : 2 to 33 kg /ha per year (Cooke, 1981)

-Swedden : 2 to 56 kg /ha per year (ibid)

-USA : 450 kg /ha (unfertilized plots) to 2000 kg /ha (fertilized plots) for irrigated citrus orchard (Pratt and Harding, 1957); 5 to 60 lb/acre per year under general soil conditions (Tisdale et al., 1985)

SODIUM (Na)

Except for halophytic species most field crops do not require Na as an essential component in their growth process (Tisdale et al., 1985). In semi-arid and arid regions it is even a common practice to leach out most of the topsoil Na because of its adverse effects on plants and soils (phytotoxicity and dispersion of soil aggregates). The leaching of Na in general does not appear to constitute a major problem in agricultural soils. Literature reviewed by Cooke (1981) estimated that English soils may be losing up to as much as 32 kg/ha of Na per year. (N.B. : for supplementary information on this element, please refer to preceding sections).

SULFUR (S)

The common factors relating to sulfur transformations in the soil as a result of applied animal/plant residues can be characterized as follows (cf. Tisdale et al., 1985; pp. 310-316) :

Mineral content of organic matter : Generally the mineralization of sulfur occurs in the soil when C/S weight ratios of applied materials are in the range of about 200 : 1. Beyond this range and particularly at C/S ratios greater than 400 : 1 there seems to be in contrast more sulfur immobilization than release into mineral forms.

Temperature : Studies from Australia appear to suggest that sulfur mineralization would increase with soil temperatures between 20 and 40 C.

Moisture : Sulfur mineralization seems to be most activated at soil moisture contents of 60 % field capacity.

Wetting and drying : Alternate wetting and drying is considered to result in increased sulfur mineralization and availability in soils.

Soil pH : Even though the effect due to the pH factor is not quite clear yet, there are some reports suggesting that nearly neutral pH conditions would be most appropriate, especially with respect to microbial activity.

Presence or absence of plants : According to some studies twice as much sulfur mineralization seems to occur when soils are cropped than when fallowed.

Time and cultivation : Generally during the mineralization process the rate of release of sulfur would first increase then decrease over time until equilibrium is reached.

Mineralization patterns : Four major patterns have been recognized as follows : 1) immobilization during initial stages, then followed by mineralization; 2) steady mineralization throughout incubation period; 3) rapid release followed by slower linear release; 4) gradually decreased mineralization rate with time.

Sulfatase activity : The major role of this enzyme is to induce the hydrolyzing process of esters that would eventually release the inorganic sulphate.

Source of mineralizable sulfur : Generally most of the available sulfur is derived from the ester sulfate fractions under field conditions. However, experience shows that these ester fractions would be lower in cultivated soils compared to pastures. Literature reviewed by Cooke (1981) suggested that average sulfur losses would account for as much as 15, 33, 4.5, and 1 kg /ha per year in Europe, North America, and southern hemisphere, respectively.

<u>CHLORINE (Cl)</u> :

Most Cl occurs in soils as Cl^- derived from soluble salts, such as NaCl, $CaCl_2$, $MgCl_2$, etc... According to Tisdale et al. (1985) the relative concentrations of this element in soil solution varies greatly from about 0.5 to 6000 ppm. In Wisconsin, Endelman (1974) found in Plainfield loamy sands that there were many similarities between the compared downward movement of Cl^- and NO_3^- ions, respectively. Jackson et al. (1977) reported after a 2 year study that Cl ions could move as far down as 107 cm in a soil profile, and even deeper if relatively high Cl rates were applied. Cooke (1981) in reviewing this subject concluded that unless taken up by crops most of the applied Cl in soils will be leached away by the percolating waters.

<u>IRON (Fe) AND MANGANESE (Mn)</u> :

According to Tisdale et al. (1985), the major factors influencing the availabilty and/or movement of these two elements in the soil would include among other things the following :

<u>Ion imbalance</u> : The availability of Mn in the soil is generally considered to be affected by imbalances with Cu, Fe, or Zn whereas the availability of Fe seems to be

affected mostly by imbalances with either Cu or Mn.

Soil pH : Iron is considered to be the least soluble when soil pH is between 7.4 and 8.5. For Mn, the minimum solubility occurs at pH above 7. The highest solubility for these two elements normally occurs under very acid conditions, i.e. around pH 3 or so. Under such acidic conditions the concentrations of these elements may be too high for most crop production.

Carbonates and bicarbonates : Soils rich in carbonates or bicarbonates tend to be characterized by high pH that could range from about 7.3 to 8.3. Therefore the presence of carbonates/bicarbonates can be considered to produce an adverse effect on the solubility and/or movement of Fe and Mn in the soil.

Excessive water and poor aeration : Under flooding and/or poorly drained soil conditions both Fe and Mn are normally reduced therefore contributing to release relatively high soluble forms of these elements as Fe^{2+} and Mn^{2+}, respectively.

Organic matter : Due to their chelating properties and beneficial effects on soil structure most organic materials are considered to increase the solubility of both Fe and Mn. In some cases it has been reported that low availability could result as well due to the formation of insoluble organic complexes.

Interrelationships with other elements : Reduced availability for these elements has been related to the following soil conditions. High levels of P, Mo, or NO_3^- appear to be antagonistic to Fe availability, while imbalances due to the presence of high levels of P seem to affect in some cases the availability of Mn in soils. Neutral potassium salts have been considered on the other hand to increase extractable Mn in soils as follows : KBr > KNO_3 > K_2SO_4.

Climatic effects : Wet winter weather conditions seem to be conducive to higher Mn solubility (Mn^{2+}) compared to warm dry summer conditions where the formation of oxidized /less soluble forms of Mn result. Similar effects would probably be obtained with Fe as well.

Soil microorganisms : Certain bacteria and fungi have been reported capable of reducing Mn availability in the soil via the oxidative conversion Mn^{2+} / Mn^{4+}. Reddy et al. (1983) pointed out that the mobility of Fe and Mn could be mostly related to the intensity of anaerobiosis obtained in each soil environment. Field applications of high O_2 demanding (also known as high BOD) wastes may be considered to have a conducive effect on the availability/mobility of these nutrients in the soil. Under these anaerobic conditions Reddy et al. (1983) suggested that Mn which is relatively more soluble could be leached first. In comparing the oxidized versus the reduced forms Ellis et al. (1970) found reduced Fe^{2+} form (soluble) to be about 5 times faster in diffusion with montmorillonite than the oxidized Fe^{3+} form. This leads to the conclusion that the leaching of essential nutrients Fe and Mn in soils would appear rather unlikely to occur unless they are converted first into their reduced Fe^{2+} and Mn^{2+} forms, respectively.

ZINC (Zn) :

Factors affecting the availability and/or movement of Zn in soils can be summarized as follows (Tisdale et al., 1985) :

Soil pH : Calcareous soils and those with pH from 6.0 to 8.0 tend to significantly reduce the availability and mobility of Zn in soils. In general the higher the pH the greater the adsorption and vice versa. Such adsorption is normally considered to increase in the soil with the amounts of carbonates present as follows : calcite ($CaCO_3$) < dolomite [Ca Mg $(CO_3)_2$] < magnesite Mg (CO_3).

Complexing by soil organic matter : Three types of reactions are generally observed : 1) immobilization by high molecular organic substances; 2) solubilization and mobilization by short chain organic acids and bases; and 3) complexation by organic compounds (such a reaction which basically entails a solubilization of Zn via the chelation process may be induced by the presence of fresh organic materials).

Interactions with other nutrients : High P or the presence of basic or neutral N fertilizers are known to have a net depressing effect on the Zn solubility and mobility in the soil. The presence of SO_4^{2-}, complex $ZnSO_4^{o}$, as well as acid N fertilizers are considered on the other hand to increase the Zn availability and mobility in soils. The production of sulfides (H_2S) has been related to some extent to observed Zn deficiencies during anaerobic flooding conditions.

Climate : Warm temperatures appear to normally be conducive for higher Zn availability than cool climatic conditions.

Literature reviewed suggests that excessive Zn accumulation and leaching are not likely to result in soils that are normally treated with crop residues and/or animal manures because of their relatively low concentrations in heavy metals. Such problems would seem more likely in instances where industrial sewages and related by-products are applied. Typical sewage compositions (in ppm) reported by Page (1974) read as follows : Cu (500), Zn (2000), Cd (10), Pb (500), and Ni (50). Studies with sewage sludge by Boswell (1975) in Georgia indicated that there was not much movement for Zn beyond the 30 cm zone in the soil profile. Tisdale et al. (1985) were of the same opinion that Zn is a relatively immobile element in most soils. Giordano et al. (1976)

pointed out that the heavy metals from organic sewage were relatively less mobile in the soil compared to similar treatments from inorganic sources. While Sidle et al. (1977) considered the mobility of Zn in the soil to be rather intermediate between that for Cd and Cu (i.e. Cd > Zn > Cu), Hinesly et al. (1977) estimated that in a soil receiving annual applications of sludge there may be up to 50 per cent Zn and Cd that could move down below the 15 cm zone in the soil profile. Under disposal ponds Lund et al. (1977) reported having obtained some heavy metal enrichment to depths as low as 300 cm in the considered soil profiles. Warncke et al. (1972) suggested that Zn mobility in the soil may be to some extent related to corresponding changes in the volumetric water contents. Ellis et al. (1983) concluded that despite its relative mobility Zn leaching in most soils would be rather unlikely unless the application rates are greater than 150 kg Zn per ha.

COPPER (Cu) :

Factors that are of importance for the availability and/or movement of Cu in soils are as follows (Tisdale et al., 1985) :

Texture : There seems to be more Cu leaching under leached podzol and calcareous sands than in finer textured soils.

Soil pH : The adsorption or retention of Cu in the soil is increased directly with pH.

Incorporation of crop residues : Adverse effects on Cu availability and mobility may result from the application of haystack or brassica residues in the soil (Tisdale et al., 1985).

Ellis et al. (1983) contended that, except for sandy soils excessive Cu leaching would be rather unlikely given the nature of its strong bonding with the organic fraction of soil complex.

MOLYBDENUM (Mo) :

Factors that affect Mo availability and/or movement in soils can be briefly characterized as follows (Tisdale et al., 1985) :

Soil pH and liming : Liming and high pH conditions are considered to significantly increase the availability of Mo in soils whereas low pH or acid conditions tend reduce it.

Reaction with Fe and Al oxides : The presence of these oxides generally results in strong Mo adsorption contributing to reduce both its availability and mobility in soils.

Interrelationships with other elements : Mo availability is normally improved by the presence of high levels P and/or NO_3-N whereas the presence of high levels sulfates or Cu seems on the other to be antagonistic.

Environmental effects : High temperatures, especially in the range between 26 and 65 C are generally considered to be favorable for Mo availability in soils. With dry climatic conditions the effects seem to be reversed.

Literature reviewed by Ellis et al. (1983) pointed out that there is currently little information regarding Mo leaching in soils. These authors considered that Mo leaching would be mostly important under calcareous soil conditions where the nature of its bonding to colloids appears to be relatively weaker compared to acid soils.

BORON (B) :

General factors relating to B availability and/or movement in soils are essentially as follows (Tisdale et al., 1985) :

Soil texture : Low organic matter, coarse texture, and well drained conditions are generally considered to increase the mobility and leaching of B in the soil whereas fine textured soils with relatively high organic matter contents tend to increase the adsorption process.

Amount and type of clays : The adsorption of B in the soil is considered to increase respectively with clay types as follows : micaceous clays (illite) > montmorillonite > kaolinite.

Soil pH and liming : Boron availability and mobility is normally reduced by liming, especially at pH values greater than 6.3 to 6.5. Similar effects may also be obtained by the presence of freshly precipitated Al $(OH)_3$ and $Fe(OH)_3$ at pH 7 and pH 8-9, respectively.

Interrelationships with other elements : Free Ca tends to significantly restrict the availability of B to plants. Similar effects have also been reported from imbalances due to high level N in the soil. The effects of K seem to vary with crops. In some cases B deficiencies may result (alfalfa) whereas in some other instances highly toxic levels of B are likely to occur (tomato).

Soil moisture : Dry climatic conditions are generally considered to be more restrictive on B availability and mobility in the soil compared to humid conditions.

Ellis and Knezek (1972) pointed out that in soils rich in Fe and Al oxides the adsorption of B appeared to be relatively stronger than for the other anions, such as Cl^- and NO_3^-.

F) RECOMMENDED RATES AND MANAGEMENT ALTERNATIVES

Murphy et al. (1972) observed that the applications of animal manures or other wastes to land at rates equal or above 100 Mg/ha tend to be environmentally incompatible. With corn silage Mathers et al. (1984) found the annual application of 224 metric ton/ha of cattle manure resulted in detrimental effects, such as reduced yields and nitrate and salt accumulations in soils. Given these results, the authors suggested that 22 Mg/ha per year would have been in this instance appropriate. On silty clay loam soils, Wallingford et al. (1975) considered the yearly application of 29 to 68 Mg /ha of dry matter beef feedlot manure to be beneficial since it contributed to producing nearly maximum forage corn yields without showing any adverse effects from salts. Lund et al. (1975) suggested that optimum application rates for dairy cattle manure may be in the range of 45 to 90 Mg/ha per year when coastal bermudagrass is grown. Jackson et al. (1977) reported that the semi-annual application of 22.4 Mg/ha of poultry manure on tall fescue appeared rather to be excessive in terms of N losses in soils. These results as well as those discussed earlier suggest that optimum rates for manure applications on croplands need to be established not only with respect to soil characteristics, but with regard to the types of crops, varieties and management systems. With respect to the latter Pratt et al. (1977) indicated that organic manures should not be applied without due consideration for the water percolation rates in relation to given irrigation systems in the soil. Tunney (1980), and Donahue et al. (1977) proposed the following set of important guidelines :

-Season : Spring application is considered to be the most appropriate time for best manure results on both plant growth and soil properties (Tunney, 1980).

-Nutrient balance : In order to avoid excessive nutrient accumulations in the soil, Tunney et al. (1980) recommended to apply manure at rates that would produce a balance between nutrient losses and soil buffering capacity. He also suggested that pig manure slurry be applied at rates that would supply adequate phosphorus while complementary fertilizer nitrogen and potassium are added, respectively. Cattle manure slurry application rates need to be adjusted so that adequate potassium is supplied to crops which may be supplemented with fertilizer nitrogen and phosphorus.

Literature surveyed suggests overall not to apply for most crops more than 40 to 50 Mg /ha per year of a good manure slurry. Generally, split applications with at least 30 days between consecutive applications were found to produce better effects on plants compared to single applications at once. On grassland, up to 45 Mg/ha of cattle or pig manure slurry may be applied if at least 4 weeks are allowed before grazing (Tunney, 1980). For high value crops on irrigated land Donahue et al. (1977) considered it appropriate to apply anywhere from 33.6 to 56 Mg manure/ha/year, but only 20 % of these amounts for non-irrigated and dry land conditions.

LITERATURE REVIEW PART II : MAJOR CHARACTERISTICS OF PLANT RESIDUES AND GREEN MANURES

A) HISTORICAL OVERVIEW

The use of green manures and plant residues in agricultural production appears to be an age-old practice that goes back to the early days of the world civilization. A glance at some ancient records reveals the following pertinent evidence :

-Xenophon around 400 B.C. indicated that grass was plowed under during Spring season to render soil more friable (Tisdale et al., 1956).

-Cato who lived between 234 and 149 B.C. reported a great deal on the soil ameliorating value of many legume crops, such as acinum (i.e. bean crop), field bean, lupine, vetch, etc...(ibid).

-Columella (ca. 60)and Virgil (70-19 B.C.) not only confirmed previous findings about the agricultural role of legume crops, but even went further to advocate their extensive use as a means to restoring soil fertility (ibid).

-Varahamihira (500 A.D.) observed that the incorporation of of sesanum crop in Asian soils goes back to as early as 500 B.C. (Singh, 1980).

As the evidence shows, green manures and plant residues along with animal manures an essential role in the process of world food production throughout recorded history (Singh, 1975).

With the discovery of guano deposits and saltpeter (i.e. KNO_3 or $NaNO_3$) during the middle ages followed by the rapid development of manufactured fertilizers after world war II, the agricultural role of those traditionally valued manures shifted from essential to a rather secondary and marginal role. Despite such a depreciation, it seems that the agricultural role of green manures and plant residues may be on the verge of regaining some momentum.

Higher fertilizer prices due to recent fuel shortages coupled with current environmental concerns about waste disposal hazards (Singh, 1975) appear to have indeed prompted the increasing revival of interest for organic manures in the world agricultural production.

B) COMPOSITION

Typical composition of green manures and plant residues collected under both temperate and tropic climatic conditions are presented in the following tables :

Table VIII. Characteristics of some green manures.

Item	Green Matter	Moisture	N Content
CULTIVATED ANNUAL LEGUMES	mt/ha	(%)	(% dry wt)
Astragalus, sinicus	15.0	89	3.15
Cassia, mimosoides	4.7	74	2.99
Crotalaria, juncea	16.5	73	3.01
Cyamopsis, tetragonoloba	7.0	60	3.53
Indigofera, anil	6.8	74	3.66
Sesbania aculeata	14.8	78	2.43
S. speciosa	7.8	78	2.43
Vigna unguiculata	10.0	85	2.63
V. radiata var aureus	7.7	82	2.96
V. trilobus	5.3	79	2.47
PERENNIAL LEGUMES			
Cassia hirsuta	5.0	81	2.52
Desmodium gyroides	1.4	72	3.35
Gliricidia maculata	3.0	75	3.36
Sesbania punctata	3.7	73	2.42
Tephrosia candida	2.3	67	3.20
WILD ANNUAL LEGUMES			
Aeschynomene americana	8.9	78	3.14
Calopogonium mucunoides	4.5	74	3.02
Cassia tora	5.2	71	2.13
Cassia occidentallis	4.3	78	2.80
Lathyrus sativus	-	82	4.60
Tephrosia purpurea	3.5	70	3.46

Source : Singh, 1983

Table IX. Chemical analysis of common green manures used in Sri Lanka (S.E. Asia).

Sinha Name	Botanical Name	N	P	K	C/N
TREES WHOSE LEAVES ONLY ARE USED		----------	%	----------	
Tamarind	Taminrindus indica	1.59	0.19	1.19	27
Margosa	Azadirachta indica	2.38	0.20	1.30	20
Dadap	Erythrina lithosperma	4.00	2.29	3.95	14
Madera	Gliricidia maculata	4.15	0.27	3.00	12
Kaduru	Cerebera adoliam	2.31	0.10	1.80	22
Taikekuna	Aleurites triloba	2.34	0.17	2.65	19
Palmyra	Bossarus flabellifera L.	1.62	0.10	1.07	32
PLANTS WHOSE LEAVES AND STEMS ARE USED					
Pita	Tephrosia purpurea	3.73	0.28	1.78	11
Penitora	Cassia occidentalis	4.91	0.20	1.87	12
Suriya	Thespesia populnea	3.43	0.25	3.30	14
Wild sunflower	Thithonia diversifolia	3.83	0.29	5.90	14
Wara	Calotropis gigante (L)	3.86	0.30	3.45	11
Keppitiya	Croton aromaticus	3.50	0.30	2.15	15

Source : Nagajarah, S. and Amarasiri, S.L. (1977), "Use of organic materials as fertilizers for lowland rice in Sri Lanka", Soil Organic Matter Studies, Vol. K.IAEA, Vienna. As reported in Weerakoon (1983).

Table X. Estimates of nitrogen fixation by tropical legumes in field experiments.

CROP	RANGE (kg/ha)	No. of Estimates
Glycine max	64-206	3
Vigna unguiculata	73-240	3
Arachis hypogaea	61-342	2
Cajanus cajan	72-240	3
Cicer arietenum (chickpea)	96-280	3
Canavalia ensiformis	103	1
Cyamopsis tetragonolobus (guar)	49	1
Lens culinaris (lentil)	41-220	2
Pisum sativum	88-114	1
Vicia faba	52-77	1
Caloponium mucunoides	45-552	4

Source : Ayanaba (1980) and Nutman (1976).

Table XI. Mean nutrient concentrations of crop residues.

Crop and Plant Parts	N	P	K	Ca	Mg	S
	-------	-------	%	-------	-------	-------
Millet-stover	.65	.09	1.82	.35	.23	.15
Sorghum-stover	.58	.10	1.51	.21	.13	.10
Maize-stover	.70	.14	1.43	.36	.11	.12
Wheat-straw	.62	.12	1.72	.27	.15	.12
Rice-straw	.58	.13	1.33	.20	.11	-
Groundnut leaves	2.56	.17	2.11	1.98	.68	-
Groundnut stems	1.17	.14	2.20	.92	.50	-
Groundnut haulms	1.18	.07	1.28	.65	.34	-
Groundnut shells	1.40	.21	1.80	.90	.50	.18
Cowpea leaves	1.00	.06	.90	.25	.10	.10
Cowpea stems	1.99	.19	2.20	3.16	.46	-
Cowpea roots	1.07	.14	2.54	0.69	.25	-
Cotton stalks and leaves	1.33	.27	2.35	1.27	.25	-

Source : Balasubramanian et al., 1980

Table XII. Approximate organic carbon and total nitrogen contents and C:N ratio of common organic materials and soil microbes and humus on/in arable soils (dry weight basis).

Organic Material	Organic Carbon	Total N	C:N Ratio
CROP RESIDUES	(%)	(%)	
Alfalfa (young)	40	3	13 : 1
Clovers (mature)	40	2	20 : 1
Bluegrass	40	1.3	30 : 1
Corn stalks	40	1	40 : 1
Straw, small grain	40	0.5	80 : 1
Alfalfa hay	43	2.40	18 : 1
Grass clippings, fresh	43	2.20	20 : 1
Leaves, freshly fallen	20-80	0.5-1.0	40 : 1-80 : 1
Moss peat	48	0.83	58 : 1
Corn cobs	47	0.45	104 : 1
Wheat straws	45	0.12	375 : 1
SOIL MICROBES			
Bacteria	50	10	5 : 1
Actinomycetes	50	8.5	6 : 1
Fungi	50	5	10 : 1
SOIL HUMUS	2	0.2	10 : 1

Source : Follett et al., 1981.

C) DECOMPOSITION FACTORS

Plant nutrients contained in the organic residues are released into soil systems via the decomposition or mineralization process. Such a process is known to be affected or controlled by the following set of factors or conditions.

1) Carbon:Nitrogen (C:N) Ratio

In general, the mineralization process which leads to the release of inorganic nutrients occurs readily in soils when organic residues have a C:N ratio less than 20 : 1 or if their total N content is greater than 1.8 per cent (Jenkinson, 1981; Parr, 1975; Tisdale et al., 1985; Singer et al., 1987). Organic materials with higher C:N ratios (especially in the order of 30 : 1 or above, or by a total N content lower or equal to 1.2 to 1.3 per cent) are known on the other hand to result in serious immobilizing effects (intake by microorganisms) on nutrients in the soil.

Jensen (1929) reported the following C:N ratios for several organic materials : wheat straw, 84:1; sweet clover, 26:1; farm yard manure, 16:1; lucerne meal, 13:1; fungal mycellium, 10:1. The chemical composition of organic substrates seem to have equally a direct influence over the extent of the mineralization process that occurs in soils. According to a number of research studies (Parr, 1975; Yagodin, 1984), it has been found that organic materials composed of water-soluble compounds, such as starch, sugar, pentosanes, pectins, tannins, or organic acids, tend to mineralize faster in soils than those characterized by more complex and water-insoluble components as cellulose, lignin, fats and waxes. Singer et al. (1987) noted that aged organic matter, like humus, normally mineralizes more slowly in soils (only 3 % per year) compared to younger fresh residues that decompose much faster at a rate of about 50 per cent per week.

2) <u>BOD (Biochemical Oxygen Demand)</u>

BOD refers to the amount of oxygen required by soil microorganisms in the process of decomposing organic wastes under standard conditons and during a specific period of incubation (Parr, 1975). This implies that organic materials characterized by high BODs would normally take longer to mineralize than those having rather low BODs given that the oxygen supply in most soils appears to be relatively limited. BOD values reported in literature range from 100 to 100,000 mg O_2/l for low demanding materials and exceed 100,000 mg O_2/l for high demanding materials.

3) <u>Soil Oxygen</u>

The decomposition of organic residues cannot normally proceed without an adequate supply of molecular oxygen. An oxygen concentration of at least 5 % of the soil air is considered necessary (Singer et al., 1987). Parr et al. (1970) found that a soil incubated aerobically with 1 % glucose evolved 3 times as much carbon dioxide (i.e. decomposition rate) than when treated the same anaerobically under argon. The diffusion of molecular oxygen appears to be generally lowest for soils that are either too compacted or waterlogged, such as clays, bogs, or swamps.

4) Particle Size or Accessibility

Coarse organic materials have commonly been observed to endure longer in soils than the fine ones (Cheshire et al., 1974; Allison et al., 1960; Drift et al., 1960; Singer et al., 1987). According to Jenkinson (1981), this accounts for the fact that ground or fine organic materials appear to be more accessible to microbial attack compared to the rather lumpy residues. The physical effects from soil animals (chewing, digesting, transporting) and from cultivation in reducing particle size may be considered thus to play an important role in the accessibility of organic materials to attack by the diverse microorganisms in the soil (Jenkinson, 1981; Singer et al., 1987).

5) Soil Moisture

The diverse soil microorganisms do not usually respond the same at given soil moisture regime conditions. Some like fungi for instance tend to survive well under water potentials between -3 and -15 bars while others like bacteria do not seem to tolerate such dry conditions (Parr, 1975). Despite these differences, studies reviewed by Singer et al. (1987) suggest that organic matter decay would go fastest in soils with water potentials comprised between -10 and -50 kPa.

6) Soil Temperature

As with most chemical reactions, the rate of organic matter oxidation tends to be very much dependent on the variations of ambient temperature. Singer et al. (1987) observed that the overall soil respiration (CO_2 production and O_2 consumption) dropped steadily to zero when soil temperatures decreased from 20 to 5 C. Under subtropical conditions, Bunt and Rovira (1955) noted that the van't Hoff's rule (i.e. Q_{10} of the decomposition rates) was verified for soil temperatures ranging from 10 to 40 C. According to Parr (1975) the maximum decomposition rates for organic residues and wastes seem to be generally obtained when soil temperatures fall within the range of about 30 to 35 C.

7) Soil pH or Reaction

There is ample evidence to suggest that extreme soil pH conditions (below 4.5 or above 9) contribute to the slowing down of organic matter decomposition in soils (Singer et al., 1987). In general it is considered that acidic conditions tend to be more appropriate for fungal organisms compared to the bacteria and actinomycetes manifest optimal activity at pH values near neutrality. In spite of such differences, the optimum soil reaction for a rapid decomposition of common wastes and residues in soils has been reported to occur at values between 6.5 and 8.5 (Parr, 1975).

8) Soil Nutrients

It is well established that the lack of available nutrients (especially N,P,K, and S) in soils usually results in slower microbial activity and hence less decomposition (Parr, 1975; Jenkinson, 1981; Singer et al., 1987). In soils deficient in N for intance, immobilization is generally common. In order to prevent such immobilization most studies suggest an application of either small residue loads or a supplemental application of required nutrients along with the organic substrate.

9) Soil Texture and Structure

Soil texture and structural properties are generally considered to have an important role in the adequate balance of moisture and molecular oxygen in soils. Without such a balance, excessive conditions may result (too dry/too wet; aerobic/anaerobic), and thus eventually restrict microbial activity and the decomposition process. Massive clays or waterlogged (bogs, swamps) soils are considered to have a relatively greater slowing effect on the mineralization of applied organic materials compared to coarse textured and granular soils. The protective effect of clays and non-crystalline materials (allophane) are viewed by some authors (Lynch et al., 1956; Broadbent et al., 1964) as a plausible explanation for the slow organic matter decay in certain soils. Lynch et al. (1956) stated that montmorillonite clays usually can provide a stronger protection against rapid organic matter decomposition in the soil compared to either illite or kaolinite type clays.

D) INFLUENCE ON SOIL PROPERTIES

I) STUDIES IN AFRICA

Most studies conducted in Africa regarding the influence of plant residues on soil properties appear to be very promising. Ayanaba et al. (1975), who reviewed the effects from various plant residue mulching, i.e. the laying over and/or incorporation of dead plant remains in the soil, found the following associated benefits :

1) net increase in soil moisture contents;

2) reduced soil surface run-off;

3) reduced soil erosion losses;

4) reduced soil temperature, resulting in better germination of maize and soybean crops,

5) improved water infiltration rate into the first 15 cm of soils profile;

6) reduced proliferation of weeds;

7) increased soil carbon and CEC;

8) improved nutrient supply, especially of N

9) increased microbial activity and nodulation in soybean;

and

10) no case of phytotoxity

Lal (1987) who also reviewed various studies conducted in Africa concurred with the fact that crop residue mulching tends to result in important beneficial effects on both soil CEC and microbial activity by reducing the rapid decline of the organic matter content. In West Africa similar results with millet and cotton seed residues have been also reported by Pichot et al., (1974), Charreau (1974) and Poulain (1980).

Working with some "ferriginous" soils from West Africa, Sedgo (1981) found that incorporating sorghum straw with mineral sulfur resulted in the net improvement of available phosphorus from rock phosphate.

In Madagascar studies with maize stover suggested that it could take at least two years before the beneficial effects on the soil begin to emerge (Velly and Longueval, 1976). In East Africa, Robinson et al. (1965) found the beneficial effects from straw mulching to include among other things the reduction of soil acidity, the improvement of soil carbon and the increased availability of nutrients, such as N, P, and K. Among the side effects they observed that available Fe and Mg were reduced when 25 mt/ha of elephant grass or purpureum were applied as a mulch.

Studies with green manures were found to be relatively less beneficial on soil characteristics compared with mulching. Except for a few cases of promising results (Charreau and Nicou, 1971) no definite pattern seems to be shown (Young, 1976). To account for this situation some contended that unsolved difficulties, such as loss of one season crop, no immediate returns as well as lack of appropriate tools for digging in the green manure crop may have contributed to render such a practice somewhat unacceptable for the african farmer (Wrigley, 1982;

Agboola, 1975).

II) STUDIES IN ASIA

In Asia, studies regarding the effects of crop residues appear to be mostly concerned with the use of rice and wheat straws and their associated plant parts

In India Gaur (1983) found that the incorporation of wheat or rice straw in alluvial sandy loam soils contributed to apparent increases in total soil C, humin C, humus, as well as the amount of available N. Better weed control, conservation of soil moisture, and improvement in groundnut nodulation were also found to be beneficial effects.

In the Republic of China, Nan-Rong Su (1983) who conducted similar studies with rice straw and husk materials reported increased soil organic matter contents and increased nutrient availability, especially for P, K, and Si. Soil bulk density was also improved which allowed better root penetration. Rice straw additions decreased soil pH by about 0.1 to 0.2 units.

In Japan, Egawa (1975) reported pratically the same benefits as those already found in China. However, in paddy fields Inoko (1983) contended that the direct application of rice straw could be detrimental due to severe N immobilization.

Besides rice straw, cotton wastes have also been reported to constitute a valuable soil amendment for mushroom producers in Sri Lanka. Mulch studies conducted with collected Ceylon and Chinese tea leaves from restaurants failed to produce any meaningful results (Hui, 1983).

With respect to green manures, asian research appears to have been targeted at these three major plant groups:

1) legume green manures

2) blue green algae

3) azolla

While legume green manures usually refer to cultivated legume crops, blue green algae and azolla seem to evoke aquatic plants that are generally harvested from ponds and applied to adjacent fields. As green manures, both cultivated and aquatic plants are normally incorporated into soils in order to bring about their decomposition and eventual release of nutrients (mostly N) for plant growth and yields. According to reviewed literature (Meelu et al., 1981; Bhardwadj et al., 1981; Tiwari et al., 1980; Venkataraman, 1983; Singh, 1977; Joshy, 1983; Khan et al., 1983; Marquez et al., 1983; Weerakoon, 1983) the main benefit from these plant types comes primarily from their supply of N ranging from 60 to 90 kg N/ha per year (Singh, 1983). Under alkali soil conditions there have been studies suggesting that the plowing under of certain green manures, such as sesbania could also result in some beneficial reclamation effects on the soil although the related mechanism was not clearly presented (Uppal, 1955; Singh, 1963; Singh, 1969).

III) STUDIES UNDER TEMPERATE CONDITIONS

Research studies conducted under temperate climatic conditions have been mostly concerned with composts and crop residue mulch whereas results regarding use of green manures have been rather scanty. The availability of cheap inorganic fertilizer N may have perhaps had something to do with this.

In Switzerland, studies with composted organic residues were found to produce the following important benefits (Stickelberger, 1975) :

-reduced erosion by wind and water

-increased porosity and water retention capacity

-improvement of soil structure

-stimulation of soil microbial activity

In England, Cooke (1967) reported that plowing in straw with inadequate fertilizer N usually results in temporary N immobilization in soils. Incorporation of straw appeared to result in relatively little effect on soil structure, even on structurally degraded soils.

In the United States, Follett et al. (1981) who reviewed the effects of " stubble mulching " listed in addition to the benefits already mentioned the following :

-increased soil humus

-potential increase of germination

-lower tractor fuel cost

-more desirable bacteria, actinomycetes, and fungi

Higher fertilizer costs as well as growing environmental concerns seem to have recently prompted in the United States the adoption of the so-called conservation tillage systems. Under these systems tillage practices vary from little to none and crop residues from harvest are usually left on the field to protect the soil all year around. Besides the protection of the soil against erosion losses it is also believed that essential nutrients being released by mineralization would contribute to enhanced plant growth and yields. Blevins et al. (1985) in their evaluation of these systems noted the following associated benefits :

-improved water infiltration rate

-increased soil organic nitrogen and

-increased availability of P and K

Among the adverse efffects Blevins et al. (1985) indicated that the pratice of conservation tillage may result in the reduction of soil pH, reduced availability of plant nutrients, especially of Ca, Mg, and N as well as toxicity problems due to excessive increases aluminium and manganese availability. Ellis et al. (1985) in a similar assessment added that even though conservation tillage appears to reduce total net losses of sediment bound P and N, there has been some evidence suggesting that increased concentrations of these elements in run-off waters may also be obtained.

E) INFLUENCE ON PLANT GROWTH AND YIELDS

I) STUDIES IN AFRICA

Due to favorable effects on soil moisture mulching with plant residues has been considered to work best in those areas of Africa with low to marginal rainfall conditions. In less humid zones such Northern Nigeria, mulching with groundnut shells (65 mg/ha) has proven to be very beneficial on the yields of cultivated plants, especially sunflower and cotton. During dry seasons it has been observed that yam farmers usually manage to increase their yields by laying various residues (leaves, dry grass, sorghum stalks, etc...) over the cultivated ridges or mounds (Wriley, 1982).

Experimental studies with diverse plant residues or chemically killed cover crops have confirmed the stimulating role of mulching over many crop yields, including soybean, cowpea, maize, pigeon pea, and cassava (Wrigley, 1982). In French West Africa beneficial yield increases have been similarly reported from studies that applied groundnut shells, millet, cotton, or sorghum stalk residues (Gillier, 1964; Lienart and Nabos, 1967; Pichot et al., 1974; Poulain, 1975; Ofori, 1980; Sedgo, 1981).

Not much information with respect to green manures has been obtained under African farming conditions. Ayanaba (1980) considered that under tropical conditions legume plants in Africa may be fixing as much as 40 to 450 kg N/ha per year for subsequent non-fixing crops. Balasubramanian et al. (1980) observed that legume crops grown in rotation with cereals were in general found to always have resulted in increased yields for the follwing crop, even when the tops of the green manure crop were removed from the field.

II) STUDIES IN ASIA

In Asia there are contrasting reports concerning the effects of crop residues. In countries such as India and the Republic of China the application of rice mulch was shown to be beneficial on cultivated crops (Gaur, 1983; Nan-Rong Su, 1983). However, in Japan Inoko (1983) observed some detrimental effects on rice due to the immobilization of N. The application of certain industrial wastes, such as sugar molasses, rice husk, soybean cake, press mud cake and penicillin mycelium residues have been reported to induce significant yield increases for several crops, particularly rice, when inorganic fertilizer was given along with the residues (Gaur, 1983; Nan-Rong Su, 1983; Khan et al., 1983).

With respect to green manures (legume crops, blue green algae, and azolla) reviewed literature suggest that the observed crop yield responses appear to be related to the extent of available N contained in the applied residues. The higher the N content of green manure the better would be in general the resulting crop response and vice-versa.

For a complete discussion on this subject, the reader can refer to authoritative treatises presented in the 1983 report of the Asian Productivity Organization (APO).

III) STUDIES UNDER TEMPERATE CONDITIONS

Research studies reviewed by Cooke (1967) have shown that plowing in straw appeared to usually produce adverse effects during the first years before eventually showing more favorable effects in wheat-oat-barley rotations. This may be related to some extent to the fact that organic matter decomposes more slowly under temperate climates compared to tropical conditions

(Sanchez, 1976), but was probably due to N immobilazation. Besides these effects from crop residue treatments, peat composts have also been found to produce beneficial yield results on certain crops. In Russia for instance the application of peat compost with mineral fertilizer treatments have produced higher yields of vegetable crops, such as potato, carrot, and cabbage compared to when mineral fertilizer alone was applied. Besides these results it was also observed that the peat with fertilizer treatments had relatively more beneficial lasting effects on subsequent crops (Shapiro, 1968).

Research studies in temperate zones with green manures do not seem to differ very much from the results already discussed under tropical conditions. This stems from the fact that in most cases the increased crop yields have also been found to be ralated to the relative supply of N released from the applied residues.

Long term studies (1955-1962) at the Woburn research station in England indicated (Cooke, 1967) generally that :

-legume green manures (trefoil) tend to be more effective in increasing crop yields than the non-legume green manure crops (rye grass).

-when non-legume green manures are applied it may be necessary to add a supplementary fertilizer N in order to reach optimum yields

-incorporation of green manures during the Spring season is normally best for higher crop response than in Autumn

Similar research in the United States has shown that plowing in vetch as a green manure can result in the same crop yields as from the equivalent application of 112 to 135 kg N/ha (Follett et al., 1981). Other studies in Montana pointed out, however, that crop yield responses may be limited when green manure is incorporated in areas of annual rainfall no greater than about 18-20 inches (Army et al., 1959).

F) LIMITATIONS AND ALTERNATIVE MEASURES

I) LIMITATIONS

Major limitations resulting from current agricultural use of green manures and/or plant residues include the following.

LIMITATIONS FROM MULCHING

- One of the most serious limitations associated with mulching that has been widely recognized is the immobilization of available N in soils. According to various studies (Cooke, 1967; Duncan, 1975; Egawa, 1975;

Follett et al., 1981; Tisdale et al., 1985; Vitosh et al., 1985; Singer et al., 1987; etc...) it is fairly well established that N can be immobilized by soil microorganisms when organic materials with wide C:N ratios, especially in the order of 30:1 or above, are applied without an adequate supply of fertilizer N.

-Even though increased soil moisture contents due to organic residues applied as a mulch appears to be beneficial for plant growth and yields, it is considered that such a practice can result in rather detrimental effects if implemented under poorly drained and/or excessive rainfall regime conditions (Follett et al., 1981; Wriley, 1982; Triplett et al., 1985).

-Reduced microbial activity and seed germination due to excessively low temperatures in the soil have sometimes been related in temperate regions to the adverse effects from mulching (Follett et al., 1981; Blevins et al., 1985).

-Allelopathy or reduced plant growth due to the release of phytotoxic substances in soils treated with mulch has been recently suggested in a number of reports (Linderman, 1970; Langdale, 1970; Parr et al., 1976; Follett et al., 1981).

-Concentrations of P and N in runoff waters were found to be relatively increased under the conservation tillage systems (Ellis et al., 1985). However the amount of runoff is usually reduced.

-The application of organic residues as a mulch has been shown to increase to some extent the potential for crop damage from diseases, pests, weeds, and rodents, respectively (Follett et al., 1981; Kells et al., 1985; Kirby, 1985; Ruppel et al., 1985).

-The overall effects from such limitations are of course the ultimate reduction of plant growth and yields.

LIMITATIONS FROM GREEN MANURES

-In many regions, especially in the tropics, the green manure crop is grown simultaneously with the main crop in the same field. Before the green manure reaches maturity it is usually plowed under so that the main crop can benefit from the relatively high level of available N. Even though such a practice has proven to be beneficial for plant growth it can sometimes become very limiting if there is either direct competition between the two crops for space, water and nutrients, or if the time required to grow the green manure overlaps too much with the development cycle of the main crop (Wrigley, 1982; Singh, 1983) .

-In cases where the green manure crop is grown in a separate field one crop season is likely to be lost since the time left after the green manure is grown may not be sufficient for the main crop to complete its growth cycle (Wrigley, 1982; Singh, 1983). The loss of one crop season due to green manuring results in no immediate returns in terms of cash or food for the farmer (Agboola, 1975).

-The lack of proper tools to incorporate the green manure crop into the soil has been considered in some areas as a serious limitation for farmers, especially in developing countries (Wriley, 1982).

-Farmers in many developing countries generally attempt to reduce their economical risks by planting several crop on the same field. Such a practice, also known as mixed cropping systems, is considered to be incompatible with the plowing under of green manures (Agboola, 1975). With several crop stands in the same field there seems to be insufficient space left for the manure crop to grow.

-According to some studies the practice of green manuring appears to have no beneficial carryover influence beyond the first subsequent crop (Singh, 1975). This clearly indicates that this practice has to be implemented over and over again each year. In the long run this can very tedious and perhaps not economically profitable for the farmer.

-The fact that most green manures do not supply many nutrients except for N is also considered by some as a relatively important limitation to crop production (Singh, 1983; Yagodin, 1984).

-Research studies in Africa have shown that sole green manure crops tend to result in marked lowering effects on soil organic matter contents (Agboola, 1975). This can be explained by the fact that immature green tissue usually decomposes more rapidly without leaving much residue in the soil. With the decomposition of immature green tissue, it has been observed that the more resistant organic matter or humus also appeared to be mineralized relatively faster. The lowering of soil organic matter contents thus constitutes an important limitation with respect to soil fertility.

-Potential N leaching problems have been suggested to occur if the green manure is plowed under too long before the main crop is able to fully take advantage of the available N (Singh, 1983).

II) ALTERNATIVES MEASURES

Suggested management practices to complement mulching and the use of green manures are as follow.

MULCHING

A supplemental application of fertilizer N is generally suggested in soils that have been treated with slow decomposing mulch. This has proven to be effective in reducing or preventing the N immobilization problem that was discussed above. Follett et al. (1981) considered the addition of 4.5 kg N/ha (or 4.0 lb N/A) for each 454 kg /ha (or 404 lb /A) of plant residues left on soil surface to be generally appropriate.

In order to reduce the potential for serious limitation effects from mulching Parr (1975) also suggested that the annual residue application rates should not exceed 112 mg/ha (or 50 t/A). This compares with recommended optimum mulch loads of between 22 mg/ha and 67 mg/ha, i.e. 10 and 30 t/A, respectively.

GREEN MANURE

For incorporated non-legume green manures, Cooke (1967) observed that applying a supplemental fertilizer N can be very beneficial in stimulating the decomposition process and eventually the release of plant nutrients. In addition to applying fertilizer N, he also pointed out that the practice of green manuring would work best if implemented in abundant rainfall zones or with supplementary irrigation in arid land conditions. The basis for such recommendation stems from the fact that most green manures are legume crops and therefore tend to require soils with good moisture conditions for fast growth and satisfactory fixation of the atmospheric N_2. Thus, the drier the climatic conditions the less beneficial would be the effects from green manuring.

According to Yagodin (1984) the finer the soil texture the shallower should be the depths at which plant residues including green manures are incorporated. The reason for this is simply due to the fact the decomposition of organic matter in the soil usually requires adequate oxygen to be present. In fine textured soils such as clays there is little doubt, however, that more oxygen is likely to be present in the upper layers compared to the subsoil zones.

It has been generally observed that fresh plant remains tend to decompose a lot faster compared to dead and/or old residues (Singer et al., 1987). Taking this into consideration some suggest that with all things equal old plant remains should be plowed under much deeper in order to stimulate their decomposition process in the soil (Yagodin, 1984).

Other conditions that seem to result in the rapid decomposition of organic matter in the soil include among other things the implementation of early tillage (versus delayed tillage) as well as the additions of night soil and animal manures (Yagodin, 1984).

Under certain conditions, such as very coarse textured soils and/or delayed crop planting, it may be necessary to slow down the relatively rapid decomposition of green manures in order to reduce excessive N losses by leaching. To realize this objective it is considered that adding slowly decomposing materials can be very effective (Yagodin, 1984).

M A T E R I A L S   A N D   M E T H O D S

I) FIELD NUTRIENT MOBILITY STUDY

This Study was conducted in Summer 1984 as follow-up research to an earlier Michigan State University (MSU) long term project (1963-1982) on farm yard manures.

Under this initiative, the major objective was to investigate the long term effects of applied fertilizer and manure treatments on the downward movement of essential nutrients through the surveyed soil profiles. The essential nutrients analyzed included : P, K, Ca, Mg, Fe, Mn, Zn, and Cu. Nitrogen was deliberately excluded, given the relatively well established literature regarding the movement of this element in soils. The experimental field located at the MSU Soils'Farm, East Lansing, contained five distinct treatments described as follows :

- A : Control with 0.168 Mg/ha/year of fertilizer N
- B : 0.168-0.168-0.168 Mg/ha/year of fertilizer $N-P_2O_5-K_2O$
- C : 22.4 Mg/ha/year of cattle manure
- D : 44.8 Mg/ha/year of cattle manure
- E : 67.2 Mg/ha/year of cattle manure

The soil on the site is classified as a Metea sandy loam (loamy, mixed, mesic Arenic Hapludalfs). The experimental design was a randomized split split-block design consisting of 5 treatments (0.168 Mg N/ha/year; 0.168-0.168-0.168 Mg $N-P_2O_5-K_2O$/ha/year; 22.4 Mg Cattle Manure/ha/year; 44.8 Mg Cattle Manure/ha/year; 67.2 Mg Cattle Manure/ha/year; 2 irrigation systems (irrigated, non-irrigated), 2 crop stands (corn grain versus silage corn), and 3 replications. This resulted in 60 experimental plots in two major blocks, one harvested for corn grain and one for silage. Each block was split and one-half was irrigated and the other half not irrigated. All manure treatments were applied to each sub-block. In this study only the irrigated corn grain plots were sampled. Soil samples were taken in 0.15 m increments down to 1.05 m depth during the 1984 summer season. One hundred and five (105) distinct soil cores (7 depths x 5 treatments x 3 replications) were collected, air dried and sieved through a 2 mm screen. After such treatment, all samples were placed into separate containers and taken to the laboratory for analysis. Subsamples were analyzed for nutrients of interest.

<u>EXTRACTION PROCEDURES</u>[1]

-Phosphorus (P) : 2.0 g soil was extracted in a 50

---

[1]-For more details on these procedures, refer to the MSU Testing Guide, better known as the "General Soil Testing Methods At Michigan State University Soil Testing Laboratory"

mL Erlenmeyer flask with 20 mL of Bray-Kurtz P_1 extracting solution (0.03 N NH_4F + 0.025 N HCl). Shaking time was 5 minutes at 180 oscillations per minute. The soil extract solution was obtained by filtration through # 1 Whatman filter paper.

-Potassium (K), Calcium (Ca), Magnesium (Mg) : 2.5 g soil was extracted in a 50 mL Erlenmeyer flask with 20 mL of 1N neutral (pH 7.0) ammonium acetate (NH_4OAc) solution. Shaking time was 5 minutes at 180 oscillations per minute. The soil extract solution was obtained by filtration through # 1 Whatman filter paper.

-Iron (Fe), Manganese (Mn), Zinc (Zn) : 2.0 g soil was extracted in 125 mL Erlenmeyer flask with 20 ml of 0.1N HCl dilute solution. Shaking time was 10 minutes at 180 oscillations per minute. The soil extract solution was obtained by filtration through # 1 Whatman filter paper.

-Copper (Cu) : 2.0 g soil was extracted in 125 mL Erlenmeyer flask with 20 mL of 1N HCl solution. Shaking time was 60 minutes at 180 oscillations per minute. The soil extract solution was obtained by filtration through # 1 Whatman filter paper.

DETECTION

-Phosphorus (P) : Two mL aliquots of the soil extracts and prepared standards (0, 2, 4, 6, 8, and 10 ppm P) were diluted with 18 mL of ammonium molybdate ascorbic acid color developing solution that was obtained by respectively adding while mixing 40 mL acid molybdate stock solution + 1500 mL deionized distilled water + 20 mL ascorbic stock solution and completing to 2000 mL volume mark with distilled water. After waiting 15 minutes for color development, P levels were detected through a Bausch & Lomb Spectronic 20 colorimeter previously warmed up for at least an hour and set at 880 nm (10^{-9} m) wave length.

-Potassium (K), Calcium (Ca), Magnesium (Mg) : Prepared standards containing 00, 10.0, 20.0, 30.0, 40.0, and 50.0 ppm K and Mg, respectively and 00, 100, 200, 300, 400, 500 ppm Ca were analyzed along with corresponding soil extract solution samples in a Technicon Auto-Analyzer II.

-Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu) : Appropriate standards that contained 0.0, 5.0, 10.0, 15.0, and 20.0 ppm for Fe; 0.0, 2.0, 4.0, 6.0, and 8.0 ppm for Mn; 0.0, 1.0, 2.0, 3.0, 4.0, and 5.0 ppm for Zn; and 0.0, 2.0, 4.0, 6.0, 8.0, and 10.0 ppm for Cu were analyzed with corresponding soil extract solution samples with an atomic absorption spectrophotometer warmed up and set at 248.3, 279.5, 213.9, and 324.8 nm wave-lengths, respectively.

COMPUTATIONS

Statistically all data were analyzed as a factorial split-plot design, consisting of 5 treatments (A,B,C,D, and E) by 7 depths (15, 30, 45, 60, 75, 90, and 105 cm), respectively. The MSU-MSTAT (Microcomputer Statistical Package) program was required to run the various computations.

II) LABORATORY COLUMN LEACHING STUDY

To complement the field nutrient movement study, laboratory experiments were conducted to investigate the influence of selected soil factors (texture, pH, and incubation) in relation to fertilizer and manure types on the mobilization and eventual leaching of essential nutrients P, K, Ca, Mg, Fe, Mn, Zn, and Cu.

Material Collection and Analysis

Soil A, identified as a Riddle-Hillsdale sandy loam (fine loamy /coarse loamy, mixed, mesic Typic Hapludalfs) was collected in Ingham County on the west side of the MSU Soils' Farm. Soil B, identified as a Sims silty clay loam (fine, mixed, nonacid, frigid Mollic Haplaquepts) came from a farm in Clinton County near Bauer road. The major characteristics for these two soils are given in tables XIII and XIV.

The fertilizer N-P-K was derived from the following chemical sources :

- NH_4NO_3 and $Ca(NO_3)_2$ as a combined source for N (The ratio $Ca(NO_3)_2$ / NH_4NO_3 used was 3:1 in order to maintain a neutral effect on soil pH).
- $Ca(H_2PO_4)_2$ as a source for P
- and KCl as a source for K

The organic amendments were soybean and barley residues, and cattle and poultry manure. In order to determine

Table XIII. Soil Extractable Nutrient Levels.

CEC *	pH	EXTRACTABLE				NUTRIENT			LEVELS
		P	K	Ca	Mg	Zn	Mn	Cu	Fe
		--------mg/kg---				------mg/kg--------			
60	5.7	244	160	528	105	4.5	15.7	6.7	84.(A)
140	7.1	33	182	2207	266	5.6	17.9	6.7	33.6(B)

(A) : Sandy loam soil

(B) : Clay loam soil

* : CEC values are in $mmol^+$ per kg

Table XIV. Some Physical Characteristics of the Soils.

	Field Capacity	Sand	Silt	Clay+
	%			
Soil A	26.	71.	11.	18.
Soil B	31.	33.	32.	35.

+ : The Particle Size Analysis Was Determined According To The Bouyoucos Procedure

Soil A : Sandy Loam

Soil B : Clay Loam

their respective nutrient composition, the organic amendments were dried, ground through a 1 mm and digested with nitric and perchloric acid according to the method described by Blanchard et al. (1965). During such digestion the following major steps were followed :

1) 0.5 g of ground samples were first weighed in to 50 ml graduate test tubes

2) two glass beads as well as 3 ml of concentrated nitric acid (HNO_3) were added in each tube

3) after being covered with small funnels, the tubes were left to stand pre-digesting overnight

4) the following day after all tubes had been transferred to an aluminum digestion block under a fume hood, heat was turned on and the temperature maintained at 150 C for an hour

5) at the end of this period, 2 ml of 60-70 % perchloric acid ($HClO_4$) were added to each tube through the funnel and the temperature raised up to 235 C for 2 hours

6) after all these digestions the funnels were removed and 1 ml concentrated HCl was dripped into each tube; the digestion was continued for another 20 minutes at 150 C

7) subsequently, all tubes were taken out of the block and set aside in a rack to cool

8) once cool, the content in each tube was diluted

up to the 50 ml mark with additions of 3N nitric acid (HNO_3) containing 1000 ppm Li^+

9) finally the digest solutions were analyzed for nutrient contents with directly coupled plasma emission spectrogragh.

The corresponding results of these analyses are reported in table XV.

Table XV. Average compositions of plant residues and animal manures analyzed with the D.C.P (Directly Coupled Plasma) Emission Spectrogragh.

	N+	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
	%					mg/kg					
Barley	1.8	.33	2.4	0.43	.11	48	15	24	12	23	nd
Soybean	3.5	.32	1.5	1.10	.72	603	47	34	21	55	3.2
Cattle	2.6	.66	.56	1.30	.39	360	163	165	45	40	nd
Poultry	3.7	2.5	1.9	7.90	.66	866	348	354	39	50	nd

nd : not detectable.

\+ : as determined with the micro-Kjeldahl procedure.

Treatment Preparations

With each soil type, fifteen (15) distinct treatments were prepared by combining selected soil factors (S_1a, S_1b, S_2a, S_2b, S_3a, S_3b) and nutrient sources or amendments (B, S, C, P, F) as follows :

	SOIL FACTORS					
AMENDMENTS	S_1a	S_1b	S_2a	S_2b	S_3a	S_3b
Barley Residue (B)	BS_1a	BS_1b	BS_2a	BS_2b	BS_3a	BS_3b
Soybean Residue (S)	SS_1a	SS_1b	SS_2a	SS_2b	SS_3a	SS_3b
Cattle Manure (C)	CS_1a	CS_1b	CS_2a	CS_2b	CS_3a	CS_3b
Poultry Manure (P)	PS_1a	PS_1b	PS_2a	PS_2b	PS_3a	PS_3b
Fertilizer N-P-K (F)	FS_1a	FS_1b	FS_2a	FS_2b	FS_3a	FS_3b

LEGEND

S_1a : non-incubated sandy loam (soil A) at native pH 5.7.

S_1b : non-incubated silty clay loam (soil B) at native pH 7.1.

S_2a : sandy loam soil (A) destined to be incubated at native pH 5.7.

S_2b : silty clay loam soil (B) destined to be incubated at native pH 7.1.

S_3a : sandy loam soil (A) destined to be incubated only after pH is increased from 5.7 to 7.1.

S_3b : silty clay loam soil (B) destined to be incubated only after pH is reduced from 7.1 to 5.7.

For the required pH change in the Riddles-Hillsdale sandy loam (soil A), soil samples were pre-treated prior to additions of the indicated amendments with a solution of 0.1 N NaOH. For the Sims silty clay loam (soil B) corresponding soil samples were conversely pre-treated with a solution of 0.1 N H_2SO_4. The purpose of such procedure was to allow comparisons to be made between treatments of these two soil types at the same pH. The ultimate pH values obtained after the incubation and leaching studies are respectively reported in the " Results and Discussion " section. The amount of organic amendments (barley residue, soybean residue, cattle manure, and poultry manure) applied in each case was computed in such a way to reflect an equivalent rate of 60 Mg /ha (dry weight basis) or 20,000 mg residue /kg soil. The amount of inorganic fertilizer N-P-K added to corresponding soil units was on the other hand based on the average nutrient contents found in the plant residues and animal manures, i.e. 590-193-323 ppm N-P-K, respectively. These relatively high rates were to apply similar nutrient loading to that of the manure treatments. A control for each soil type was also included. This resulted considering four replications per treatment, in 128 experimental units (2 soil types x 16 treatments x 4 replications).

Treatment Incubations

In order to minimize the experimental error, similar soil units were gathered into respective treatment groups and kept in polyethylene plastic bags during the 8 week incubation period. The soils to be incubated were moistened with distilled water to bring their moisture content to about 45-50 % of their respective field capacities. Non-incubated treatments on the other hand remained at 6 and 12 % moisture contents, for soils A and B, respectively. During this period all treatment bags were closed loosely with rubber bands and were allowed to aerobically incubate on the lab-bench at 20 ^{C}.

At the end of the 8 week incubation period, all treatments were transferred from the laboratory to a near-by cold chamber (about 4 C) to minimize any further microorganism activity.

Soil Column Packing

Soil samples were packed in translucent PVC columns, 0.46 m (18 in.) long and 0.14 m (5.5 in) in diameter. In order to ease the packing process, non-incubated samples that remained mostly dry were pre-wetted with deionized distilled water with an amount equivalent to that received earlier by the incubated treatments.

To pack a column, moist soil was poured gently into the column from the incubation bag. In each case, the bottom 18 cm inches of the column was packed first with untreated native soil before the addition of 18 cm of treated soil. It was important that each column be packed in such a way in order to simulate the occurrence of treated topsoils over untreated layers under normal field conditions. Caution was exercised to avoid undue compaction during the column packing process. The bottom end of each column was covered with eight (8) layers of cheesecloth and secured with rubber bands. Four layers of cheesecloth were placed between the treated and untreated soil and four layers were placed on the soil surface to minimize surface puddling.

Soil Column Leaching[2]

After being packed, each soil column was set vertically (with the untreated core on the bottom) on a specially prepared wooden rack and secured with rubber bands. In order to obtain a uniform rate of water addition, a plastic funnel containing two Whatman # 2 filter paper was placed on the top of each column. Deionized distilled water was then poured gently and intermittently into each column until complete saturation of the entire column occurred.

Once saturation of the columns was completed, a

---

[2].For more details, see descriptive diagram in Figure 1.

beaker topped with # 2 Whatman filter paper was placed underneath each column for collection of subsequent leachate. Enough distilled water was added to each column to displace about 120 ml of leachate. The filter paper on the beakers allowed direct filtering of the leachate as it percolated out of the column. The leachate was collected in three sequential samples of forty (40) ml each and then transferred from the beakers into plastic bottles. After collection of the leachates all bottles were capped and stored in a cold chamber at 4 C.

Since all 128 soil units could not be leached at once, it was deemed appropriate to proceed with only one series of 12 organic residue treatments at a time. After each sequence of leaching the PVC columns were washed free of soil and dried before being used again.

<u>Leachate Analysis</u>

After appropriate standard solutions had been made, all collected leachates were analyzed with a DC plasma Emission Spectrograph.

<u>Statistical Analysis</u>

For the statistical analysis the data were grouped according to manure sources and analyzed as :

1) a complete randomized block design for the incubation factor, and

2) as a 2 x 2 factorial design for both the pH and texture factors, respectively.

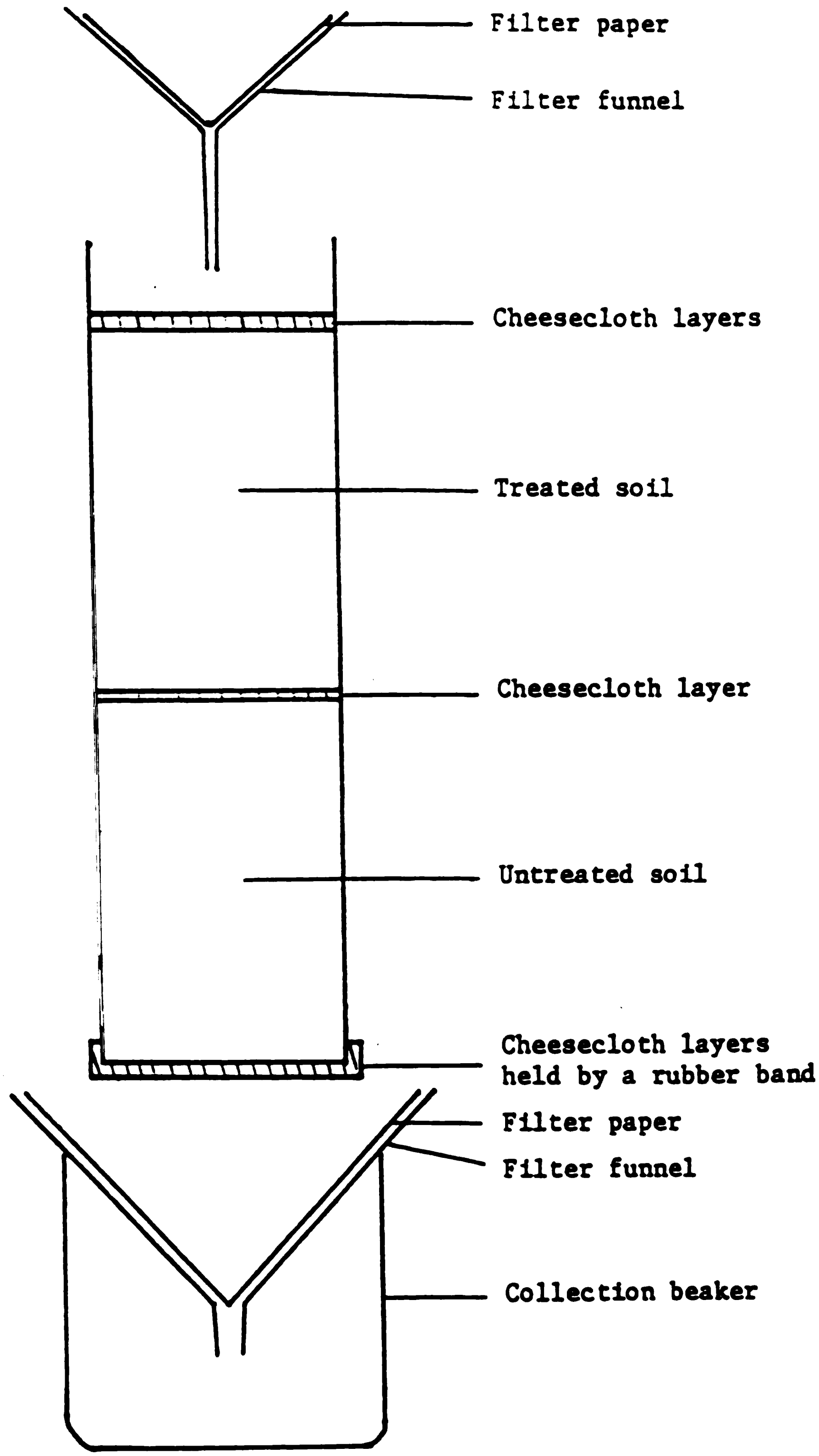

Figure 1. Schematic diagram of the leaching column setup.

R E S U L T S A N D D I S C U S S I O N S

P A R T I

LONG TERM EFFECTS OF FERTILIZER AND MANURE APPLICATIONS ON NUTRIENT PROFILE DISTRIBUTIONS AND DOWNWARD MOVEMENT IN A METEA SANDY LOAM SOIL

PHOSPHORUS (P)

The data relative to the long term influence of fertilizer and manure treatments on the downward movement of P in the Metea sandy loam soil are presented in Table 1. In the top 75 cm depth zone, it can first be observed that relatively greater P concentrations occurred with the treated plots (B,C,D,E) compared to the control (treatment A). Below this zone, i.e. from 90 cm to 105 cm depths similar comparisons failed, however, to indicate any significant differences in the observed P concentrations between the control A and the considered treatments B, C, D and E. Such results thus suggest that the downward movement of P in the Metea sandy loam soil was essentially restricted to the upper 75 cm depth zone. The fact that only small amounts of P (5 to 10 mg/kg) were obtained below the 75 cm depth zone leads therefore to the supposition that leaching alone may not account

Table 1. Long Term Effects of Manure and Fertilizer Treatments On Phosphorus (P) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	TREATMENTS A	B	C	D	E	Depth Mean
cm	mg per kg					
00-15	62	233	102	147	162	142
15-30	59	214	94	125	126	123
30-45	40	175	50	103	139	101
45-60	27	110	60	93	115	81
60-75	16	32	37	71	63	44
75-90	5	3	8	10	4	6
90-105	6	4	5	7	6	6
LSD (5%) Trt x Dpth For any 2 Means			38 mg/kg			

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer N-P_2O_5-K_2O

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 2. F ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob.
Rep	02	06.97	.017
Treatment	04	47.33	.000
Error	08		
Depth	06	66.01	.000
Treat.x Depth	24	04.29	.000
Error	60		

Coefficient Of Variation : 36.22 %

satisfactorily for most P losses in agricultural soils. The effects of other depleting mechanisms such as erosion and/or surface water run-off ought to be in this regard taken into consideration as well. Estimates based on 52 % dry matter and 14 lb P_2O_5 /ton manure or 6 lb /ton manure (Vitosh et al., 1986) indicate that the manure treatments C, D and E may have contributed as much as 0.067, 0.134, and 0.202 Mg P /ha /year, respectively to correspondingly treated plots. This implies that the fertilizer treatment (B) or 0.072 Mg P/ha/year had supplied a comparable amount of P as did the manure treatment C, i.e. 0.067 Mg P /ha /year. In contrast the amount of P supplied by the manure treatments D and E can be considered to have amounted to about 2 and 3 times more the amount supplied by the inorganic fertilizer treatment (B). Despite these high P inputs from the manure treatments (D,E), it is quite surprising to observe that cumulatively greater P concentrations occurred down to the 45 cm and 60 cm depth zone from the fertilizer treatment compared the manure treatments C, D and E. A plausible explanation for these results could be related to the fact that certain limitations in soil microbial activity may have contributed to slowing down the mineralization process of the organic residues therein. Such effects taken into account would explain then to some extent why there were relatively lower P concentrations from the manure treatments. Compared P distribution patterns from the 75 cm to the 105 cm depth zone seem to indicate nonetheless that relatively lower P concentrations from the fertilizer treatment (B) occurred with respect to correspondingly recorded P values with the manure treatments C, D and E. Such results thus may be interpreted to mean that the potential risks for groundwater pollution in P are likely to become greater with continuous applications of animal manures than with similar treatments with inorganic fertilizer P. Studies conducted in England with farm yard manure have revealed in this regard that about twice as much P was displaced to the 50-60 cm depth zone when the manure treatments were applied compared to the amounts of P displaced due to the applications of the inorganic fertilizer P treatments alone (Cooke, 1981). The presence of organic compounds, which usually tend to prevent the fixation of P by soil colloids may have probably played in this instance an effective role, hence this relatively greater downward mobility of P from the organic treatments. In addition to these results, it is worth noting furthermore that the downward movement of P in this study showed to be all the more important as the manure rates were greater. Based on these data there was no evidence, however, to conclude that long term applications of manures would result in any major harmful movement of P in soil environments, except perhaps under very sandy and/or shallow water table conditions.

POTASSIUM (K)

The data relative to the long term influence of fertilizer and manure treatments on the profile distribution of K in the Metea sandy loam soil are reported in Table 3. Estimates based on 52 % dry matter and 0.009 Mg K /Mg manure or 9 lb K ton of manure (Vitosh et al., 1986) suggest that the amounts of K supplied to the soil were equivalent to 0.213; 0.427; and 0.640 Mg /ha /year, respectively for the manure treatments C (22.4 Mg /ha), D (44.8 Mg /ha) and E (67.2 Mg /ha). Comparatively, these K inputs represent about 1.5, 3.0 and 4.6 times greater the amount of K supplied (0.139 Mg K /ha /year) by the inorganic fertilizer treatment (B). The analysis of variance performed indicated (Table 4) that with the fertilizer treatment (0.139 Mg K /ha /year) significantly greater movement of K occurred down to the 75 cm depth zone compared to the control (A). Below that zone, i.e. from the 90 cm to 105 cm depth zone, similar comparisons failed, however, to reveal any significant treatment effects. Such effects thus seem to indicate that the influence of the fertilizer treatment (B) on the downward movement of K was essentially restricted to the upper 75 cm depth zone. With the manure treatment C (22.4 mg /ha /year) respectively K concentrations compared to the

Table 3. Long Term Effects of Manure and Fertilizer Treatments On Potassium (K) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	TREATMENTS A	B	C	D	E	Depth Mean
cm	mg per kg					
00-15	76	149	99	187	224	147
15-30	73	146	121	156	218	143
30-45	46	120	100	131	186	117
45-60	38	78	77	123	149	93
60-75	40	85	73	127	174	100
75-90	46	73	57	92	104	75
90-105	65	69	87	98	96	83
LSD(5%) Trt x Dpth For any 2 Means			40 mg/kg			

A : Control With 0.168 Mg/ha/year Of Fertilizer N.

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer $N-P_2O_5-K_2O$

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 4. K ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	4.42	.050
Treatment	04	23.98	.000
Error	08		
Depth	06	23.23	.000
Treat. x Depth	24	02.21	.007
Error	60		

Coefficient Of Variation : 21.13 %

control (A) showed similarly that a greater movement of K occurred, although the significant effects appeared mostly to be confined in the top 45 cm depth zone. The fact that relatively less movement of K resulted from the manure treatment (C) despite the proportionally higher K inputs compared to the inorganic fertilizer treatment (B) could be interpreted to mean that some limitations in the soil microbial activity might have prevailed, hence preventing the full release of the K from the manure treatments. With higher rates of manures, i.e. with the treatments D (44.8 mg /ha /year) and E (67.2 mg /ha /year) similar comparisons revealed nonetheless that significantly greater concentrations of K occurred down to the 90 cm depth zone. Such results seem to suggest in turn that the potential for an excessive downward movement of K in the soil would be greater with proportional increases in the manure loading rates. In the lower depths of 90-105 cm it is worth noting though that the respectively K concentrations obtained were not found to be significantly different regardless of the treatments considered. Given these results it is fair then to conclude that long term applications of moderate inorganic fertilizer treatments (0.139 Mg K /ha /year) or of manure loads no greater than 67.2 Mg /ha /year are not likely to produce any harmful movement of K in the considered soils.

CALCIUM (Ca)

The data relative to the long term influence of fertilizer and manure treatments on the profile distributions of Ca in the Metea sandy loam soil are presented in Table 5. The analysis of variance performed (Table 6) indicated that no significant treatment effects occurred with respect to the downward movement of Ca in the Metea sandy loam soil. Despite these results, it is worth considering that two distinct patterns with respect to the Ca profile distribution appeared to have emerged. First from the 15 cm to 60 cm depth zone, it can be observed that Ca concentrations were found to be relatively lower as soil depths increased inward. In the remaining sampled depths below, i.e. from the 75 cm to 105 cm depth zone, similar observations revealed in contrast that the Ca concentrations tended to become proportionally greater with the corresponding increases in soil depths. With regard to this latter pattern, the fact that calcareous concretions were encountered during the sampling operation leads then to the supposition that indigenous Ca materials were probably present in the considered sampled depths. Partial regression analysis which resulted in a correlation coefficient of +0.92 with respect to Ca values (Y) versus soil depths (75 cm $< X <$ 105 cm) appeared indeed to support such hypothesis. Similar partial regression analysis performed for the

Table 5. Long Term Effects of Manure and Fertilizer Treatments on Calcium (Ca) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	TREATMENTS A	B	C	D	E	Depth Mean
cm	kg per ha					
00-15	679	650	827	975	1004	827
15-30	629	615	824	877	943	778
30-45	532	587	825	755	811	702
45-60	399	487	413	576	605	496
60-75	508	554	566	624	612	573
75-90	659	652	1464	435	1456	933
90-105	1189	937	895	853	1035	982
LSD (5%) for 2 Treatment Means			240 mg/kg			
LSD (5%) for 2 Depth Means			247 mg/kg			

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer N-P_2O_5-K_2O

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 6. Ca ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	1.73	.237
Treatment	04	2.13	.168
Error	08		
Depth	06	3.35	.006
Treat. x Depth	24	0.81	
Error	60		

Coefficient Of Variation : 50.09 %

Ca (Y) Regression Over Depths (15-60 cm) : -0.95

Ca (Y) Regression Over Depths (75-105 cm) : +0.92

Overall Ca (Y) Regression Over Depths (X) : +0.28

upper soil zone (15-60 cm depths) showed in contrast a correlation coefficient of -0.95. The occurrence of such negative coefficient thus suggests that there were essentially no indigenous Ca materials present in this considered upper soil zone. These relatively lower Ca concentrations with depths may be interpreted then to mean that the influence of the respective treatments (manure or inorganic fertilizer N-P-K) on Ca movement in the Metea sandy loam soil was practically ineffective. Notwithstanding these results it is worth considering that the amounts of Ca accumulated in the topsoil zone appeared to be relatively more important as the rates of applied manures became greater. Such results therefore seem to indicate that long term applications of organic manures to soils could be beneficial in terms of Ca and/or lime needs for plants. Long term studies with farm yard manure at Michigan State University have indicated in this regard that the pH of soils in which continuous treatments of manures occurred tended indeed to be comparatively higher than the pH of soils where inorganic fertilizer N-P-K alone had been applied (Vitosh et al., 1975-82).

MAGNESIUM (Mg)

The data relative to the long term influence of fertilizer and manure treatments on the profile distribution of Mg in the Metea sandy loam soil are reported in Table 7. Even though the analysis of variance performed revealed not to be statistically significant (Table 8), it is worth considering the fact that the occurred Mg distribution showed a pattern that was quite similar to the pattern discussed earlier with Ca. Indeed from the 30 cm to 60 cm depth zone, it can first be observed that the Mg concentrations tended to be proportionally lower with the increased soil depths. However, from the 75 cm to the 105 cm depth zone, similar observations seemed to indicate in contrast a reversed trend in which relatively greater Mg concentrations were obtained proportionally to the increases in soil depths. Such apparent similarity with Ca thus leads to the supposition that indigenous Mg materials were by analogy present in the lower parts of the profile, i.e. from the 75 cm to 105 cm depth zone. Partial regression analysis which showed a correlation coefficient of +0.89 for the Mg values (Y) versus soil depths (75 cm $< X <$ 105 cm) appeared in this regard to support such hypothesis. With respect to the upper zone (15 cm-75 cm), the fact that the Mg concentrations were proportionally lower with the increases in soil depths could be in turn interpreted to mean that the potential for excessive downward movement of Mg into lower depths would be rather small. Notwithstanding these effects, it is also worth

Table 7. Long Term Effects of Manure and Fertilizer Treatments On Magnesium (Mg) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	A	B	C	D	E	Depth Mean
	TREATMENTS					
cm	mg per kg					
00-15	122	126	153	193	197	158
15-30	130	140	171	189	196	165
30-45	114	130	197	172	178	158
45-60	107	109	128	168	166	136
60-75	129	155	152	147	161	149
75-90	139	176	161	125	161	152
90-105	266	227	206	180	172	210
LSD 0.05 for 2 treatment means within one depth			22 mg/kg			

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer $N-P_2O_5-K_2O$

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 8. Mg ANALYSIS OF VARIANCE TABLE

Source	Degree of Freedom	F Value	Prob
Rep	02	3.63	.075
Treatment	04	2.39	.137
Error	08		
Depth	06	6.37	.000
Treat. x Depth	24	1.92	.021
Error	60		

Coefficient Of Variation : 22.41 %

Mg (Y) Regression Over Depths (15-60 cm) : -0.30

Mg (Y) Regression Over Depths (30-60 cm) : -0.95

Mg (Y) Regression Over Depths (75-105 cm) : +0.89

Overall Mg (Y) Regression Over Depths (X) : +0.40

considering that the amounts of Mg accumulated in the soil showed in general to be in a good accordance with the levels of manures applied. Given these results it is fair then to surmise that plant needs for Mg would be relatively alleviated if regular applications of manures were to be maintained in deficient soils.

IRON (Fe)

The data relative to the long term influence of fertilizer and manure treatments on the profile distributions Fe in a Metea sandy loam soil are presented in Table 9. The analysis of variance performed (Table 10) failed to reveal any significant treatment effects. This is an indication that the respective Fe concentrations obtained were most likely to represent the effects of a natural Fe occurrence in the Metea sandy loam soil. The relatively high levels of Fe found in the control, especially in the very low depths of 90-105 cm appeared indeed to support such interpretation. Notwithstanding these results, it is worth considering that the amounts of Fe accumulated in the top 75 cm depth zone showed to be proportionally greater with the applications of both the manures and inorganic fertilizer N-P-K treatments compared to the control. A plausible explanation for these effects could be related to the fact that plant roots under the treated plots had contributed more actively to

Table 9. Long Term Effects of Manure and Fertilizer Treatments On Iron (Fe) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	TREATMENTS A	B	C	D	E	Depth Mean
cm	mg per kg					
00-15	220	287	262	217	244	246
15-30	251	293	241	248	234	254
30-45	244	304	367	266	287	294
45-60	248	308	304	283	297	288
60-75	217	304	300	291	300	283
75-90	318	360	202	394	241	303
90-105	476	412	445	573	368	455
LSD 0.05 of 2 treatment means within one depth			32 mg / kg			

LEGEND

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer $N-P_2O_5-K_2O$

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 10. Fe ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	28.36	.000
Treatment	04	2.96	.089
Error	08		
Depth	06	12.10	.000
Treat.x Depth	24	01.22	.262
Error	60		

Coefficient Of Variation : 25.70 %

Fe (Y) Regression Over Depths (X) : .79

the recycling of Fe by pumping it from the underneath soil horizons. The mineralization of relatively greater amounts of organic residues may be also considered as another plausible explanation for these relatively higher levels of Fe obtained with the treated plots compared to the control. In any case the long term applications of either the manures or inorganic fertilizer N-P-K did not appear after all to have played in this instance a major role with respect to the downward movement of Fe in the Metea sandy loam soil. In currently available literature it is considered that the most leachable form of Fe in the soil is normally obtained by the Fe^{2+} form. But, for this reduced Fe form to obtain in the soil poorly drained / water logging conditions must prevail first. This taken into account seems to explain then why the applied treatments failed overall to result in any significant downward movement of Fe in the Metea sandy loam soil. Under poorly drained /water logging conditions the downward movement of soil solutions is likely indeed to become very restricted, hence the resulting limitations on the movement of Fe as well.

MANGANESE (Mn)

The data relative to the long term influence of fertilizer and manure treatments on the profile distribution of Mn in the Metea sandy loam soil are

Table 11. Long Term Effects of Manure and Fertilizer Treatments On Manganese (Mn) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	A	B	C	D	E	Depth Mean
	<----------	----------	TREATMENTS	----------	---------->	
cm		--------------	mg per kg	--------------	--------------	
00-15	133	198	251	244	268	218
15-30	147	164	226	231	278	209
30-45	117	133	182	190	275	180
45-60	90	112	145	162	194	140
60-75	51	40	60	137	85	75
75-90	28	46	35	66	46	44
90-105	53	41	51	60	60	53
LSD 0.05 of 2 treatment means within one depth			19 mg /kg			

<u>LEGEND</u>

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer $N-P_2O_5-K_2O$

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 12. Mn ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	10.35	.006
Treatment	04	20.96	.000
Error	08		
Depth	06	35.49	.000
Treat. x Depth	24	01.00	
Error	60		

Coefficient Of Variation : 36.6 %

Mn (Y) Regression Over Depths (X) : -.97

presented in Table 11. The analysis of variance performed showed (Table 12) in this regard that highly significant treatment effects occurred with respect to the control (A). With the inorganic fertilizer treatment, it can indeed be observed that relatively higher concentrations of Mn occurred down to the 60 cm depth zone. Similar observations made with the manure treatments also revealed that relatively greater Mn concentrations had resulted, although at much lower depths, i.e. down to the 90-105 cm depth zone. Such results thus suggest that the movement of Mn in the Metea sandy loam soil was essentially more effective with the applications of manures than with the inorganic fertilizer treatments. This seemed particularly to be verified with the higher rates of manures (44.8 Mg /ha; 67.2 Mg /ha) than lower (22.4 Mg /ha). To account for such effects, one would have to suspect that chelated Mn forms derived from the manure treatments had probably contributed to this greater downward mobility of Mn in the Metea sandy loam soil. Notwithstanding these results, partial regression analysis performed showed, however, a correlation coefficient of -0.97 with respect to Mn values (Y) versus sampled soil depths (X). Such negative coefficient could be interpreted then to mean that the potential for excessively downward movement of Mn in the Metea sandy loam soil is likely to remain minimal unless the applied treatment rates are greater than those considered in this study.

ZINC (Zn)

The data relative to the long term influence of fertilizer and manure treatments on the profile distribution of Zinc in the Metea sandy loam soil are reported in Table 13. The analysis of variance performed revealed (Table 14) that significant treatment effects occurred with respect to the results obtained with the control (A). In most cases the respective Zn concentrations obtained for the top 75 cm depth zone showed indeed to be relatively greater with the treated plots compared to the control. Below this 75 cm depth zone, i.e. from the 90 cm to 105 cm depth zone similar comparisons made failed, however, to indicate any apparent changes in the occurred Zn concentrations from the applied treatments vis-à-vis the control. Such results thus suggest that these increases in the downward movement of Zn were essentially restricted to the upper 75 cm depth zone. Within that zone it is worth noting particularly that the amounts of Zn accumulated appeared to be comparatively greater with the manure treatments (C,D,E) than with the inorganic fertilizer treatment (B). Such effects though did not appear to be evident until the manure rates were increased from 22.4 Mg /ha /year (C) to 44.8 Mg /ha /year (D) and 67.2 Mg /ha /year,

Table 13. Long Term Effects of Manure and Fertilizer Treatments On Zinc (Zn) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	A	B	C	D	E	Depth Mean
	<-----------		TREATMENTS		----------->	
cm			mg per kg			
00-15	8	11	8	22	21	14
15-30	6	21	23	22	30	21
30-45	23	25	28	29	32	27
45-60	27	28	30	31	34	30
60-75	30	30	31	34	33	32
75-90	33	34	34	33	34	34
90-105	38	36	37	35	37	36

LSD (5%)
for any 2 treatment
means within one depth 13 mg /kg

LSD (5%)
Treatment x Depth 42 mg / kg
For any two means

LEGEND

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer $N-P_2O_5-K_2O$

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

Table 14. Zn ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	01.15	.363
Treatment	04	7.27	.000
Error	08		
Depth	06	99.32	.000
Treat. x Depth	24	04.44	
Error	60		

Coefficient Of Variation : 11.03 %

Zn (Y) Regression over Depths (X) : .96

respectively. These results thus clearly indicate that the potential for excessive downward movement of Zn in the soil is likely to be greater with the applications of relatively higher rates of manures than otherwise. The basis for this interpretation stems from the fact that with heavier rates of manures the levels of chelated Zn forms being released in the soil are likely to be greater, hence resulting in the increased movement of Zn to lower depths. Based on these results there is no reason though to believe that excessively downward movement of Zn would result in the Metea sandy loam soil unless the applied treatment rates were to exceed those prescribed in this study.

COPPER (Cu)

The data relative to the long term influence of fertilizer and manure treatments on the profile distribution Cu in the Metea sandy loam soil are presented in Table 15. The analysis of variance performed showed (Table 16) that significant movement of Cu occurred with both the applications of manures and of inorganic fertilizer treatments compared to the control. With the manure treatments relative increases in the Cu concentrations seemed indeed to be obtained down to the 105 cm depth zone. With the fertilizer treatment the occurred increases in the Cu concentrations indicated in

Table 15. Long Term Effects of Manure and Fertilizer Treatments On Copper (Cu) Profile Distribution in a Metea Sandy Loam Soil.

Soil Depth	A	B	C	D	E	Depth Mean
	<-----	-----	TREATMENTS	-----	----->	
cm	mg per kg					
00-15	.97	.97	.97	.97	1.5	.97
15-30	1.5	1.5	1.5	1.5	3.5	2.0
30-45	1.5	2.5	3.5	2.5	2.5	2.5
45-60	2.5	3.0	1.5	2.5	3.5	2.5
60-75	2.5	3.0	1.5	2.5	3.5	2.5
75-90	na	na	na	na	na	na
90-105	.97	.97	2.0	3.5	4.0	2.0

LSD (5%) for 2 treatment means within one depth: 2.04 mg per kg

LEGEND

A : Control With 0.168 Mg/ha/year Of Fertilizer N

B : 0.168-0.168-0.168 Mg/ha/year Of Fertilizer N-P_2O_5-K_2O

C : 22.4 Mg/ha/year Of Cattle Manure

D : 44.8 Mg/ha/year Of Cattle Manure

E : 67.2 Mg/ha/year Of Cattle Manure

na : data not available due to analytical error

Table 16. Cu ANALYSIS OF VARIANCE TABLE.

Source	Degree of Freedom	F Value	Prob
Rep	02	0.17	
Treatment	04	6.21	.014
Error	08		
Depth	06	19.80	.000
Treat. x Depth	24	03.44	.000
Error	60		

Coefficient Of Variation : 29.9 %

contrast to be restricted to the 75 cm depth zone. Such results thus suggest that the applications of manures had resulted in relatively more Cu movement compared to the inorganic fertilizer treatment. As with the other metals (Zn and Mn in particular) this relatively higher Cu movement observed with the manure treatments can be related to the fact that ions in organic forms tend to be generally more soluble in soil solutions compared to those in inorganic forms. In terms of the manure loading effects, it is worth noting furthermore that the occurred Cu movement appeared to be all the more important as the applied rates were greater. Even though copper is not normally considered to be a very mobile element (Ellis et al., 1983) these results thus appeared after all to suggest that relatively important movement of Cu cannot be discounted in soils where long term applications of manures have occurred.

SUMMARY

From this study the following conclusions can be drawn :

-Long term applications of inorganic fertilizer or cattle manure appeared to have resulted in significant nutrient accumulations/movement in the Metea sandy loam compared to the control.

-For most nutrients considered it was observed that the potential for excessive downward movement into lower soil zones and hence the risks for groundwater pollution reflected the amounts of manures applied.

-At equal rates there seemed to be relatively greater P movement to the 90-105 cm zone in the soil from animal manure compared to inorganic treatments.

-At equal rates it appeared on the other hand as though more K had moved to the 90-105 cm zone in the soil from the inorganic treatments compared to manure applications.

-Despite their various movement characteristics, there was no evidence of significant nutrient movement beyond the 75 cm depth zone in the Metea soil. This indicates then that long term applications of organic manures in soils can be very beneficial in building up complementary nutrient levels for plant growth.

-Risks for potential pollution of groundwaters were found to be of relatively little concern, although there were clear indications that serious problems (phytotoxicity and/or pollution) could result in the Metea sandy loam soil if given manure rates were to exceed those considered in this study.

R E S U L T S   A N D   D I S C U S S I O N

PART II

INFLUENCE RELATIVE TO THE EFFECTS OF ORGANIC AMENDMENTS (PLANT RESIDUES/ANIMAL MANURES) AND SOIL FACTORS (INCUBATION, pH, AND TEXTURE) ON POTENTIAL LEACHING OF ESSENTIAL NUTRIENTS IN SOILS

INFLUENCE RELATIVE TO INCUBATION

A) IN A RIDDLES-HILLSDALE SANDY LOAM SOIL

The results relative to the effects of the control soil compared to the respectively applied treatments in non-incubated soils are reported in Table 17. From these data it can be observed that with the barley and soybean residue treatments the quantity of P, K, Ca and Mg leached was in most cases not significantly greater than the quantity leached from the control soil. With the cattle manure and poultry manure treatments similar comparisons showed, in contrast, that significantly greater leaching of nutrients occurred in the treated soils compared to the non-treated control. Such results suggest that the potential for excessive nutrient leaching in a Riddles-Hilldale sandy loam soil

Table 17. Effects of plant residues, animal manures and fertilizer N-P-K on nutrient leaching in a Riddles-Hillsdale sandy loam soil (pH 5.7).

Amount of nutrients leached in mg per 120 ml of leachate

	Soil Treatments+										
	Control Soil	Barley Residue		Soybean Residue		Cattle Manure		Poultry Manure		Fertilizer N-P-K	
P	1.57	0.43	**	1.91		4.30	**	0.36	**	.19	**
K	23.16	23.16		31.32		83.28	**	108	**	173	**
Ca	60	51.12		62.52		83.88	**	160	**	317	**
Mg	21	20.4		20.88		30.72	**	56.16	**	91.56	**
Fe	0.87	0.45	*	1.69	**	4.36	**	0.08	**	0.08	**
Mn	0.09	0.03	**	0.22	**	0.49	**	0.35	**	0.44	**
Zn	0.09	0.03	**	0.04		0.10		0.11		0.10	
Cu	0.05	0.01	**	0.05		0.12	**	0.01	**	0.005	**

LEGEND

+ : all treatments were non-incubated.

* : significant leaching effects (5% level) with respect to the control.

** : significant leaching effects (1% level) with respect to the control.

is likely to be higher with the application of animal manures compared to similar treatments with plant residues. Even though minimal incubation occurred in this instance, the fact that significantly greater nutrient concentrations in the leachate resulted with the animal manure treatments leads to the supposition that relatively higher levels of soluble organic complexes were present in these latter treatments compared to the barley and soybean residue treatments. Studies have indicated that metals in the form of organo-complexes tend to percolate faster with water downward through the soil profile than otherwise (Tan, 1982). This would explain why a relatively greater leaching of nutrients resulted with the cattle and poultry manures compared to the barley and soybean residues. With the inorganic fertilizer, the nutrient concentrations obtained in the leachates similarly showed, except for P and Fe, that significant leaching occurred with respect to the control. Comparisons between the fertilizer and the other treatments suggest that the leaching of major nutrients K, Ca and Mg was increased by factors of about 5 to 6 with respect to the control and plant residue (soybean and barley) treatments, and by factors of about 2 to 3 with respect to the animal manure (cattle and poultry) treatments. Such effects which are consistent with the data presented in Table 18 appear to support the hypothesis that in the short run there would probably be a tendency for greater nutrient movement downward in the soil from the application of inorganic compared to organic materials. A plausible explanation for this may be related to lower levels of soluble organic compounds being available for the mobilization of soil nutrients, especially when the microbial activity is in its initial intense phase. By contrast the inorganic fertilizer treatment which is usually water soluble tended to have resulted in relatively more leaching for major nutrients K, Ca and Mg compared to being adsorbed or fixed by soil colloids. Given these reasons, it seems fair then to suggest that the potential for excessive nutrient leaching from the applications of organic treatments in a given soil would depend not only on the amounts of soluble organic compounds, but also on the relative intensity of the microbial activity occurring there-in.

The results relative to the effects of incubation on nutrient leaching in a Riddles-Hillsdale sandy loam soil are presented in Table 18. Under barley residue treatments, the results obtained indicate no significant effects on the leaching of most nutrients, except for Fe, Cu, and to some extent P. With P and Fe it is worth noting that incubation of the treated soil compared to non-incubation resulted in a net immobilization effect, since their concentrations in the non-incubated leachate turned out to be relatively greater. Statistically these

Table 18. Influence of Incubation on Nutrient Leaching Resulting from Applied Crop Residues and Animal manures on a Riddle-Hillsdale Sandy Loam Soil (pH 5.7).

Amount of nutrients leached in mg per 120 ml of leachate

	BARLEY RESIDUE		SOYBEAN RESIDUE		CATTLE MANURE		POULTRY MANURE		FERTILIZER N-P-K	
	NI	I	NI	I	NI	I	NI	I	NI	I
P	0.43	0.34	1.91	1.82	4.30	6.74	0.36	1.34	0.19	0.22
K	23.16	27.84	31.32	** 64.44	83.28	* 91.68	108	116	173	180
Ca	51.12	58.68	62.52	* 77.28	83.88	* 96.96	160	** 195	317	335
Mg	20.4	22.68	20.88	** 25.44	30.72	** 36.36	56.16	* 64.08	91.56	95.04
Fe	** 0.45	0.01	1.69	1.74	4.36	** 7.54	0.08	** 2.56	0.08	** 0.12
Mn	0.03	0.03	0.22	* 0.28	0.49	** 0.78	0.35	** 0.65	0.44	0.54
Zn	0.03	0.04	0.04	0.04	0.10	* 0.17	0.11	0.08	0.10	* 0.12
Cu	* 0.013	0.010	0.054	** 0.127	0.124	* 0.183	0.012	** 0.036	0.004	0.006

<u>LEGEND</u>

I : Incubated; NI : Non-Incubated;

* : Significant at 5 %; ** : Significant at 1 % .

immobilization effects were significant only with respect to Fe, but not with P and Cu. Despite these results it can be observed overall that the influence of incubation in soils treated with barley residues showed relatively more leaching for K, Ca, Mg and Zn. Incubation had a much larger effect on increasing nutrient leaching with the soybean residue treatment than with the barley residue. Of the eight nutrients considered five (K, Ca, Mg, Mn and Cu) were found to have significantly higher concentrations in leachate from the incubated soil than from the non-incubated soil. Nutrients that remained practically unaffected included P, Fe and Zn. Despite the risks for potentially greater leaching, these data seem to indicate that on equal dry weight basis the incorporation of soybean residue would be more effective in mobilizing nutrients in the soil compared to the barley residue.

Data for the incubated cattle and poultry manure treatments indicate relatively more leaching of K, Ca and Mg from incubated compared to non-incubated treatments. The influence of incubation seemed to be somewhat less pronounced with the poultry manure than with the cattle manure treatments. With cattle manure the leaching of the nutrients K, Ca, Mg, Fe, Mn, Zn and Cu appeared to be significantly greater under incubated conditions. With poultry manure there was apparently an immobilization effect on Zn. The leaching of K under this treatment was in contrast greater with incubation, but not significantly different when compared to the non-incubated treatments. In comparison with the plant residue treatments these data suggest that soil treated with animal manures resulted in relatively greater nutrient mobilization and leaching under comparable rates and incubation conditions.

With inorganic fertilizer leaching from incubated soil treatments appeared to be relatively greater compared to non-incubated soil although the differences were not significantly different except for Fe and Zn. This suggests that incubation is not likely to play a major role in observed nutrient leaching under inorganic fertilizer treatments. It is worth noting that the highest nutrient leaching occurred from the inorganic fertilizer treatments. This indicates that in the short run the potential for downward nutrient movement in soils would be relatively higher with inorganic fertilizer compared to organic treatments. Data from field studies (cf. Results and Discussions, Part I) suggest, however, that this trend may be reversed with time in the long run.

B) IN A SIMS SILTY CLAY LOAM

The results relative to the effects of the manure treatments in non-incubated soils compared to the control soil are reported in Table 19. Data obtained with the barley residue, soybean residue, and cattle manure treatments indicated no significant differences occurred in nutrient leaching with relative to the control. The concentrations of K, Ca and Mg in the poultry manure and inorganic fertilizer treatments suggested, however, that significant nutrient leaching occurred. This clearly indicates as in the Riddles-Hillsdale sandy loam soil (Table 17) that these elements would have a greater susceptibility to leaching loss in the soil. With poultry manure, the significantly higher leaching of P, Ca, Mg, Fe and Zn which resulted in spite of the restricted incubation conditions also suggests that water soluble organic compounds were probably present in this treatment. Studies have shown that fulvic acids, which are normally characterized by water soluble chelates tend to be easily dispersed and move more rapidly in the soil compared to humic acids which by contrast are considered to be slowly soluble compounds in water (Tan, 1982). As a result, this suggests that the potential for excessive nutrient leaching from applied organic treatments in the soil would depend not only on the incubation /mineralization factors, but also on the respective ratios

Table 19. Effects of plant residues, animal manures and fertilizer N-P-K on nutrient leaching in a Sims silty clay loam soil (pH 7.1).

Amount of nutrients leached in mg per 120 ml of leachate

	Soil Treatments+					
	Control Soil	Barley Residue	Soybean Residue	Cattle Manure	Poultry Manure	Fertilizer N-P-K
P	0.04	0.04	0.00**	0.06	0.10 **	0.04
K	9.36	8.76	8.52	9.12	11.64	14.4 *
Ca	61.8	53.88	62.64	58.8	82.32 *	169 **
Mg	20.52	19.56	21.36	21.84	27.6 **	56.16 **
Fe	0.002	nd	0.003	0.001	0.014**	0.016 **
Mn	nd	nd	nd	nd	nd	nd
Zn	0.003	0.002	0.007	0.031*	0.090 *	0.013 *
Cu	0.002	0.004	0.001	0.003	0.003	0.003

LEGEND

+ : all treatments were non-incubated.

* : significant leaching effects (5% level) with respect to the control.

** : significant leaching effects (1% level) with respect to the control.

nd : not detectable.

of water soluble versus insoluble chelates in each treatment. In spite of the relative similarity in the observed leaching patterns between these two soil types it is worth noting that the respective nutrient concentrations (essentially major nutrients) in the leachates were generally lower with the clay loam compared to the sandy loam soil. The finer texture and higher pH of the soil probably contributed to these effects.

The results relative to the effects of incubation on essential nutrient leaching in a Sims silty clay loam are reported in Table 20. The data obtained with the barley residue, soybean residue, cattle manure and fertilizer N-P-K treatment indicate that overall nutrient leaching from the incubated soils was not significantly different from that which occurred in the corresponding non-incubated soil. With poultry manure, similar comparisons showed, however, that significantly higher nutrient leaching occurred in the incubated soils. Such results suggest that incubation was practically ineffective, except with poultry manure, on the respective nutrient leaching in the Sims silty clay soil.

Table 20. Influence relative to incubation on nutrient leaching from applied organic manures under the Sims silty clay loam soil (pH 7.1).

Amount of nutrients leached in mg per 120 ml of leachate

	BARLEY RESIDUE		SOYBEAN RESIDUE		CATTLE MANURE		POULTRY MANURE		FERTILIZER N-P-K	
	NI	I	NI	I	NI	I	NI	I	NI	I
P	0.04	0.04	0.00	0.01	0.06	0.01 *	0.10	0.18	0.04	0.05 *
K	8.76	8.76	8.52	8.16	9.12	9.00	11.64	13.92 *	14.4	14.88
Ca	53.88	50.28	62.64	55.56	58.8	59.16	82.32	113 *	169	168
Mg	19.56	18.84	21.36	19.32	21.84	21.72	27.6	37.44 *	56.16	60
Fe	nd	0.004 **	0.003	nd **	0.001	nd	0.014	0.014	0.016	0.009
Mn	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Zn	0.002	0.007	0.007	0.006	0.031	0.015	0.090	0.165	0.013	0.014
Cu	0.004	0.006 *	0.001	0.002	0.003	0.002	0.003	0.006 *	0.003	0.002

<u>LEGEND</u>

I : Incubated; NI : Non-Incubated.

* : Significant at 5 %; ** : Significant at 1 % .

nd : not detectable.

INFLUENCE RELATIVE TO THE pH FACTOR

A) INFLUENCE OF INCREASING SOIL pH

The results relative to the influence of increasing the soil pH on nutrient leaching from applied fertilizer and manure treatments are presented in Table 21. The goal of increasing soil pH to 7.1 was not attained due to the buffering capacity of the soil. However, the NaOH treatment generally increased the soil pH by about one unit after incubation. Increasing the soil pH induced significantly more leaching of P with the plant residue treatments (barley and soybean). With the animal manures (cattle and poultry) and inorganic fertilizer treatments a similar increase in soil pH resulted, by contrast, in a reduction in leached P. With the plant residues, the higher P leaching which occurred could be related to the fact that increasing the soil pH to about 6.5 contributed to producing higher P concentrations in soil solutions, hence increasing the potential for its movement in the soil. With a pH value of 6.5 it can be considered that the solubility of P in the soil was somewhat close to the maximum. With the animal manures, the reduction in P leaching could suggest on the other hand that some soluble P was converted into insoluble Ca-P complexes. The corresponding soil pH which was increased to about 6.7 leads in this regard to the conclusion that more Ca^{2+}

Table 21. Influence of Increasing Soil pH On Essential Nutrient Leaching from Applied Organic Manures in a Riddle-Hillsdale Sandy Loam Soil.

Amount of nutrients leached in mg per 120 ml of leachate'

	BARLEY RESIDUE		SOYBEAN RESIDUE		CATTLE MANURE		POULTRY MANURE		FERTILIZER N-P-K	
pH	5.2	6.1	5.4	6.5	5.5	6.8	5.6	6.7	5.3	6.5
P	0.34	** 0.99	1.82	** 2.77	** 6.72	4.68	1.34	1.03	** 0.22	0.12
K	** 27.84	13.56	** 64.44	34.08	91.68	87.84	** 116	69	** 180	153
Ca	** 58.68	15.60	* 77.28	69.72	* 96.96	82.2	** 195	143	* 335	290
Mg	** 22.68	5.88	25.44	23.52	** 36.36	29.88	** 64.08	49.92	95.04	89.76
Fe	0.01	** 1.81	1.74	** 3.99	** 7.56	5.76	** 2.56	0.01	** 0.12	0.04
Mn	0.03	** 0.13	0.28	0.30	0.78	0.64	** 0.65	0.28	0.54	0.53
Zn	0.04	0.03	0.04	** 0.19	* 0.17	0.12	0.08	0.08	** 0.12	0.07
Cu	0.01	** 0.02	0.12	0.11	0.18	0.15	** 0.03	0.01	0.006	0.004

<u>LEGEND</u>

NS : Non-Significant; (+): Reading indicates pH obtained after the incubation process.

* : Significant at 5 % ; ** : Significant at 1 % .

species were available, hence contributing to the formation of Ca-P complexes. The increase in the soil pH generally reduced the leaching of K, Ca and Mg. With the fertilizer treatment relatively greater amounts of K, Ca and Mg were displaced at lower pH. The resulting effects of increased pH on Fe, Mn, Zn, and Cu were somewhat similar to the effects obtained with the basic cations. The leaching effects on micronutrients were nonetheless much less important compared to the effects on K, Ca and Mg. The relatively lower contents of micronutrients in organic manures perhaps could account for these effects. It may also be that these effects were simply reflecting the stronger bonding of the micronutrients to the organic complexes. Selected stability constants for metal-fulvic acid complexes calculated by Tan et al. (1971b) show the following decreasing log K values at pH 5.5 : Cu-FA, 8.26; Zn-FA, 5.73; Mg-FA, 4.06. This suggests that Cu-FA or Zn-FA complexes would be generally less soluble in the soil solution compared to the Mg-FA complexes. All these factors combined appear to explain why the increased soil pH resulted in relatively greater movement of the major nutrients compared to the micronutrients.

Results from soil pH and CEC analyses performed after the leaching process are reported in Table 22. From the data obtained it appears that increasing the soil pH tended to result in relative increases in the Table 22.

Influence of Increased pH on CEC Changes
In the Riddle-Hillsdale Sandy Loam Soil*.

	pH_1 (5.4)	pH_2 (6.5)
Soil Treatments	CEC_1 (me/100g)	CEC_2 (me/100g)
Barley	5.8	6.0
Soybean	6.2	6.3
Cattle	6.3	6.8
Poultry	6.9	7.3
Fertilizer	6.0	6.2

LEGEND

CEC_1 : CEC Readings Before Additions of 0.1 N NaOH

CEC_2 : CEC Readings After Additions of 0.1 N NaOH

pH_1 : Average pH Before additions of 0.1 N NaOH

pH_2 : Average pH After additions of 0.1 N NaOH

* : Analysis Performed After Leaching Process

corresponding soil CEC. Despite this trend, no clear conclusions could be drawn regarding CEC and nutrient movement.

B) INFLUENCE OF LOWERING SOIL pH

The results relative to the influence of lowering soil pH on nutrient leaching from applied fertilizer and manure treatments are presented in Table 23. In this study the lowering of soil pH was obtained by mixing the native soil (pH 7.1) with appropriate amounts of 0.1 N H_2SO_4. The objective of this procedure was to obtain a lower pH of about 5.7. Due to the relative soil buffering effects from the treatments the resulting pH's shown in this table differ somewhat from the expected values. Reduction of the soil pH resulted in no significant differences in the leaching of P regardless of treatment. This could be related to the fact that the optimum pH range for P availability in the soil is normally obtained anywhere between 6.0 and 7.0. Reducing or increasing soil pH within this range is not likely therefore to result in any appreciable change in solubility for P and, hence, in its movement in the soil. The quantity of K, Ca, and Mg leached increased as soil pH decreased. This suggests that acidification would play an important role in the solubility and downward movement of these nutrients in the soil. These increased leaching effects occurred to a lesser degree with soybean residue and inorganic fertilizer than with barley residue, cattle manure, and poultry manure treatments. Similar comparisons made with Fe, Mn, Zn and Cu indicated, on the other hand, only a few

Table 23. Influence of Lowering Soil pH On Essential Nutrient Leaching from Applied Organic Manures in a Sims Silty Clay Loam.

Amount of nutrients leached in mg per 120 ml of leachate

	BARLEY RESIDUE		SOYBEAN RESIDUE		CATTLE MANURE		POULTRY MANURE		FERTILIZER N-P-K	
pH	5.8	6.5	6.2	6.6	6.5	6.7	6.7	6.9	6.3	6.6
P	0.05	0.04	0.01	0.01	0.007	0.010	0.17	0.18	0.06	0.05
K	* 9.36	8.76	8.4	8.16	** 11.04	9.00	* 16.32	13.92	15.96	14.88
Ca	** 65.64	50.28	60.84	55.56	** 84.96	59.16	* 147	113	208	168
Mg	** 22.8	18.84	20.88	19.32	** 30.36	21.72	* 47.88	37.44	67.32	60
Fe	nd	** 0.004	* 0.002	nd	* 0.003	nd	0.021	0.014	0.009	0.009
Mn	nd	nd	nd	nd	nd	nd	** 0.000	nd	nd	nd
Zn	0.007	0.007	0.003	0.006	0.014	0.015	0.112	0.165	0.010	0.014
Cu	0.007	0.006	* 0.003	0.002	* 0.003	0.002	0.006	0.007	0.002	0.002

LEGEND

NS : Non-Significant.

(+): Reading indicates pH obtained after incubation.

* : Significant at 5 % ; ** : Significant at 1 % .

nd : not detectable.

cases of significantly increased leaching as the soil pH decreased. Hence small pH changes in this soil pH range are not likely to bring about any appreciable mobilization or movement of the micronutrients contained in the organic treatments.

Results from soil pH and CEC analysis performed after the leaching process are reported in Table 24. From the data obtained it appears that soil CEC tended to decrease as the pH dropped from 6.7 to 6.3. Despite this trend, no clear conclusions could be drawn regarding CEC and nutrient leaching.

Table 24. Influence of Decreased pH on CEC Changes In the Sims Silty Clay Loam Soil*.

	pH_1 (6.7)	pH_2 (6.3)
Soil Treatments	CEC_1 (me/100g)	CEC_2 (me/100g)
Barley	12	11.6
Soybean	12.8	13.3
Cattle	13.5	13.1
Poultry	14	13
Fertilizer	12.5	12

LEGEND

CEC_1 : CEC Readings Before Additions of 0.1 N H_2SO_4

CEC_2 : CEC Readings After Additions of 0.1 N H_2SO_4

pH_1 : Average pH Before additions of 0.1 N H_2SO_4

pH_2 : Average pH After additions of 0.1 N H_2SO_4

* : Analysis Performed After Leaching Process

INFLUENCE RELATIVE TO TEXTURE

The results relative to the influence of texture on nutrient leaching from applied fertilizer and manure treatments are presented in Table 25. With barley residue treatments significantly greater leaching of both Ca and Mg occurred in the clay loam compared to the sandy loam soil. By contrast the concentrations of the other nutrients were found to be significantly higher in the leachate of the sandy loam soil. With the soybean residue, cattle manure, poultry manure, and fertilizer treatments similar comparisons showed, for the most part, significantly lower leaching effects on all nutrients in the clay loam soil compared to corresponding nutrient movement in the sandy loam soil. These results indicate, as one would have suspected, that coarse textured soils are more conducive to greater nutrient movement compared to finer textured soils. It is worth noting though that this seemed to be verified to a greater extent with P and the major cations K, Ca, and Mg than with the micronutrients Fe, Mn, Zn, and Cu. This is particularly illustrated by the fact that compared Zn concentrations under the poultry manure treatments as well as Zn and Cu concentrations under the inorganic fertilizer treatments were not significantly different between the two soil textures. In terms of comparative treatment effects, cumulative ratios of the texture results suggest

Table 25. Influence of Soil Types On Essential Nutrient Leaching from Applied Organic Manures+.

Amount of nutrients leached in mg per 120 ml of leachate

	BARLEY RESIDUE		SOYBEAN RESIDUE		CATTLE MANURE		POULTRY MANURE		FERTILIZER N-P-K	
	A	B	A	B	A	B	A	B	A	B
P	** 0.66	0.05	** 2.30	0.01	** 5.76	0.00	** 1.19	0.18	** 0.18	0.06
K	** 20.64	9.00	** 49.2	8.28	** 89.76	10.08	** 92.64	15.12	** 167	15.36
Ca	37.2	** 57.96	** 73.56	58.20	** 89.52	72.00	** 169	130	** 313	188
Mg	14.4	** 20.88	** 24.48	20.04	** 33.12	26.04	** 57.00	42.72	** 92.4	63.6
Fe	** 0.914	0.002	** 2.880	0.001	** 6.60	0.002	** 1.32	0.024	** 0.084	0.009
Mn	** 0.081	nd	** 0.300	nd	** 0.720	nd	** 0.469	0.002	** 0.540	nd
Zn	** 0.042	0.007	** 0.120	0.004	** 0.147	0.014	0.085	0.139	0.100	0.013
Cu	** 0.019	0.007	** 0.120	0.002	** 0.168	0.002	** 0.002	0.007	0.006	0.002

LEGEND

A : Riddles-Hillsdale Sandy Loam Soil.

B : Sims Silty Clay Loam Soil.

(**) : Significant at 1 % .

(+) : Reading averaged over pH .

nd : not detectable.

with respect to major cations K, Ca, and Mg that the potential for nutrient movement in the sandy loam soil increased by factors of 0.8; 1.7; 2.0; 1.7; and 2.1 when the nutrient concentrations in the leachate from barley residue, soybean residue, cattle manure, poultry manure, and fertilizer treatments, respectively, were compared to corresponding treatments in the clay loam soil. This clearly underlines how determinant could be the influence the texture in the process of essential nutrient leaching in soils. Studies have suggested in this regard that in soils with low sorptive capacity there seems in general to be a relatively greater movement of the acid phenols compared to soils with higher sorptive capacity (Shindo and Kuwatsuka, 1976). A comparison of the respective ratio results indicate furthermore that the effects due to soybean residue treatment were to some extent comparable to those obtained with the poultry manure, although relatively lower when compared to either the cattle manure or fertilizer treatments. Compared ratio results with the fertilizer and cattle manure treatments were not significantly different. This could be interpreted to mean that the potential for nutrient movement and leaching loss in soils treated with either poultry manure or inorganic fertilizer treatments would be about the same when comparable nutrient rates are applied.

SUMMARY

From this study the following conclusions can be drawn :

-Without incubation the extent of nutrient leaching which occurred in both soils appeared generally to reflect the relative solubility of the organic compounds contained in the applied treatments. In most nutrient cases, however, the solubility of these compounds under non incubated conditions were apparently much lower in the clay loam soil compared to the sandy loam.

-Incubation generally resulted in increased leaching of the considered nutrients except with the inorganic fertilizer treatment and to some extent under barley residue treatments, respectively.

-Under incubation, nutrients that seemed to be leached relatively faster included K, Ca, and Mg compared to non-incubated conditions. This indicates that the potential for release and movement in soils for these nutrients would be greater than with P, Fe, Mn, Zn, and Cu, respectively.

-With respect to soil texture the results obtained suggest relative increases in nutrient leaching that amounted up to 1.7 to 2.0 times more under the sandy loam compared to clay loam soil conditions. This clearly underlines how important the influence of the texture can be in the process of essential nutrient leaching in soils.

-Compared pH effects indicated that nutrient leaching in soils would be more important when corresponding pH are lower. There were apparently no clear effects from the soil pH changes on corresponding CEC values.

-Based on applied dry matter rates these data suggest that the extent of nutrient leaching in the soil tended to be relatively greater, regardless of considered factors, with the applications of animal manures compared to plant residues, respectively.

-Supplementary studies would have to be implemented, however, before definite conclusions/recommendations can be made.

L I S T O F R E F E R E N C E S

REFERENCES

Abdullahi A. 1971. Monocropping trial - Samaru Institute for Agricultural Research, Samaru. Unpublished data. Cited in Mokwunye, 1980. pp. 195.

Adriano D.C., L.T. Novak, A.E. Erickson, A.R. Wolcott, and B.G. Ellis. 1975. Effect of long term land disposal by spray irrigation of food processing wastes on some chemical properties of the soil and subsurface water. J. Environ. Qual., 4:242-248.

Agarwal R.R. 1965. Soil fertility in India. Asia Publishing House, London. 123 pp.

Agbim N.N. 1985. Potential of cassava peels as a soil amendment. II: Field evaluation. J. Environ. Qual., 14:411-414.

Agboola A.A. 1975. Problems in improving soil fertility by the use of green manuring in the tropical farming system. FAO Soils Bulletin No.27. pp 147-164.

Aikman C.M. 1894. Manures and the principles of manuring. William Blackwood and sons, London. pp 474-492 and 493-528.

Allison E.F. and G.R. Cover. 1960. Rates of decomposition of short-leaf pine sawdust in soil at various levels of nitrogen and lime. Soil Sci. 89:194-201.

Amoozegar-Fard A., W.H. Fuller, and A.W. Warrick. 1975. Migration of salt from waste as affected by moisture regime and aggregate size. J. Environ. Qual., 4:468-472.

Amoozegar-Fard A., W.H. Fuller, and A.W. Warrick. 1980. The movement of salts from soils following heavy applications of feedlot. J. Environ. Qual., 9:269-272.

Anonymous. International Institute of Tropical Agriculture (IITA). Farming systems program annual reports (1971, 1972, 1973).

Avnimelech Y. and J. Raveh, 1975. Nitrate leakage from soil differing in texture and nitrogen load. J. Environ. Qual., 5:79-81.

Ayanaba A. and B.N. Okigbo. 1975. Mulching for improved soil fertility and crop production. FAO Soils Bulletin No.27. pp 97-121.

Ayanaba A. 1980. The potential contribution for nitrogen from rhizobia-A review. FAO Soils Bulletin No.43. pp 211-229.

Azevedo J. and P.R. Stout. 1974. Farm animal manures. Univ. Calif. Agric. Ext. Serv., Manual No.14. pp 45-56; 62-66.

Baker J.L., K.L. Campbell, H.P. Johnson, and J.J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. J. Environ. Qual., 4:406-412.

Baker J.L. 1985. Conservation tillage : water quality considerations. pp 217-238. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc, Chelsea, MI.

Balasubramanian V. and L.A. Nnadi. 1980. Crop residue management and soil productivity in savanna areas of Nigeria. FAO Soils Bulletin No.43. pp 106-120.

Bandel V.A., C.S. Shaffner, and C.A. McClurg. 1972. Poultry manure - A valuable fertilizer. Fact Sheet No.39, Cooperative Extension Service, University of Maryland.

Barber S.A. 1984. Soil nutrient bioavailability-A mechanistic approach. John Wiley and Sons, New York, NY.

Barlett R.J. and J.M. Kimble. 1976. Behavior of chromium in soils. II: Hexavalent forms. J. Environ. Qual., 5:383-386.

Beek J., F.A.M. de Haan, and W.H. van Riemsdijk. 1977. Phosphates in soils treated with sewage water : II. Fractionation of accumulated phosphates. J.Environ.Qual., 6:07-12.

Bhardwadj S.P., S.N. Prasad, and G. Singh. 1981. Economizing N by green manures in rice wheat rotation. Indian J. Agric. 51:86-90.

Bittell J.E. and R. Miller. 1974. Lead, cadmium and calcium selectivity coefficients on a montmorillonite, illite, and kaolinite. J.Environ.Qual., 3:250-252.

Blanchar R.W., G. Rehm, and A.C. Caldwell. 1965. Sulfur in plant materials by digestion with nitric and perchloric acid. Soil Sci. Soc. Proc. 29:71-72.

Blevins R.L., W.W. Frye, and M.S. Smith. 1985. The effects of conservation tillage on soil properties. pp 99-110. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Boyer J. 1973. Comportement du potassium dans les sols tropicaux cultives. Proc. 10th Colloq. Int. Potash Inst., Abidjan, Ivory Coast. pp 83-102.

Broadbent E.F. 1974. Nitrogen release and carbon loss from soil organic matter during decomposition of added plant residues. Soil Sci. Soc. Am. Proc. 12:246-249.

Bunt S.J. and D.A. Rovira. 1955. The effect of temperature and heat treatment on soil metabolisms. J. Soil Sci. 6:129-136.

Calvert D.V. 1975. Nitrate, phosphate, and potassium movement into drainage lines under three management systems. J. Environ. Qual. 4:183-185.

Charreau C. and R.Nicou. 1971. L'amelioration du profil cultural dans les sols sableux et sablo-argileux de la zone tropicale seche ouest africaine et ses incidences agronomiques. L'Agr. Trop. XXVI 9:903-978/11:1194-1247.

Charreau C. 1974. Soils of tropical dry and dry wet climatic areas and their use and management. A series of lectures given at Cornell University. Cornell Univ., NY.

Charreau C. 1975. Organic matter and biochemical properties of soil in the dry tropical zone of West Africa. FAO Soils Bulletin No. 27. pp 313-336.

Cheshire V.M., M.C. Mundie, and H. Shepherd. 1974. Transformation of sugar when rye hemicellulose labelled with ^{14}C decomposes in soils. J. Soil Sci. 25:90-98.

Chun-Wai Hui. 1983. Part III. Country Reports : Republic of China. pp 112-118. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Cooke G.W. 1967. The control of soil fertility. Hafner Publishing Co. New York, NY. pp 375-393.

Cooke G.W. 1981. The fate of fertilizers. pp 563-592. In D.J. Greenland and M.H.B. Hayes (ed). The chemistry of soil processes, John Wiley and Sons, Chichester.

Cooke G.W. 1982. Fertilizing for maximum yield. 3rd ed., Macmillan Publishing Co., Inc. New York, NY. pp 94-123.

Cremer L., L.C.N. de la. 1976. Effect of rate of application of organic and inorganic nitrogen on crop production and quality. In " Utilisation of manure by land spreading ". E.C.C. Luxembourg. pp 73-86.

Cunningham R.K. and G.W. Cooke. 1958. Changes in levels of inorganic nitrogen in a clay loam soil caused by fertilizer additions by leaching and uptake by grass. J. Sci. Fd Agric. 9:317-324.

Dalton, J.D., G.C. Russel, and D.H. Sieling. 1952. Effect of organic matter on phosphate availability. Soil Sci. 73:173-181.

Debruck J. and E. von Boguslawski. 1979. Die Wirkung der Kombination von organischer und mineralischer Dungung auf Grund von langjahrigen versuchen. Landw. Forsch., Sonderh. 36, 405-419, Kongressband Gissen (1979).

Devitt D., L. Letey, L.J. Lund, and J.W. Blair. 1976. Nitrate-nitrogen movement through soils as affected by soil profile characteristics. J. Environ. Qual. 5(3)283-288.

Donahue L., R.W. Miller, and J.C. Shickluna. 1977. Soils-An Introduction to soils and plant growth. 4th edition, Englewood Cliffs, NJ. pp 289-292.

Doss B.D., Z.F. Lund, F.L. Long, and L. Mugwira. 1976. Dairy waste management : Its effects on forage production and run-off water quality. Auburn University Agricultural Experiemnt Station, Bul. No.485, Auburn Univ. AL.

Drift J. van der and M. Witkamp. 1960. The significance of the breakdown of oak litter by Enoicyla pusilla. Burm., Archs. Neerl. Zool. 13:486-492.

Duncan, A. 1975. Economic aspects of the use of organic materials as fertilizers. FAO Soils Bulletin No. 27. pp 353-378.

Egawa T. 1975. Utilization of organic materials as fertilizers in Japan. FAO Soils Bulletin No.27. pp 253-272.

Ellis B.G. and B.D. Knezek. 1972. Adsorption reactions of micronutrients in soils. pp 59-78. In J.J. Mortvedt, P.M. Giordano, and W.L. Lindsay (ed). Micronutrients in Agriculture, Soil Sci. Soc. Am., Madison, WI.

Ellis B.G., B.D. Knezek, and L.W. Jacobs. 1983. The movement of micronutrients in soils. pp 109-122. In " Chemical mobility and reactivity in soil systems", Soil Sci. Soc. Am. Special Publication No.11. Madison, WI.

Ellis B.G., A.J. Gold, and T.L. Loudon. 1985. Soil nutrient losses with conservation tillage. pp 275-298. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Ellis J.H. and R.E. Phillips, and R.I. Barnhisel. 1970a. Diffusion of iron in montmorillonite as determined by x-ray emission. Soil Sci. Soc. Am. Proc. 34:591-595.

Fahm L.A. 1980. The waste of nations. Allanheld, Osmun & Co. Publishers, Inc., Montclair, NJ. pp 102.

Flaig W., B. Nagar, H. Sochtig, and C. Tietjen. 1978. Organic materials and soil productivity. FAO Soils Bulletin No.35. Cited in Tunney, 1980. pp 25.

Follett R.H., L.S. Murphy, and R.L. Donahue. 1981. Fertilizers and soil amendments. Prentice-Hall, Inc., Englewood Cliffs, NJ. pp 458-505.

Fox R.L., and E.J. Kamprath. 1971. Adsorption and leaching of P in acid organic soils and high organic matter sand. Soil Sci. Soc. Am. Proc. 35:154-158.

Ganry F., J. Bideau, and J. Nicoli. 1974. Action de la fertilization azotee et de l'amendement organique sur le rendement et la valeur nutritionnelle d'un mil Souma III. L'agronomie Tropicale 31:403-416.

Gaur A.C. 1983. Organic fertilizers : Appraisal and outlook. Asian Productivity Organization (APO). pp 53-79. Tokyo, Japan.

Godz P. 1972. The effects of chicken manure and fertilizer on some soil chemical characteristics. MS Thesis, Michigan State University.

Greenland D.J. 1972. Biological and organic aspects of plant nutrition in relation to needed research on tropical soils. Com. Sem. on Tropical Soils, IITA, Ibadan (Nigeria). Cited in Balasubramanian et al. 1980. pp 114.

Griffith G. 1949. Fertility problems in Uganda. Proc. first Comm. conf. on Tropical and Sub-Tropical Soils, pp 160-165.

Gentzsch E.P., E.C.A. Runge, and T.R. Peck. 1974. Nitrate occurrence in some soils with and without natric horizons. J. Environ. Qual. 3:89-93.

Giordano P.M. and J.J. Mortvedt. 1976. Nitrogen effects on mobility and plant uptake of heavy metals in sewage sludge applied to soil columns. J. Environ. Qual. 5:165-167.

Haan A.F.M. de, T.M. Lexmond, and F.D. Dijman. 1976. Aspects of Copper accumulation in soil following hog manure application. In " Utilization of manure by land spreading". E.E.C. Luxembourg, pp 289-298.

Hartley T.K. 1937. An explanation of the effect of farm yard manure in Northern Nigeria. Emp. J. Expl. Agric. 19:244-263.

Hartmans J., 1975. The effect of intensification on crop composition and on health and production of livestock. Stikstof 18:12-21.

Heathcote G.R. 1970. Soil fertility under continuous cultivation in Northern Nigeria. 1. The role of organic manures. Exp. Agric. 6:229-237.

Hinsley T.D., O.C. Braids, R.I. Dick, R.L. Jones, and Jean-Alex E. Molina. 1974. Agricultural benefits and environmental changes resulting from the use of digested sludge on field crops. Final report. US-EPA, Grant No.Do1-U1-00080. pp 375.

Hoyt G.D., E.O. McLean, G.Y Reddy, and T.J. Logan. 1977. Effects of soil, cover crop, and nutrient source on movement of soil, water, and nitrogen under simulated rain-slope conditions. J. Environ. Qual. 6:285-290.

Inoko A., 1983. Part III. Country Reports : Japan. pp 124-140. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Jackson W.A., R.A. Leonard, and S.R. Wilkinson. 1975. Land disposal of broiler litter-Changes in soil potassium, calcium, and magnesium. J. Environ. Qual. 4:202-206.

Jackson, W.A., S.R. Wilkinson, and R.A. Leonard. 1977. Land disposal of broiler litter: changes in concentration of chloride, nitrate nitrogen, total nitrogen, and organic matter in a Cecil sandy loam. J. Environ. Qual. 6:58-62.

Jenkinson D.S. 1981. The fate of plant and animal residues in soil. pp 505-562. In D.J. Greenland and M.H.B. Hayes (ed). The chemisrty of soil processes. John Wiley and Sons, Chichester.

Jensen L.H. 1929. On the influence of carbon : nitrogen ratios of organic material on the mineralization of nitrogen. J. Agric. Sci. Camb, 19. 71-82.

Jones M.J. 1971. The maintenance of soil organic matter under continuous cultivation at Samaru, Nigeria. J. Agric. Soil Sci. Camb. 77:473-482.

Joshy D. 1983. Part III. Country Reports : Nepal. pp 155-163. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Kadeba O. and J.N. Benjaminsen. 1976. Contribution of organic matter and clay to the cation exchange capacity of soils in the savanna zone of Nigeria. Com. Soil Sci. Plant Anal. 7:129-143.

Karlen D.L., M.L. Vitosh, and R.J. Kunze, 1976. Irrigation of corn with simulated municipal sewage effluent. J. Environ. Qual. 5:269-273.

Keller R.E. 1982. The influence of farming systems on the optimization of yield. Prcoeedings of the 12th IPI Congress. International Potash Institute (IPI), Switzerland. pp 47-63.

Kells J.J. and W.F. Meggitt. 1985. Conservation and weed control. pp 123-130. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Khan D.M. and A.H. Khan. 1983. Part III. Country Reports : Pakistan. Asian Productivity Organization. pp 164-180. Tokyo, Japan.

Kimble J.M., R.J. Barlett, J.L. McIntosh, and K.E. Varney. 1972. Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. J. Environ. Qual., 1:413-414.

King L.D., P.W. Westerman, G.A. Cummings, M.R. Overcash, and J.C. Burns. 1985. Swine lagoon effluent applied to coastal bermudagrass. II. Effects on soil. J. Environ. Qual., 14:14-21.

Kirby H.W. 1985. Conservation tillage and plant disease. pp 131-136. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Kissel D.E., J.T. Ritchie, and E. Burnett. 1974. Nitrate and chloride leaching in a swelling clay soil. J. Environ. Qual., 3:401-404.

Lal R. 1987. Tropical ecology and physical edaphology. John Wiley and Sons, Chichester.

Langdale G.W. 1970. Phytotoxic phenolic compounds in Sericea lespedeza residues. Diss. Abstr. Int. B. 30:354-B.

Larsen J.E., R. Langston, and G.F. Warren. 1958. Studies on the leaching of applied labelled phosphorus in organic soils. Soil Sci. Soc. Am. Proc. 22:558-560.

Linderman R.G. 1970. Plant residue decomposition products and their effects on host roots and fungi pathogenic to roots. Phytopathology 60:19-22.

Lund Z.F., B.D. Doss and F.E. Lowry. 1975. Dairy cattle manure-Its effects on yield and quality of coastal bermudagrass. J. Environ. Qual., 4:358-362.

Lund L.J., A.L. Page, and C.O. Nelson. 1976. Movement of heavy metals below sewage disposal ponds. J. Environ. Qual., 5:330-334.

Lund Z.F. and B.D. Doss. 1980. Coastal bermudagrass yield and soil properties as affected by surface applied dairy manure and its residue. J.Environ. Qual. 9:157-161.

Lynch L.D. and Cotnoir. 1956. The influence of clay minerals on the breakdown of certain organic substances. Soil Sci. Soc. Amer. Proc. 20:367-370.

Marquez J.R. and M.S. Ana. 1983. Part III. Country Reports: Philippines. pp 181-216. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Mathers A.C. and B.A. Stewart, 1974. Corn silage yield and soil chemical properties as affected by cattle feedlot manure. J. Environ. Qual. 3:143-146.

Mishra M.M. and P. Tauro. 1983. Use of organic fertilizer vis-a-vis mineral fertilizers. pp 29-39. In Asian Productivity Organization. Tokyo, Japan.

Mokwunye U. 1980. Interaction between farmyard manure and NPK fertilizers in savanna soils. FAO Soils Bulletin No.43, pp 192-200.

Muir J., J.S. Boyce, E.C. Seim, P.N. Mosher, E.J. Deibert, R.A. Olson. 1976. Influence of crop management practices on nutrient movement below the root zone in Nebraska soils. J. Environ. Qual. 5:255-258.

Murphy L.S., G.W. Wallingford, W.L. Powers, and H.L. Manges. 1972. Effects of solid beef feedlot wastes on soil conditions and plant growth. In "Waste Manage. Res., Proc. 1972, Cornell Univ. Agric. Waste Manage. Conf., Graphics Management Corp., Washington, D.C. pp. 449-464.

Nan-Rong Su. 1983. Part III. Country Reports: Republic of China. pp 91-111. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Nastiti S.H. 1983. Part III. Country Reports : Indonesia. pp 119-123. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Ofori C.S. 1980. The use of organic materials in increasing crop production in Africa. FAO Soils Bulletin No.43. pp 121-128.

Okigbo B.N. 1980. A review of cropping systems in relation to residue management in the humid tropics of Africa. FAO Soils Bulletin No.43. pp 13-37.

Olsen R.J., R.F. Hensler, and O.J. Attoe, 1970. Effect of manure application, aeration, and soil pH on soil nitrogen transformations and on certain soil test values. Soil Sci. Soc. Amer. Proc. 34:222-225.

Page, A.L. 1974. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. A literature review study. EPA 670/2-74-004. pp 95.

Parr J.F., S. Smith, and G.H. Willis. 1970. Soil anaerobiosis, I. Effect of selected environments and energy sources on respiratory activity of soil microorganisms. Soil Sci. 110:37-43.

Parr J.F. 1975. Chemical and biological considerations for land application of agricultural and municipal wastes. FAO Soils Bulletin No. 27. pp 227-252.

Pichot J., S. Burdin, J. Charoy, and J. Nabos. 1980. Ploughing of millet straw into the sandy dune soils. L'Agronomie Tropicale, Paris, 29:959-1005.

Poulain J.F. 1976. Amelioration de la fertilite des sols agricoles du Mali. Bilan de treize annees de travaux (1962-174). L'Agronomie Tropicale 31:403-416.

Poulain J.F. 1980. Crop residues in traditional cropping systems of West Africa - Effects on the mineral balance and level of organic matter in soils and proposals for their better management. FAO Soils Bulletin No.43, pp 38-71.

Pratt, P.F., S. Davis, and A.E. Laag. 1977. Manure management in an irrigated basin relative to salt leachate to ground water. J. Environ. Qual. 6:397-401.

Pratt, A. and R.B. Harding. 1957. Decreases in exchangeable magnesium in an irrigated soil during 28 years of differential fertilisation. Agron. J. 49:419-21.

Reddy K.R., M.R. Overcash, R. Khaleel, and P.W. Westerman, 1980. Phosphorus adsorption-desorption characteristics of two soils utilized for disposal of animal wastes. J. Environ. Qual. 9:86-92.

Reedy K.R. and W.H. Patrick, Jr. 1983. Effects of aeration on reactivity and mobility of soil constituents. pp 11-34. In " Chemical mobility and reactivity in soil systems", Soil Sci. Soc. Am., Special Publication No.11, Madison, WI.

Richard L. 1967. Evolution de la fertilite en culture cotonniere intensive. Colloque sur la fertilite des sols tropicaux, Tananarive 2:1437-1471.

Rixhon L. 1979. Impact des techniques modernes sur les bases traditionelles de l'agriculture. Schweiz. Landw. Forschung 18, 3, 135-152.

Robinson J.B.D. and E.M. Chenery. 1958. Magnesium deficiency in coffee with special reference to mulching. Emp. J. Agric. 26 : 259-273.

Robinson J.B.D. and H. P. Hosegood. 1965. Effects of organic mulch on fertility of a latosolic coffee soil in Kenya, Exp. Agric. 1:67-80.

Roche P. 1970. Soil fertility problems. L'Agronomie Tropicale 25 : 875-892.

Roose E.J. and J.C. Talineau. 1973. Influence d'un niveau de fertilisation sur le bilan des elements nutritifs majeurs de deux plantes fourrageres cultivees sur un sol sableux de basse Cote d'Ivoire. Proc. 10th Colloq. Int. Potash Institute, Abidjan, Ivory Coast. pp 305-320.

Ruppel R.F. and K. Sharp. 1985. Conservation tillage and insect control. pp 137-144. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Chelsea, MI.

Russel W.E. 1961. Soil conditions and plant growth. 9th edition, Longmans.

Sabey, B.R., N. N. Agbim, and D.C. Markstrom. 1977. Land application of sewage sludge : IV. Wheat growth, N content, N fertilizer value, and N use efficinecy as influenced by sewage sludge and wood waste mixtures. J. Environ. Qual. 6:52-57.

Sawhney B.L. 1977. Predicting phosphate movement through soil columns. J. Environ. Qual. 6:86-89.

Sanchez P.A. 1976. Properties and management of soils in the tropics. John Wiley and Sons. New York, NY.

Schreiber J.D. and L.L. Mcdowell. 1985. Leaching of nitrogen, phosphorus, and organic carbon from wheat straw residues. I. Rainfall intensity. J. Environ. Qual. 14:251-255.

Schreiber J.D. 1985. Leaching of nitrogen, phosphorus, and organic carbon from wheat straw residues. II. Loading rate. J. Environ. Qual. 14:256-260.

Sedgo J. 1981. Contribution à l'étude de la valorisation agronomique des phosphates de Kodjari (Haute-Volta). DEA (MS) Thesis ENSAIA /INPL. University of Nancy I, France.

Shapiro D. 1968. In Simultaneous applications of organic and mineral fertilizers. Translated from Russian. Published for the USA and the Natural Science Foundation, Washington, D.C. by the Israel Program for Scientific Translations, Jerusalem, 1968. Original authors : E.M. Bodrova and Z.D. Ozolina.

Shindo H. and S. Kuwatsuka. 1976. Behavior of phenolic substances in the decaying process of plants. IV. Adsorption and movement of phenolic acids in soils. Soil Sci. and Plant Nutr. 22:23-33.

Sidle, R.C., and L.T. Kardos. 1977. Transport of heavy metals in a sludge-treated forest area. J. Environ. Qual. 6:431-437.

Singer M.J. and D.N. Munns. 1987. Soils - An introduction. Macmilian Publishing Company, New York. pp 139-169.

Singh A. 1975. Use of organic materials and green manures as fertilizers in developing countries. FAO Soils Bulletin No.27, pp 19-30.

Singh A. and V. Balasubramanian. 1980. Organic recycling in Asian agriculture. FAO Soils Bulletin No.43, pp 235-278.

Singh N.T. 1963. Effect of sugarbeet cultivation in the reclamation of saline alkali soils in Punjab. M. Sc. Thesis, Punjab Agricultural University, Ludhima, India.

Singh N.T. 1969. Changes in sodic soils incubated under saturated environments. Soil Sci. Plant Nutri. 15: pp 156-160.

Sommerfeldt T.G., U.J. Pittman, and R.A. Milne. 1973. Effect of feedlot manure on soil and water quality. J. Environ. Qual. 2:423-427.

Stephens D. 1969. Fertilizer trials on peasant farms in Ghana. Emp. J. Expl. Agric. 28:1-15.

Stevens J.R. and I.S. Cornforth. 1974. The effect of pig slurry applied to a soil surface on the composition of the soil atmosphere. J. Sci. Fd. Agric. 25:1263-1272.

Stickelberger D. 1975. Survey of city refuse composting. FAO Soils Bulletin No.27, pp 185-210.

Sukovaty J.E., L.F. Elliott, and N.P. Swanson. 1974. Some effects of beef-feedlot effluent applied to forage sorghum grown on a Colo silty clay loam. J. Environ. Qual., 3:381-387.

Sumner M.E., P.M.W Farina, and V.J. Hurst. 1978. Magnesium fixation - a possible cause of negative yield responses to lime applications. Commun. Soil Sci. Plant Anal. 9:995.

Sutton A.L., D.W. Nelson, D.T. Kelly, and D.L. Hill. 1986. Comparison of solid vs. liquid dairy manure applications on corn yield and soil composition. J. Environ. Qual. 15:370-375.

Tan K.H., R.A. R.A. Leonard, A.R. Bertrand, and S.R. Wilkinson. 1971. The metal complexing capacity and the nature of the chelating ligands of water extract of poultry litter. Soil Sci. Soc. Amer. Proc. 35:226-269.

Teppoolpon M. and S. Wasinarat, 1983. pp 217-225. In Recyclyng organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Thorne C.E., 1914. Farm Yard Manures. Orange Judd Company, New York. pp 112-198.

Tisdale S.L. and W.L. Nelson. 1956. Soil fertility and fertilizers. The Macmillan Company, New York. pp 1-21.

Tisdale .L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers, 4th edition, Mcmillan, New York, NY.

Tiwari K.N., S.P. Tiwari, and A.N. Pathak, 1980. Studies on green manuring of rice in double cropping system in a partially reclaimed saline sodic soil. Indian J. Agron. 25:137-146.

Triplett G.B., Jr. and D.M. Van Doren, Jr. 1985. An overview of the Ohio conservation tillage research. pp 59-68. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Tunney H. 1975. Fertilizer value of livestock wastes. In " Managing Livestock Wastes ", Proc. 3rd Int. Symp. Livestock Wastes, ASAE, Proc. 275:594-597.

Tunney H. 1977. Fertilizer value of livestock wastes. Ph.D. Thesis, Plant physiology. The University of California, Berkeley.

Tunney H. 1980. Agriculture wastes as fertilizers. pp 01-39. In M.W.M. Bewick (ed). " Handbook of organic waste conversion ", van Nostrand Reinhold Company. New York, NY.

Turk J., A. Turk and K. Arms. 1984. Environmental Science. Third edition. CBS College Publishing /Saunders College Publishing. New York, NY.

Tyler D.D. and G.W. Thomas. 1977. Conventional and no-tillage corn. J. Environ. Qual. 6:63-66.

Uppal H.L. 1955. Green manuring with special reference to sesbania aculeata for treatment of alkaline soils. Indian J. Agric. Sci. 25:211-217.

Veily J. and C. Longueval. 1976. Evolution d'un sol ferralitique sur gneiss de Madagascar sous l'influence d'apports annuels de paille et d'azote. Proc. Joint FAO/IAEA. A Prochimica Symp. on Soil Organic Matter Studies, IAEA, Vienna. pp 69-81.

Venkataran G.S. 1982. Transcript, 12th International Congress of Soil Sci., New Delhi, India. pp 69-82.
Vez A. 1979. Influence a long terme de diverses mesures culturales sur la teneur en matiere organiques du sol et le rendement des cultures. Rev. Suisse Agric. 11, 3, 125-128.

Vitosh M.L., J.F. Davis, and B.D. Knezek. 1973. Long term effects of manure, fertilizer, and plow depth on chemical properties of soils and nutrient movement in a monoculture corn system. J. Environ. Qual. 2:296-298.

Vitosh M.L., W.H. Darlington, C.W. Rice, and D.R. Christenson. 1985. Fertilizer management for conservation tillage. pp 89-98. In F.M. D'Itri (ed). A systems approach to conservation tillage. Lewis Publishers, Inc., Chelsea, MI.

Vitosh M.L., H.L. Person, and E.D. Purkhiser. 1986. Livestock manure management for efficient crop production and water quality preservation. Coop. Ext. Bull. WQ 12. Michigan State Univ. E.Lansing, MI.

Wallingford G.W. L.S. Murphy, W.L. Powers, and H.L. Manges. 1974. Effect of beef feedlot-lagoon water on soil chemical properties and growth and composition of corn forage. J. Environ. Qual. 3:74-77.

Wallingford G.W., L.S. Murphy, W.L. Powers, and H.L. Manges. 1975. Disposal of beef-feedlot manure : Effects of residual and yearly applications on corn and soil chemical properties. J. Environ. Qual. 4:526-531.

Warncke D.D. and S.A. Barber. 1972. Diffusion of zinc in soil: II. The influence of bulk density and its interaction with soil moisture. Soil Sci. Soc. Am. Proc. 36:42-46.

Weerakoon W.P. 1983. Part III. Country Reports: Sri Lanka. pp 197-216. In Recycling organic matter in Asia for fertilizer use. Asian Productivity Organization. Tokyo, Japan.

Wriley G. 1982. Tropical agriculture, 4th edition, Longman,Inc., New York, NY. pp 90-95.

Yagodin B.A. (ed). 1984. Agricultural chemistry. Vol. 1 and 2. Translated from Russian by V.G. Vopyan, Mir Publishers, Moscow.

Young A. 1976. Tropical soils and soil survey. Cambridge University Press, London. pp 119.