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Authors

Allison, M., Harris, P.J.C., Hofny-Collins, A.H. and Stevens, W.

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DFID Natural Resources Systems Programme

NRSP, HTSPE, Thamesfield House
Boundary Way, Hemel Hempstead, HP2 7SR
United Kingdom

t: +44 (0) 1442 202447
f: +44 (0) 1442 219886
e: nrsp@htspe.com
w: www.nrsp.org.uk

DFID Department For International Development

A Review of the use of Urban Waste in Peri-Urban Interface Production Systems

M Allison, PJC Harris, AH Hofny-Collins & W Stevens

with contributions from

HR Barrett and S Tyrrel

HDRA FOR ORGANIC EXCELLENCE

THE HENRY DOUBLEDAY RESEARCH ASSOCIATION

A Review of the Use of Urban Waste in Peri-Urban Interface Production Systems

For

The Peri-Urban Interface Production System
Natural Resources Systems Programme
Renewable Natural Resources Research Strategy
Department For International Development

1998

M Allison[1], PJC Harris[1,3], AH Hofny-Collins[1] and W Stevens[2]
with contributions from
HR Barrett[3] and SF Tyrell[2]

[1]*International Research Department*
The Henry Doubleday Research Association
Coventry CV8 3LG
Telephone: +44 1203 303517
Fax: +44 1203 639229
Email: enquiry@hdra.org.uk

[2]*School of Agriculture, Food & Environment*
Cranfield University, *Silsoe*
Bedford, MK45 4DT
Telephone: +44 1525 863296
Fax: +44 1525 863384
Email: w.stevens@cranfield.ac.uk

[3]*African Studies Centre*,
Coventry University
Priory Street, Coventry CV1 5FB
Telephone: +44 1203 838444
Fax: +44 1203 838447
Email: h.barrett@coventry.ac.uk

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Natural Resources International
PO Box 258, Chatham, Kent ME4 4PU
Tel: +44 1634 883111 Fax: +44 1634 883937
Email: chris.lewcock@nri.org
http//:www.nrinternational.co.uk

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SUMMARY

Urban waste types, including both solid and liquid wastes, have the potential for use as animal feed, soil improvers and fuel; for weed, pest and disease control, aquaculture, the cultivation of lower organisms; and for irrigation.

Constraints to the use of waste for animal feed include the need to ensure that the waste forms part of a balanced diet, and the facts that the waste may be perishable, seasonally or otherwise variable, anti-nutritional or toxic, may require further processing, and may introduce diseases into food chains.

The use of organic wastes to improve soil fertility usually involves composting which sanitises waste, reduces waste volume, weight and water content, enables storage, and alters the composition of waste making it more suitable for agriculture. Constraints to the use of wastes for soil improvement include variability of quality, toxicity, difficulties with transporting bulky materials, need for further processing, need for additional separation and collection procedures, high inputs of labour, lack of availability of land for processing, need for technology for municipal scale processing, inefficient collection and transport systems, adverse climatic conditions, difficulties in matching raw material supply with processing capacity, seasonal supply, low market value, limited markets, contamination with non-organics, and unwillingness to work with wastes for cultural or other reasons.

Constraints to the use of wastewater for irrigation include the need for appropriate technology to facilitate collection and treatment, and the risks of disease, soil salinisation and heavy metal contamination.

Factors affecting the use of wastes in agriculture include types of farming system, crops and livestock involved, farm and household economics, markets, availability and use of alternatives, priority of use, farmer knowledge and perceptions, cultural aspects, gender, land availability and tenure, institutional support, and the ability to solve technological constraints including collection and separation, transport, processing, availability and quality, health and safety, and environmental concerns.

The principal gaps in existing knowledge relate to the quantitative need for organic wastes in urban and peri-urban agricultural systems of target cities/regions, the potential to satisfy these needs within current resource constraints and the institutional and policy frameworks affecting waste management and utilisation. Concentrating on potential soil improving wastes, topics requiring further research include methods to assess the value of waste materials as fertilisers and soil conditioners, and to determine possible phytotoxic, environmental and health impacts. Small-scale community or on-farm composting of wastes and the efficacy of waste materials in on-farm trials to determine use and application rates in specific crops also merit further research. The use of organic wastes in mixtures with inorganic inputs, mixtures of different organic wastes, and the optimum use of high and low value organic fertilisers for composting, with a view to overcoming seasonal and other variations in waste quality and supply, also require further research, as do the acceptability, economics and labour requirements of waste use at the farm level. An aim of this research should be to develop decision trees and choice pathways for waste utilisation by different kinds of farmers.

A bibliography on the use of urban waste using Papyrus as a reference handling system is supplied on computer disk.

BACKGROUND

Many parts of the world are experiencing a rapid population increase, accompanied by rural unemployment and migration to urban areas. Such urban expansion creates particular problems and challenges in terms of poverty alleviation and the provision of adequate food supplies and food security. Urban areas place considerable demands upon agricultural production in the surrounding countryside, but also offer diverse and more sophisticated markets. Similarly, urban areas generate environmental and health problems associated with waste collection and disposal, but offer the potential of recycling with associated income and employment opportunities. Salvage and recycling of metals and other materials of value is common in many developing countries and partly accounts for the fact that organic wastes make up 50-75% of urban waste, compared with 16% in Europe. In addition to domestic refuse, urban wastes include nightsoil or sewage sludge and, increasingly, agro-industrial wastes from processing and livestock.

The increasing importance and potential of peri-urban interface agriculture has been recognised in its designation as a Production System within the Natural Resources Systems Programme of the Department for International Development Renewable Natural Resources Research Strategy with the aim of "more efficient management of resources in order to enhance productivity, increase energy efficiency, minimise environmental degradation, and make greater use (including recycling) of waste materials".

There is an extensive literature base on the technologies and procedures for urban waste disposal, but less attention given to the potential agricultural demand for urban wastes and how their use might be integrated into farming regimes. Detailed studies of projects on the utilisation of urban wastes in agriculture in less developed countries have been reported for backyard, neighbourhood, and municipal schemes. Although many of these studies cover demand, constraints, cost-benefit analysis and social factors, they are mostly reported as case studies and little attempt has been made to draw these together to synthesise an overview.

1. Classification and use of urban wastes

1.1 General introduction to waste types

Most organic production occurs in rural areas, and consequently most organic wastes are found there, including manure from livestock and residues from crops. Use of these wastes is often integrated into the farming system. However, there is a vast traffic of organic raw materials into cities to feed and clothe the inhabitants and provide the raw materials for the industries that tend to be located there. In cities in developing countries significant quantities of organic wastes are also generated by urban agricultural enterprises. Large quantities of human excrement are generated and vast amounts of water are contaminated by organic material, either from agro-industrial processing or sewage.

Although rural areas produce most organic waste, waste management in urban areas is a serious issue, as less per capita is recycled. As development occurs and urban populations increase, the type of waste generated is likely to change and the amount to increase.

Parr & Willson (1980) produced data for the annual production of organic waste in the USA (Table 1). Figures produced for the UK by Border (1995) follow a similar pattern (Table 2).

A city with one million inhabitants is estimated to consume 25,000 t of water and 2,000 t of food per day and to produce 50,000 t of effluent water and 2,000 t of waste material daily (Deelstra 1989).

Table 1.
Annual production of organic waste in the USA.

Organic waste	Million t (dry)	% of total
Animal manure	158.7	21.8
Crop residues	391.0	53.7
Sewage sludge	4.0	0.5
Food processing	2.9	0.4
Industrial organic	7.5	1.0
Logging & wood processing	32.4	4.5
Municipal refuse	131.2	18.1

However, there are vast differences in the levels of consumption and production of waste between the inhabitants of industrialised and developing countries.

Estimates for waste generation in cities vary, particularly where much of the waste is not collected and the population of the city is growing rapidly. Some cities in developing countries are reported to be increasing in population by 7%

Table 2.
Annual production of organic waste in the UK.

Waste	Million t	% of total
Agricultural	200-250	80
Sewage sludge	30	10
Domestic waste (30% organic)	14	4.6
Civic amenity waste	4	1.3
Forestry	2	0.6
Abattoir	1.5	0.5
Food processing	1.5	0.5

per annum, often more than twice the rate of increase for the country as a whole. In contrast to Deelstra's figures (Table 3), Metro Manila, Philippines, with 12 million people generates 4,000 t of waste per day (Medina 1993), Jakarta, Indonesia, with a similar population produces 5,000 t per day (Simpson 1993), Dar es Salaam, Tanzania, with about 3 million people generates 740 t of organic waste per day (Lopez-Real 1995), Calcutta, India, with 10 million people produces 3000 t per day (Kundu 1995), Kano, Nigeria, with 1.4 million people generates 450 t per day (Lewcock 1994).

In general waste production increases with development and urbanisation. Levels of waste generated in cities in developing countries are likely to increase, but whether they reach the levels currently generated in industrialised countries remains to be seen.

The above figures refer to urban waste, but should be seen in the context of total waste generation. Taking the figures from Tables 3 and 4, we can assume that the relative proportions of the total waste stream in developing countries that are due to agricultural residues will be similar to or greater than that of the USA. Logging and forestry wastes will tend to vary much more significantly between countries, but will generally be lower than USA levels. However, both these and agricultural wastes tend to be generated away from urban areas.

Taking the remaining components; municipal refuse, sewage, food processing and industrial organic, which are most important in the urban context, it is apparent that municipal refuse is by far the most significant. In developing countries, with their much lower levels of industrialisation, food processing and industrial organic wastes (Table 5) will be considerably less significant than in developed countries (Table 2).

Other figures are provided by Oepen (1993) for Jakarta where waste is 60-75% organic, Warmer (1995a) for Hanoi where waste is 52% organic, Lewcock (1994) citing Yusufu (1983) for Kano where waste is 56% organic. More recent figures (Jalan et al 1995) put the generation of paper waste in domestic waste at India 7%, UK 50%, USA 54.5% and Switzerland 33.5%. The figures can mainly be attributed to

Table 3.
Production of waste per head of population (from Deelstra 1989).

Place	kg per person per day	Volume per day (litres)
India	0.25	1.00
Ghana	0.25	1.00
Aden	0.25	1.00
Egypt	0.30	1.25
Syria	0.30	1.25
Sri Lanka	0.40	1.60
Philippines	0.50	2.00
Turkey	0.60	2.40
Malaysia	0.70	3.50
Singapore	0.85	4.25
Arab Oil States	1.00	5.00
Europe	1.00	8.00
USA	1.25	12.00

the large amounts of packaging used in industrialised countries. In developing countries, where cities have grown rapidly and there is not enough money for environmentally sound waste disposal, a large proportion of collected waste is dumped on unused land such as abandoned quarries or wetlands near to the city. In Brazil it has been estimated that 76% of the 90,000 t of waste generated per day is disposed of in this way (Wells 1995). Deelstra (1989) estimated that 90% of all waste from cities in developing countries is dumped when over 60% of it could be recycled. In many cities the wastes will simply accumulate only to be dispersed by the effects of wind, rain and microbial action, all the while causing problems of odour, flies, vermin and scavenging animals and birds.

The above refers mainly to solid urban waste, but wastewater also forms a major component of urban waste and represents both a significant problem for effective disposal and a potential resource for agriculture. Following use in households for drinking, bathing, washing, cooking, toilet flushing, and in industry as water for cooling or processing, wastewater is discharged into sewers or directly into watercourses. Urban sewer networks are of two main types; one where wastewater and storm water are kept in discrete systems, the other where they are co-mingled. Systems combining waste and storm water tend to be found in temperate regions. In arid areas waste water is only rarely diluted with storm water run-off or infiltrated groundwater.

Wastewater generally comprises 99.9% water and 0.1% suspended colloidal and dissolved solids (Strauss 1995). These solids may be organic; carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as a variety of other natural and synthetic organic compounds from processing industries.

1.2 Waste as animal feed

1.2.1 Introduction

Animal feeds need to provide livestock with:

- Carbohydrates to provide energy necessary for survival and weight increase
- Protein, to provide energy and amino-acids necessary for survival and growth
- Vitamins and similar nutrients, essential for survival and health
- Minerals, essential for the health of blood, bones, teeth, glands and other parts of the body
- Fats, to provide energy and increase weight
- Fibre or roughage, to assist the animal's digestion
- Water, which may also be provided separately

Stock that are penned and therefore unable to forage for themselves, must be provided with a diet including all the necessary ingredients. Often the diet is in the form of a

Table 4. The composition of the waste (Dalzell et al 1987, Deelstra 1989).

Percentage composition Waste type	Accra	Indian city	N.European city	Middle East	Far East	South America
Organic	87.1	75.0	3.0-16.0	50.0	75.0	55.0
Paper	5.7	2.0	2.7-4.3	20.0	2.0	15.0
Metals	2.6	0.1	7.0-10.0	10.0	0	6.0
Glass	0.7	0.2	10.0-11.0	2.0	0	4.0
Textiles	1.2	3.0	3.0-7.0	10.0	4.0	10.0
Synthetics	1.3	1.0	3.0	*	*	*
Various	1.4	7.0	1.0-3.0	0	7.0	10.0
Dust	-	12.0	13.0-16.0	8.0	12.0	0

* = Textiles and Synthetics are listed together under the same category.

Table 5. Typical agro-industrial wastes worldwide (from Dalzell et al 1987).

Vegetables	Decayed cabbage, lettuce leaves, tops of root crops, wastes from tomato canning, cassava processing
Fruits	Pineapple tops and peels, mango pips and peels, banana peels, shells from cashew, groundnut, woodapple, macadamia, peel of citrus, passion fruit and durian
Cereals	Husks and bran from rice, wheat, sorghum, barley and maize cobs
Beverages	Brewery and wine wastes, cocoa pods, coffee pulp, tea stalks and sweepings
Fibres	Cotton gin wastes, coconut husks, coir dust, jute mill wastes, silkworm wastes
Sugar	Bagasse, press mud cake, vinasse (liquor from industrial alcohol distillation)
Vegetable oil cakes	Copra, castor oil bean, seeds of cotton, groundnut, karanj, linseed, mahua, mustard, neem, oil palm kernels (and fruit husks and stalks), rape, sesame and sunflower
Tobacco	Tobacco seed cake, leaf scrap and stalk
Meat	Bones, hair, horn, hooves, feather, blood, leather, fat, stomach contents and liquid wastes
Fish, river & marine waste	Fish wastes, surplus and inedible fish, prawn shells, frogs and seaweed
Timber mills	Sawdust, wood shavings and chips
Paper making	Paper pulp and effluent

natural bulk material such as grass or hay with a supplement feed to provide the protein, vitamins, minerals and certain amino-acids that may not be present in the bulk feed.

Generally, agricultural wastes are able to provide some or all of the bulk feed elements, but often cannot be substituted for the supplement. Some animals such as ruminants have very simple feed requirements and can eat material with a high cellulose content such as straw, seaweed, or even twigs. Others like pigs, have a simple digestive system that cannot manage straws or low quality fodder, but have powerful appetites and eat almost any food wastes.

Waste for use as feed may require more processing than simply separating edible components from inedible. Table 6 shows feed values for various wastes including materials commonly used for animal feeds such as blood meal (dried blood from slaughterhouses), fish solubles (a by-product of the fish meal industry) and brewers' grains (the residue from beer production). Further details are given in FAO Animal Production and Health Series No.12 "Tropical Feeds" (1981).

The table shows that the main value of animal manures is protein and to a lesser extent minerals. Cereal wastes have low protein values. Hulls and husks have little value except as fibre. Most of the wastes shown, other than the manures, straw and husks, have a considerable energy value, indicated by a high value of TDN (Total Digestible Nutrients). Wastes from protein food industries (fish, meat etc) have very high animal feed values.

1.2.2 Agro-industrial residues

Agro-industrial wastes are an important component in livestock feed all over the world.

Oil seed: Oil cakes (remaining after oil pressing) and oil extracted meal (left after solvent extraction of oil) are rich in protein and energy and mixed with bran from wheat and rice milling and can be used for direct feeding. Other oil seed residues such as castor bean, rubberseed cake, *Balanites aegyptiaca* seed cake, all of which are locally significant, require simple detoxification processes before use (UNIDO 1993).

Coffee: Factories that make soluble coffee dump the used grounds. These contain 22% to 27% oil and, when dried, can be fed to cattle as an energy source. Their protein value is very low as the amino-acids are damaged by heating during the process, but like most factory wastes, they arise regularly on a large scale and would be of value to local cattle owners.

Peanut: Peanut husks are used as poultry litter and afterwards as ruminant feed, in small amounts only as the high fibre content (60%) interferes with digestion.

Citrus: Pulp left after the extraction of lemon juice is favoured by cattle and can become a main energy source, but high levels reduce milk output. Some countries have highly seasonal supply. The high water content makes it too heavy to transport. If left, it ferments, becomes sour and attracts flies, but it can be made into silage with grass or hay, or dried after the addition of 0.5% limestone. If pressed before drying, the press liquor is 'citrus molasses' which can be used like sugar molasses. If the seeds are left in, dried citrus pulp can become toxic to pigs and poultry.

Pineapple: During pineapple canning, up to 60% of the fruit is wasted. These wastes are good feed for ruminants and older pigs, but not for poultry. They can be fed fresh or after about three days sun drying, or the juice can be concentrated into a syrup and a mixture of 80% with 20% protein supplement fed to pigs.

Cocoa: Pods are rich in potassium and are normally left in the field to fertilise the cocoa trees. They rot very quickly, but can be fed to cattle or pigs replacing of up to 35% of the maize ration without reducing weight gain, if they are dried and ground.

Banana: Reject bananas are relished by cattle, but are less liked by sheep and goats. Pigs will eat ripe fruit, but get

Table 6. Value of wastes as animal feeds, % (adapted from Vogler, undated)

		Protein	Fibre	Fat	TDN*	Calcium	Phosphorus
Animal wastes	Cattle excreta	17	0	0	?	1.6	0.7
	Poultry excreta	29	15	2	?	7.8	2.2
Slaughter-house wastes	Meatmeal	59	2	7	66	7.6	4.0
	Meat and bonemeal	45	3	8	63	11.0	5.9
	Bloodmeal	80	1	1	60	0.3	0.2
	Hydrolysed pig hair	97	0	2	?	0.3	0.1
	Poultry feather meal	91	0.4	4	63	0.4	0.5
Dairy	Dried whey	12	0	1	79	0.9	0.8
Tannery	Scrapings	85	0	10	?	0	0
	Tanned scraps	71	0	7	?	0	0
Fish processing	Fish meal	72	1	4	72	7.0	3.5
	Condensed fish solubles	40	5	6	76	0.4	1.2
Cereals	Wheat straw	3	54	1	36	0	0
	Wheat mill waste	18	7	4	81	0.2	0.9
	Rice mill waste	8	37	8	63	0.1	0.4
	Maize cobs	2	37	1	42	0.1	0.4
	Dry spent brewers' grains	19	18	5	73	0.3	0.7
Hulls and husks	Rice	4	30	1	24	0.2	0.1
	Oats	4	37	1	37	0.2	0.2
	Cottonseed	14	30	9	47	0.1	0.1
Sugar	Bagasse	2	45	1	45	0	0
	Cane tops	6	35	2	66	0	0
	Molasses	4	0	0	54	0.7	0.1
Fruit	Citrus pulp	7	13	3	74	1.4	0.1
	Banana fruit	5	2	1	63	0	0
	"Stem" of banana tree	2	20	2	65	1.2	0.2
	Pineapple bran	4	16	1	72	0.3	0.1
	Pineapple leaves	9	23	2	75	0	0
Dried algae	*Chlorella vulgaris*	45	9	8	?	0	0
	Scenedesmus obliquus	56	7	14	?	0	0

*Ruminant TDN = Total Digestible Nutrients - a measure of the energy value from all sources diarrhoea if overfed. Dehydrated flour of green bananas can be used instead of up to 10% of the grain portion of poultry feed. Bananas have a low sodium content and may therefore be sprinkled with salt. Because they are rich in starch, bananas can easily provide available energy to animals being fed on urea.

Cashew: Cashew fruit are rich in sugar and can replace some grain in poultry or ruminant rations.

Tomato: Residues from tomato pulping are protein-rich (14%), contain 41% TDN and are popular with goats.

Single celled protein: SCP grown on organic wastes can be used as a protein rich animal feed.

1.2.3 Animal wastes

Animal wastes can also be used to provide animal feed.

Cows: Cow dung has a moderate protein content and contains certain minerals. In highly intensive farming in urban areas far from arable land in industrialised countries, animal feeds are produced with high percentages of cow dung, for example in the USA. "Wastelage", a silage of 57% cattle waste and 43% ground hay is reported to give good results when fed to breeding cattle in mixtures of equal amounts of wastelage and hay (Vogler, undated). No processing or sterilisation is carried out. Other more sophisticated processes for extracting protein-rich substances from cow dung exist, but there are concerns about the risks of diseases and drug residues being passed to the feeding animals.

Poultry: Poultry manure has the highest nutrient value of any animal excreta. It is high in nitrogen, but only 20-30% of this is in the form of protein. A large part is uric acid which can be converted into protein by ruminant animals. It is rich in minerals, particularly phosphates, and provides the elements necessary for growth and health, making a mineral feed supplement unnecessary, with the possible exception of sodium which can be provided by a salt lick. However, its energy value is low.

Poultry feathers have a high protein content, but rot if left raw. To avoid this they may be hydrolysed by cooking at 130°C at low pressure for 2.5 h, followed by drying and grinding. Cattle will eat meal introduced gradually to replace up to 10% of protein concentrates in feed, but amino acids must be added. Other animals will accept up to 5%.

Tannery waste: There has been little success in using tannery wastes for animal feeds; the proteins lack certain essential amino acids and, unlike poultry feathers, animal hair is resistant to hydrolysis. However tanned trimmings can be hydrolysed and up to 8% fed to poultry and 3% fed to pigs.

1.2.4 Municipal wastes

Municipal refuse is a significant source of food for urban livestock in many developing countries as anyone who has seen chickens, goats and cattle rooting through piles of refuse can testify. Livestock rearing tends to be practised as part of a survival strategy by urban people in developing countries, but in some cases it may occur on a large scale. Khatals (feedlots) are an important feature of many Indian cities and produce milk for the urban population. A significant proportion of khatal animals' diet is urban waste (Blore pers. comm.).

Cellulose from newspapers can be used as a substitute for more conventional sources such as straw. The digestibility depends on the lignin content of the paper. Magazines and office paper are better than newspaper and can be introduced as up to 24% of the diet without compromising yields (Silva 1993). Lead may prove a problem, but newspaper could replace straw as bedding for livestock.

Silva (1993) reports the use of municipal solid waste as animal feed in the United States. After metals, glass and plastics were removed the waste was chopped and left for bacterial digestion for 5 days before dehydration and the addition of urea as a binding agent to aid pelletising.

Refuse from fruit and vegetable markets can also be fed up to 1% of live weight. In Hong Kong in the late 1970s, 130,000 t of food wastes from restaurants and food processing industries were collected annually to feed pigs (Newcombe 1977).

One in three street scavengers in Quito, Ecuador specialises in food waste collection to feed pigs in the city and 50% of dump scavengers in Cuenca look for food for cows, lambs and guinea pigs (Fundacion Natura 1993, cited in Mougeot 1994b). In Cairo, the zabaline collect household rubbish and feed the organic fraction to pigs.

1.2.5 Constraints to the use of waste for feed

Using wastes as an animal feed is not entirely without problems. It may be difficult to ensure that the waste forms part of a balanced diet, particularly as the supply is often seasonal and otherwise variable. Waste may be anti-nutritional or toxic and there is a risk that diseases may be introduced into the food chain. These constraints, which are specific to wastes as animal feed, are discussed in Section 2.11.8 along with other constraints, which apply to waste management and use in general throughout Chapter 2.

1.3 Solid waste as soil improver

1.3.1 Introduction

Organic materials are generally nutrient rich in comparison with soil (Table 7) thus they can help improve the nutrient status of soils. The material is generally applied either by incorporation into the soil during cultivation, or to the growing crops as a mulch. In addition to nutrient provision, organic matter improves biological activity and soil structure. This results in increased water infiltration of the soil, increased water holding capacity, improved aeration and permeability, soil aggregation and rooting depth, and decreased soil crusting, bulk density and runoff. Adding organic matter as a mulch helps retain soil moisture, control erosion and reduce weed growth.

There is considerable variation in the nutrient content of wastes from cities. The values are probably most similar to the values for plant residues or composted material cited in Table 7, although Gaur & Verma (1991) state that Indian municipal wastes contain 0.5% nitrogen, 0.3% phosphorus and 0.3% potassium.

Casale et al (1995) looked at a variety of wastes including garden waste, rice hulls and shredded paper and found that a number of the wastes were not only useful as mulches, but were also effective delivery agents for microbial biocontrols of pests of citrus in California.

Compost and compost leachates also have an inhibitory effect on soil borne plant pathogens (Lumsden et al 1983) either by enabling the plant to overcome subclinical root damage, or more probably by allowing increased microbial activity to take place in the rhizosphere and soil zone around the plants, thereby exhibiting a microfloral antagonism to the growth of pathogens.

Composted sewage sludge has been used in USA to suppress damping-off of peas and cotton (Lewis et al 1992). Lumsden et al (1983) report that soil incorporation of composted municipal sludge was found to control *Aphanomyces* root rot of pea, *Rhizoctonia* root rot of bean, cotton and radish, *Fusarium* wilt of cucumber and *Phytophthora* crown rot of pepper. Reduction of nematode populations as a result of compost incorporation have also been reported (Gallardo-Lara & Nogales 1987, Hunt et al 1973).

1.3.2 Processing

Wastes for use as soil improvers are often processed before use, most commonly by composting, a process suitable for all organic wastes. Composting is labour intensive and the process itself results in significant nutrient losses (Table 8). However, there are a number of good reasons for composting organic wastes before using them.

Waste sanitation: Composting is a natural process whereby micro-organisms break down organic materials. During composting heat tends to be generated, the composting pile reaching temperatures of up to 70°C. As the temperature increases, the microflora changes from being dominated by mesophilic types to being dominated by thermophiles. The high temperatures achieved during composting are very important for sanitising compost as they kill off almost all pathogens including the exceedingly resilient helminth eggs found in human nightsoil. Weed seeds are also generally destroyed.

Reduction in waste volume, weight and water content: During composting some of the waste is lost as carbon dioxide, leading to a reduction in volume and weight. Composting also reduces the water content and provides a stabilised product. Jain (1994) reported that spraying one tonne of rubbish with a solution of micro-organisms reduced the waste to 250 kg of compost.

Table 7. Nutrient values of natural fertilisers (Cross & Strauss 1985).

	Nutrient content as a percentage of dry matter		
Material	Total N	P_2O_5	K_2O
Human faeces	5-7	3-5.4	1-2.5
Human urine	15-19	2.5-5	3-4.5
Nightsoil (faeces, urine and ablution water)	10.4-13.1	2.7-5.1	2.1-3.5
Fresh cattle manure	0.3-1.9	0.1-0.7	0.3-1.2
Pig manure	4-6	3-4	2.5-3
Plant residues	1-11	0.5-2.8	1.1-11
Digested biogas sludge	1.5	1.1	1.1
Composted material	0.4-3.6	0.3-3.5	0.5-1.8

Composting may be preferred to alternative disposal strategies for organic materials for a number of reasons, even if the product is not to be used for agriculture. Line (1992) writes about the management of fish wastes by composting with bark. Composting, which considerably reduces waste volume and weight, was preferred to conversion into fish meal, surface mulching, or burial in trenches. This was not only because of the difficulty of transporting the raw wastes, but also because of the lack of suitable sites for landfill disposal of waste. The latter is an important issue worldwide and will mean that in the future as much organic waste as possible will have to be composted before safe dispersal on the land surface.

Composting enables storage of wastes: Once the waste has been composted and stabilised, it can be stored, allowing for optimum timing of application in agriculture.

Compost alters the composition of waste making it more suitable for agricultural use and pleasant to handle: Garcia et al (1992) showed that fresh sewage sludge and urban waste had severely inhibitory effects on seed germination. Phytotoxicity, in addition to that caused by ammonia, was due to excessive electrical conductivity, phenolics and low molecular weight organic acids. Reduction in crop growth can also be caused by nitrogen immobilisation that may occur when fresh organic material that contains relatively low amounts of nitrogen, such as rice straw or sawdust, is applied to soils. Conversely, the 'locking up' of highly soluble nitrogen compounds during composting can overcome problems associated with groundwater contamination from the use of fresh slurries and concentrated fertilisers, as well as potential ammonia 'burning' of crops. Ensuring that the compost is thoroughly stabilised also means that anaerobic conditions around the plant roots are avoided.

Also, composting produces an odourless crumbly material, which is more pleasant to handle than raw waste, and avoids any nuisance complaints when applying to land.

Aerobic composting

The aerobic composting process depends on a number of factors including:

- Moisture level of the substrate (<40% and microbial activity slows, >70% and anaerobic processes dominate)
- Environmental temperature
- Aeration of the substrate (substrates which permit diffusion of air will be broken down more rapidly)
- Physical form of the substrate. Substrates that are formed of smaller particles will tend to be broken down more rapidly than those formed of larger particles
- C:N ratio of the substrate

If the organic material is exceedingly carbon rich, nitrogen deficiency during microbial degradation will result and slow down the process. A heap of sawdust with a C:N ratio in excess of 150 will take a very long time to become converted to humus and some judicious mixing of the substrate with a nitrogen rich material is desirable. With a nitrogen rich substrate there is no nutrient limitation during composting, but loss of nitrogen as ammonia will be considerable, as can be seen from the figures in Table 8.

Large scale aerobic composting systems tend to come in three main types.

- Windrows where material is stacked in long piles generally up to 2-3 m tall and then turned on a regular basis to ensure adequate aeration of the substrate and that material which has been on the outside of the pile experiences the pathogen-killing temperatures achieved within the pile. Turning is done by hand or mechanically.
- Static aerated piles. These can be made either by inserting lengths of tubing such as bamboo into the pile so that air may penetrate, or by forced aeration using tubing and air pumps.
- In-vessel systems. These provide the greatest control of the composting environment resulting in the most rapid compost formation, but are rarely suitable for large scale operations in developing countries as they are technologically complex and expensive (Finstein 1992).

Components of a composting plant may include magnets to remove metals, hammer mills or shredders to reduce the size of materials before composting and sieves to remove inorganic, or large items that have not humified during the composting process.

Anaerobic decomposition

Anaerobic decomposition systems are not much used although Weixu (1991) mentions waterlogged composting of manure in China. Production of biogas by microbial digestion is effectively anaerobic decomposition albeit of a more or less liquid substrate. Generally, aerobic systems are favoured as they can be achieved using low technology, are easier to manage, reduce the waste to a stabilised form more quickly and result in pathogen kill through high temperatures. However, in reality much composting is done under a combination of aerobic and anaerobic conditions. Mixed wastes composted in pits or unturned piles typically start off under aerobic conditions then, become anaerobic as the initial break-down takes place and the material collapses and compacts.

Vermicomposting

This is not, technically, composting, as micro-organisms are not involved, but rather digestion by worms. Worms, such as the common red earthworm, *Eisenia foetida*, have the ability to improve organic wastes. They eat the waste and produce a cast which has a content of nitrogen, phosphorus and magnesium several times that of normal soil. Worms reproduce themselves in the process. One worm can, in theory, produce 1000 offspring in a year, leading to a million the next year and so on. They breed in temperatures from 5°C to 30 or 35°C and, dried, they have

Table 8.
Nitrogen losses during composting of organic wastes (Witter & Lopez-Real 1987).

Material	% Nitrogen loss
Sewage sludge and straw	8-27
Nightsoil	26-29
Sewage sludge and woodchips	4-21
Manure and bark	2-10
Pig slurry and straw	27-41
Fish and bark	8-16

a 60% protein content, comparable to fish meal. Vermicomposting is becoming increasingly widespread and important. Cuba produced 70,000 t of vermicompost in 1993 (Werner 1994).

1.3.3 Examples of composting

The composting initiatives that tend to be reported in the literature are the large-scale, single plant initiatives, rather than highly decentralised low technology programmes. For large plants the emphasis in the literature tends to be on the technology whereas for small scale programmes the emphasis tends to be on social aspects of composting and compost utilisation.

Projects to encourage composting in industrialised countries tend to rely on advanced technology and operate on a very large scale. Plants in Spain, Germany and Malta are attempting annual production of 10-20,000 t of compost, for example using waste from 200,000 people in Valencia to produce 11,500 t annually (Warmer 1995b).

In Accra, Ghana, GTZ supported the implementation of three composting plants with the idea that smaller plants would be less susceptible to disruption caused by shortages of fuel, spare parts or strikes (Schweitzer 1989). There were difficulties when the sites were initially chosen. It was not known how much waste would be collected from the district that each plant served. Subsequently, one plant turned out to be too small and another too far away from the district it served. In these plants, non-compostables were removed manually from a conveyor belt and the compost was prepared in weekly batches in windrows which were turned once they had passed the maximum temperature. However, this caused the compost to dry out and it had to be watered, particularly during the extended dry periods. Once the compost had stabilised it was screened using a manually operated drum.

In Jakarta, a system of waste pickers and traders operates. Furedy (1992) and Simpson (1993) describe an initiative supported by the municipality to promote composting of the organic residues by private individuals rather than government officials. The project concentrated on working with waste traders as they were already established and were familiar with the waste stream. They had yards available for composting and had the entrepreneurial skills to trade the compost once it was produced. The project concentrated on developing a rapid composting process that would enable rapid throughput of waste thus making the initiative profitable, could fit on a constrained site, utilised indigenous materials, was labour intensive, could operate in a densely populated environment with a minimum of nuisance, and yet resulted in a high quality soil amendment product. Each unit would process 3 t of waste per day and if each of the city's 260 administrative units had a plant, 10% of the city's waste could be processed. The project provided start up grants, technical assistance, worker training and guaranteed purchase arrangements for the compost. Jakarta city council provided collection and delivery of fresh rubbish and removal of non-compostable residues. This project however, seemed not to address one of the fundamental problems, namely, how to effectively distribute the compost to farmers who wish to make use of it. There were insufficient resources to investigate and establish markets for the compost and there was no attempt to monitor social acceptability of composting among neighbours. A subsequent document reports that compost from these plants was being sold to farmers, nurseries, golf courses, landscapers, shrimp and fish farmers, home gardeners and growers and users of potted plants for homes and offices.

In Cameroon (Ngnikam et al 1993), composting was carried out in an area where municipal rubbish collection did not take place because the streets were too narrow for the collection vehicles. The climate was favourable and suitable land was available, making composting an appropriate alternative to burning the rubbish, particularly as the waste tended to be mainly organic with a high moisture content. Other small scale initiatives have been reported in Ecuador (Landin 1994), Argentina (Seifert 1992), Guadeloupe (Clairon 1979) and India (Rosario 1994). The projects in Ecuador and India have promoted vermicomposting.

In Villa Giardina, Argentina, a town of 3,000 people decided to recycle their organic rubbish. People were provided with bins for organic waste which was collected and transported to the composting site 4 km from town (Siefert 1992). This is an unusual situation in that there was no shortage of space or transport and the community involved was small.

Proyecto Biomasa is an Austrian government supported initiative that has promoted sustainable technologies in Nicaragua since 1993. Masaya is a town of 70,000 people where 75% of the town's organic waste is composted in windrows under tarpaulins after collection and hand sorting on conveyor belts. The plant produces about 700 kg per day of semi-dry compost. The compost is sold, but the income from sales does not cover the costs of production (Foidl, pers. comm.).

1.3.4 Examples of use of solid wastes as a soil improver

Asia:

Siemonsma & Piluek (1993) report that in South East Asia all types of manure and many types of organic waste material are used for vegetable production. Where substances low in nitrogen such as rice straw are used nitrogen rich wastes are also added to compensate. Some crops such as amaranth can tolerate the very high nitrogen levels that are found in raw town waste that might burn other crops. The material is generally applied to the growing crops as a mulch.

Farmers near Ho Chi Minh City in Vietnam fertilised their vegetable crops with organic wastes, (Jansen et al 1995). City refuse (not including sewage) formed 80% of these applications, the remainder coming from composted plant residues. Coconut and rubber cellulose were also applied. Farmers growing only vegetables used much higher levels of organic inputs than farmers growing grain crops as well.

In India, Ramaswami & Kothandaraman (1991) found that coir pith applied at 15 t/ha enhanced the growth and yield of sorghum under rainfed conditions.

Honghai & Veeman (undated) described a system in China whereby crop organic wastes are used as livestock fodder, the manure is used to produce biogas from which the effluent is used as fertiliser on mushroom crops. Once the mushrooms have been picked their mycelia continue to break down the substrate which can finally be used as compost. Such a system could be used to integrate urban waste into an agricultural system.

Yeung (1986) describes a government initiative in Lae, Papua New Guinea where locally produced compost is used on allotment gardens. Compost production in Lae is intended as a method both to recycle solid wastes for nutrients and to reduce landfill. After removal of non-biodegradables, city waste is combined with manure and composted. What is not used on city gardens is sold to commercial farmers. The intention is to eventually produce 11,000 t of compost per year and reduce the amount of waste going to landfill by 10%.

Africa:

Probably the best documented system of non-municipal waste collection and recycling is that operated by the zabaline in Cairo. A group of Coptic Christians in a predominantly Muslim country, they have migrated to Cairo from Upper Egypt since 1945. Their traditional activity was pig raising, which they continued in Cairo. They collect household rubbish in donkey carts. The rubbish is sorted by the women and children of the family. Organic materials are fed to the pigs while other wastes are sold to middlemen or specialist dealers. Pig manure is collected periodically from the pens and taken to the composting plant where it is mixed with screened domestic waste and composted. It is already fairly well decayed and only needs to be composted for a couple of weeks before being sold to farmers.

A case is reported from Senegal near the town of Thies (Haramata 1991) where farmers applied untreated household rubbish from the town's waste tips to their land, not bothering to remove the plastic and other non-biodegradable items. Haramata found the optimum dose for application of town refuse to farmland was 100 t/ha which increased productivity of sorghum fourfold compared with untreated land.

Lewcock (1994) and Mortimore (1993) describe a similar practice in Kano, Nigeria. Here the use of urban waste is long established, presumably because the area around Kano and other northern Nigerian cities has been heavily cultivated, possibly for centuries. The farmers here are using the waste that accumulates on the streets of Kano. Much of this is organic household refuse, but there are also significant amounts of other materials such as stones from street sweeping, human faecal material from the clearance of open sewers and manure from the livestock kept by city residents. Application rates here for urban waste are 3.25 - 5 t/ha/year.

Lardinois & van de Klundert (1994a) report from Mali, where poor soils and an arid climate mean that fertilisers are required during the short growing season. Chemical fertilisers are imported and so are expensive and in short supply. Waste is simply dumped and left before being sieved to extract the compost. The reliable supply, low selling price and proven quality of the compost as a soil conditioner have created a high demand from vegetable farmers, especially just before the April-June planting season.

Owusu-Bennoah & Visker (1994) report that farmers in Ghana are increasingly making use of organic alternatives to chemical fertilisers such as slaughterhouse waste products and cotton refuse. Farmers also use palm oil processing by-products. The palm oil companies utilise much of the waste, but the surplus is available to farmers who must pay handling and transport costs. The potassium rich ash produced by burning the oil palm fibres is also in demand.

1.3.5 Constraints

Possible constraints to the management and utilisation of solid waste materials, which are discussed in more detail in Chapter 2, include:

- Need for further processing
- Additional separation and collection procedures may be required
- Supply may be seasonal
- Producing compost is labour intensive and expensive
- Transport difficulties and expense
- Organic wastes have a low value
- There may be limited markets

- There are difficulties in matching supply of raw materials and processing capacity
- The production and use of organic wastes may be considered obnoxious
- Climatic conditions can affect processing
- Cost and availability of land for processing
- Variability of quality
- Contamination/toxicity
- Phytotoxicity
- Nitrogen immobilisation

1.4 Nightsoil and sewage as soil improvers

Rather better documented than the use of town refuse as a soil nutrient source for agriculture, is the use of nightsoil in China, although the practice also occurs in Korea, Japan, Taiwan, Thailand and India (Cross & Strauss 1985). Nightsoil is the term used for the mixture of human faeces and urine that accumulates in waterless sanitation systems in much of the world. Seventy percent of urban dwellers in developing countries are not on a sewerage system. Generally urban dwellers have access to pit latrines (80% in Dar es Salaam, Muller & Rijnsburger 1994) that provide safe storage for faecal material unless they overflow, when contaminated leachate can cause diarrhoeal diseases.

In China, families collect nightsoil in buckets. In Shanghai only 13% of the population has access to waterborne sewerage (Robson 1991). Ninety percent of the city's nightsoil is collected, 20% of this is dumped untreated into rivers. Vacuum pumps remove >8,000 t of nightsoil and seepage each day from public toilets, septic tanks and nightsoil dumping stations. At night the wastes are shipped by river and canal in sealed barges to depots on the outskirts of the city. Here the wastes are stored in tanks for 10-30 days before being made available to farmers.

Alternatively the nightsoil is processed by co-composting with domestic wastes in windrows which kills pathogens. However, only relatively small quantities of nightsoil can be treated this way. Dry fertiliser is also produced by dewatering, mixing with waste or straw and leaving to ferment anaerobically for about 3 weeks before drying, granulating and packing (Bo Ling 1994). This dry fertiliser is popular because it is easy to transport and handle.

In the period 1950-1966, 70-90% of all nightsoil produced in Chinese cities and villages was used in agriculture. At the time this amounted to approximately a third of the nutrients supplied for cultivation (Chao 1970). Application rates of 60-100 t/ha/year of farm compost and 20-30 t/ha of nightsoil are reported from China, although this figure seems rather high (McGarry 1976). Proper storage and careful treatment and application of nightsoil to fields is necessary to minimise nitrogen losses. The importance of nightsoil as an essential and easily accessible commodity, especially for poor farmers and smallholders, has been documented by McGarry (1976), Briscoe (1978) and Djadjadiredja et al (1979).

McGarry (1976) cites a survey by the University of Nanking 1929-1933 which found that farmers were using more than 7 t/ha of nightsoil and manure combined. He reports increased use in the 1950s because of government campaigns to encourage nightsoil collection. The collection rate increased from 70% in 1952 to 90% in 1966 (Chao 1970). In China, chemical fertilisers were unknown before the 1960s, but more recently Bo Ling (1994) has estimated that 30% of nightsoil and 2.6% of city refuse are used in Chinese agriculture, containing 800 million kg nitrogen, 400 million kg phosphorus and 500 million kg potassium; equivalent to 4 million t of inorganic fertilisers although this equates to only 4% of the inorganic fertilisers currently used.

In Japan too there is a tradition of using sewage compost as fertiliser (Ishida 1989). Noguchi & Ito (1992) report the production of fertiliser from digested sludge. The sludge is mixed with calcium carbonate and then dried at 900°C before shredding and packaging. The production is fairly small, but the fertiliser is readily used by farmers and gardeners.

The use of nightsoil for fertiliser is not common in Africa, although isolated cases do exist. In Ghana, Owusu-Bennoah & Visker (1994) report that farmers were hijacking septic tank emptying vehicles in order to release the nightsoil over their fields. This is in spite of a strong traditional aversion to using human faecal material. One reason why nightsoil is not utilised lies in the difficulty of obtaining it from pit latrines, although new manual vacuum operated pit emptying apparatus should change this (Muller & Rijnsburger 1994).

1.5 Waste as fuel

In many parts of the world waste pickers scour rubbish to collect wood and charcoal for fuel. There has been a lot of work on the use of agricultural wastes as fuels for biogas digesters. The gas from biodigesters can be used for cooking, heating, lighting or generating electricity.

Urban wastes are more likely to be used for fuel as part of integrated agro-industrial enterprises, such as the scheme near Beijing described by Honghai & Veeman (undated), where methane is generated from pig slurry which is then either dried for use as fertiliser, or to feed pigs, forming up to 20% of their diet. In Dakar, household and abattoir wastes are used to provide power for the slaughterhouse in the mornings and refrigeration in the afternoons (Farinet 1995).

In India (Jain 1994) and Dar es Salaam (Lopez-Real 1995) there are schemes to convert household, market, hotel, abattoir, leather working and pulp and paper wastes into biogas.

In the Republic of Cape Verde (Sandys-Winsch & Harris 1994) an Austrian-funded pig and horticulture unit used the pig waste to generate biogas and utilised the solid waste for horticultural crops. The biogas was used to generate electricity to power the meat processing and refrigeration plants, staff housing and a local village.

Wood & Lim (1989) suggest that the effluent from a 60 t/h palm oil mill would be sufficient to produce 10,000 l diesel equivalent as biogas per day.

Wells (1995) mentions that in Brazil, coconut shells and fibres are burnt to generate steam for electricity. The ash residue is rich in potassium and used as fertiliser.

In industrialised countries there are many schemes to generate power through the incineration of waste. In the United Kingdom a number of facilities exist that burn materials such as straw and chicken manure to generate electricity that is fed into the national grid. However, such schemes are highly capital intensive and are generally not appropriate for countries with less developed economies.

There appears to have been limited work on the use of urban waste as fuel for a number of reasons:

- Lack of space for digesters
- The problem of disposing of the solid residue after digestion
- Urban areas are generally well supplied with power
- Individuals in urban areas tend not to generate waste on the same scale as farmers do and there may be insufficient waste to make a biodigester economically viable
- It is unrealistic to transport urban waste to rural areas where biogas production is most needed when the rural farmers probably have sufficient organic residues to produce biogas if they wished to do so

1.6 Waste for aquaculture

Excreta provides organic matter which bacteria can degrade. This decomposition results in the release of carbon dioxide, nitrogen and phosphorus which are necessary for algal growth. Algae and their direct predators such as rotifers and crustaceans serve as fish food. McGarry (1976) suggests that nightsoil also acts as a direct fish food as fish have been observed to gather at the input point and feed on fresh nightsoil.

The use of human and animal manure for fish production is important in East Asia and elsewhere. The most commonly cultured fish are various types of carp and *Tilapia* which are grown either in mono- or polyculture. Cointreau (1987) writing on wastewater aquaculture in Lima, Peru reported that while carp and *Tilapia* were successful, prawns could not tolerate the large fluctuations in ammonia content of the water that resulted from fresh influxes of wastewater.

Fish provides half the annual intake of protein in some parts of Asia. Yeung (1986) reports that 50% of the food fish in China comes from waste-fed ponds and in some cities more than 90% of the fish does. In Asia, fish farmed in this way reach a marketable size of 600-800 g in 4-6 months. In Taiwan productivities of 132 kg fish/ha/year are reported from unfertilised ponds compared with 619 kg/ha/year for fertilised ponds. Productivities of more than 1 t/ha/year are reported by McGarry (1976) for waste fertilised ponds.

The systems for aquaculture vary. Pig dung is used for feeding fish in S.E. Asia. The pig pen may be built over the fish lagoon and the dung simply swept through the slats. Each 100 kg of pig manure produces 3-5 kg of carp flesh (Vogler pers. comm.). In Java thousands of small family owned ponds exist which have latrines built directly over them.

In other systems sewage treatment ponds are used to produce duckweed which is then fed to fish. Dasgupta (1994) describes the system operating in Calcutta which consists of 4000 ha of waste-fed ponds. The area was formerly approximately twice that amount, but many ponds have been lost to city expansion. Here, fish are grown in 1-2 m deep tanks. Liquid effluent is introduced to a depth of 90-180 cm, the pH is controlled by adding slaked lime and the water is left to stand for a few days before fish fry are introduced. The effluent is already fairly dilute and has an organic loading rate corresponding to that of maturation ponds in warm climates (Strauss 1995). Water hyacinth *Eichornia crassipes* is then introduced to provide shade for the fish, to provide a food source for plankton, to provide protection from wave damage to the embankments, to absorb heavy metals and to produce oxygen. Generally, further effluent water is introduced, via a small tank where it is allowed to settle for a few days before being introduced into the main tank. Several species of fish are introduced. Ducks are also kept to help control weed growth and the meat and eggs are sold. The annual yield for fish is reported as 2,500 kg/ha/year which seems remarkably high. The system has been operating for about 60 years, employs 4,000 families and produces about 10% of the fish consumed in Calcutta.

Robson (1991) describes a system introduced in Bangladesh, where *Lemna* duckweed is cultivated. This plant contains 35-50% protein as a proportion of dry weight (comparable to soyabeans), and at 15-30°C can double its weight every two days. The waste from 100 people is sufficient to cultivate 0.25 ha of duckweed. Duckweed feeding can reportedly produce 10 t fish/ha/year because the duckweed is eaten as soon as it is introduced to the fish pond and does not compete with the fish for oxygen. When duckweed is used as a component of waste stabilisation ponds, effluent is rendered potable after 20 days. Duckweed is probably a better component of aquaculture systems than water hyacinth as it contains relatively less fibre and more protein and is less sensitive to cold than water hyacinth.

1.7 Waste for the cultivation of lower organisms

Poppe & Hofte (1995) studied the potential of different kinds of wastes to serve as substrates for a variety of edible species of mushrooms. Of 40 different substrates, including sugar cane bagasse, chicken manure, brewery swill, chicken feather meal, water hyacinth and shredded paper, they found that maize cobs were the best medium for cultivating *Pleurotus* sp. and sawdust for growing shiitake, but 30 of the substrates could be used directly for mushroom culture. From each kg of dry cellulosic/ligneous waste it is possible to produce one kg of fresh mushrooms.

Various wastes can serve as substrates for single celled protein (SCP), using species of yeast and algae. SCP is grown on an industrial scale on substrates such as various petroleum products and spent sulphite liquors left after paper pulping. However, it is possible to grow SCP on almost any organic, liquid waste such as effluent from palm oil mills, sisal defibring plants, rum distillery effluents and corn and pea canneries. SCP is already used as a protein animal feed. It can be gown extremely fast, requires low capital investment and simple control of production.

Honghai & Veeman (undated) describe a system in China where mushrooms are grown on the effluent from manure-based biogas production.

1.8 Waste water for irrigation

1.8.1 Introduction

The use of wastewater for irrigating agricultural crops is becoming increasingly important. Smit & Nasr (1992) state that 10% of the world's population eats food produced on wastewater. The use of wastewater for irrigation has increased because of increasing competition for freshwater resources by agriculture, industry, and human consumption (Strauss 1988). This increased use is facilitated by a growing recognition by planners of the importance and value of wastewater reuse, including recognition that:

- Nutrients in wastewater can substitute for chemical fertilisers
- Health risks and soil damage can be minimised if proper precautions are taken
- The high cost of advanced wastewater treatment plants can be offset by the use of land application of partially treated wastewater
- In some parts of the world there are no socio-cultural constraints to use

Municipal wastewater is the largest wastewater resource available for irrigation, due to the large quantities of effluent produced in urban centres. This comprises domestic wastewater and any industrial discharges to the sewer network.

The reuse of wastewater for agriculture is unsurprisingly best developed in arid and semi-arid countries where water is highly valued, particularly if it must first be obtained by desalination. However, indirect use also occurs in many countries where treated wastewater is discharged to surface water sources, that are subsequently used for irrigation. For example, in heavily populated temperate areas small rivers may comprise more than 50% wastewater during the summer period.

1.8.2 Processing

The quality of wastewater discharged from treatment plants usually has to meet standards set to minimise the impact on the environment. The quality requirements for wastewater irrigation are different because of the health risks and technical constraints set out above. Although there is a wide range of wastewater treatment technologies available, the technologies commonly used to deal with these health and technical constraints include the following:

- Waste stabilisation ponds - increasingly popular form of wastewater treatment in developing countries that remove pathogens through long retention times, although these require large areas of land
- Chlorination - kills pathogens and limits the growth of biofilms, but is a recurrent cost
- Filtration methods - remove suspended solids

The end use of the wastewater should govern the water quality target which, in turn, should determine the level of treatment required. The WHO Guidelines have produced recommended microbiological guidelines for wastewater use in agriculture (Taylor et al 1989)

The design of conventional wastewater treatment plants is usually based on the need to reduce organic and suspended solid loads to limit pollution of the environment. Pathogen removal has rarely been considered an objective, but for reuse of effluent in agriculture this is of primary importance. Treatment to remove wastewater constituents that may be toxic to crops is technically feasible, but not economically. Natural low rate biological treatment systems are available for the treatment of organic wastewater such as municipal sewage and tend to be cheaper and less sophisticated than high rate systems. Such processes tend to be land intensive compared with conventional high rate biological processes, but they are often more effective in removing pathogens and do so reliably and continuously if properly designed and not overloaded.

The different forms of irrigation commonly used, in increasing order of sophistication include:

- Flood irrigation where the growing area is simply inundated. This will contaminate crops and expose workers to effluent more than any other method of irrigation.

- Furrow irrigation contaminates crops less as they grow on ridges and the water flows along furrows between the ridges.
- Sprinkler and spray irrigation provide more efficient water use than the preceding methods, but there are risks of contamination, or possible dispersal of pathogens in aerosols. The water also has to be virtually free of solids or the sprinkler orifices will tend to clog. Sprinkler irrigation can also result in increased levels of leaf burn of crops.
- Trickle or drip irrigation provides the most efficient use of water as the water is focused on individual plants. However, again the water must have been carefully filtered to prevent clogging of orifices. With subsurface drip irrigation the pipes are 25-50 cm below the soil surface, the soil acts as a filter and the roots absorb the effluent nutrients. Soil moisture levels at the root zone remain constant maximising water uptake by the plants. The dry soil surface means that there is no direct contact between the wastewater and the above soil environment, reducing the pollution risk.

1.8.3 Examples of use

Saudi Arabia, Egypt, Morocco, Algeria, Tunisia, Israel and Jordan all have declared policies promoting wastewater recycling and reuse (Shuval 1995). Examples include:

- At a large scale wastewater reuse scheme in Jordan, the As Samra wastewater stabilisation ponds serve 76% of the sewered population. These ponds discharge into the Zarqa River and the water is then stored in the King Talal Reservoir used for unrestricted irrigation of 1100 ha in the Jordan Valley (Taha 1993). In 1991, 6% of the water used for irrigation was wastewater and, by the year 2000, the quantity of wastewater used will rise to 10%, equivalent to 110 million m^3.

- Farmers channel off raw effluent from Nakuru town before it enters Lake Nakuru in Kenya (Vogler pers. comm.).

- Farmers in Lusaka, Zambia, have cultivated land adjacent to the city's waste stabilisation ponds and irrigate vegetables with effluent illicitly taken from the ponds with buckets (Siakantu pers. comm.).

- The effluent from Mexico City is used to irrigate 100,000 ha of maize, barley, lucerne and oats since it is forbidden to grow most vegetables in this way.

- In Peru, wastewater that has been partially treated by a short stay in stabilisation ponds is used for irrigation in the coastal zone.

- In Tunisia, 78 million m^3 of water are treated annually by 25 plants before being used to irrigate fruit trees.

- In Harare, Zimbabwe (Mbiba 1995) treated effluent is applied to grazing lands by flood irrigation once a week without any further fertiliser input.

Industrial wastewater can also be used for crop irrigation, but this is less well documented than the use of sewage water, presumably because it occurs in much smaller quantities and because it is often mixed into the sewage system. Wood & Lim (1989) describe the use of palm oil mill effluent, which can enhance crop yields by 20%. It was found that raw effluent was more effective in promoting plant growth than partially digested material. Al-Nazeeb et al (1984) found a 20% increase in oil palm yields in Malaysia by furrow irrigating with rubber effluent to a level equivalent to 2 kg nitrogen per palm per year. In Mauritius, 37% of wastewater produced by sugar mills is reused for irrigation of cane (Lincoln pers. comm.).

In Havana, Cuba, experiments are in progress to recycle swimming pool outflow, after dechlorination, to provide irrigation water for small vegetable gardens (Betancourt pers. comm.).

1.8.4 Constraints

Particular constraints related to the use of wastewater in agriculture include: risk of disease, risk of soil salinity and risk of heavy metal uptake in plants and build-up in soils. These are discussed in Section 2.11.8 along with other constraints, which apply more widely to waste management and use in general, throughout Chapter 2.

2. Conditions affecting the use of wastes in agriculture

2.1 Types of agriculture

2.1.1 Farming system and household economies

For reasons of availability and transport, urban organic wastes are predominantly used in urban and peri-urban agriculture. There has been increased interest in the promotion of this kind of agriculture since it has been realised how widespread the practice is, and how important it is to many people. Presumably if any agriculturists are going to make use of urban wastes, it will be these ones.

Urban agriculture takes the form of aquaculture in ponds, livestock in gardens, along railways, roadsides and by pylons, in orchards and vineyards, and as vegetable or cereal growing in vacant lots, by canals, around institutions, along roadsides, on suburban farms and on waste ground unsuitable for construction.

According to Mougeot (1994a, 1994b) urban agriculture has the following characteristics:

- Higher productivity per unit of space than rural agriculture
- Low capital input per unit of production
- Low energy consumption
- Low marketing costs
- Freshness of products

Urban and peri-urban land is often farmed intensively and the use of fallows is generally not a soil fertility enhancing option available to these farmers. In Kampala, Uganda, only 25% of farmers practice fallowing (Maxwell & Zziwa 1992). Urban farmers often face the difficulty that they lack security of tenure and tend, therefore, to grow annual crops. As such, the land needs fertility inputs in order to sustain productivity. Urban wastes, which tend to be cheaper than artificial fertilisers, thus have great potential in these farming systems.

However, urban and peri-urban farmers cannot be grouped homogeneously. For example, some are subsistence farmers, others are dairy farmers and others highly commercialised (long or short term) intensive vegetable producers. The incentive, and ability, to use urban waste may differ amongst different types of farmers.

2.1.2 Crop

Specific farm use of waste is very poorly documented. However, since farmers all around the world make use of crop and livestock residues (e.g. 70% of agricultural residues are returned to the soil in USA); it can be assumed that most common crops are fertilised by waste materials in at least some circumstances and locations. The use of urban organic wastes is probably less universal and will predominantly be on the type of crops grown closer to urban centres, such as vegetables. Siemonsma & Piluek (1993) reported that in South East Asia all types of manure and many types of organic waste material are used for vegetable production. In a number of reports, vegetable production is mentioned as a favoured use for available urban waste owing to the intensity of production in urban areas and the potential higher market value of vegetable crops. In Cuba, organic materials from peri-urban dairy units and bulk organic materials brought into the city of Havana from surrounding areas, are specifically used for the intensive cultivation of vegetable and herbs.

Although urban waste tends to be used mainly for vegetable production, this does not preclude the use of wastes on field crops grown in peri-urban areas although there are few detailed records of this. Haramata (1991) reported that in Senegal, application of town refuse to farmland increased productivity of sorghum. Jansen et al (1995) report a case in Vietnam where the need to dispose of large amounts of waste is a significant factor in the choice of utilisation, application tends to be to grassland and forage crops because they tolerate high levels of plant nutrients and respond by producing high yields.

2.1.3 Livestock type

In many urban areas of developing countries, organised or informal livestock rearing is a significant part of the urban agricultural system. Livestock numbers per farmer are usually low, but in some cases large scale livestock rearing occurs.

Municipal refuse is often a significant source of 'free' food for urban livestock in many developing countries. The importance of livestock in the farming systems and the type of animals kept, affect the potential for waste utilisation as feed requirements differ (see Section 1.2).

There are records of agro-industrial waste being fed to ruminants generally, cattle, sheep, goats and pigs (Volger 1982). Municipal refuse is a significant source of food for chickens, goats, cattle, pigs, sheep and guinea pigs (Blore pers. comm., Newcombe 1977, Fundacion Natura 1993, cited in Mougeot 1994b).

2.2 Markets

A limited amount of information exists on the influence of markets and economic considerations on the collection, processing and use of urban wastes for agriculture. In a few cases there is evidence of trade in raw waste materials.

In Kano, Nigeria, the use of urban waste on farmland is well established (Lewcock 1994, Mortimore 1993). Traditionally farmers would enter the city with a donkey bearing panniers which would be loaded up with waste and taken to the fields. The number of farmers possessing donkeys has decreased since Mortimore studied the phenomenon in the 1960s, but use of the waste continues. Employees of the Kano municipal waste collection service, KASEPPA, drive tipper trucks to peri-urban villages where farmers purchase the wastes. Links between KASEPPA and the farmers are informal, i.e. farmers pay individual drivers to deliver rubbish to their land.

Farmers in Ghana pay handling and transportation costs for by-products from the palm oil processing companies, and copra cake, wheat bran and spent brewers grain are processed, packaged and sold locally as a livestock fodder (Owusu-Bennoah & Visker 1994).

The majority of documented cases concern the successes and failures of institutionally-organised large-scale schemes for processing urban organic waste. There are many reports of the cost of a product which has use in agriculture, usually compost produced as a fertiliser and/or soil conditioner, exceeding its value.

In an Austrian supported composting project in Masaya, Nicaragua the compost is sold to growers of mangoes and melons and organic coffee producers. However, compost sales do not nearly cover the costs of production (Foidl pers. comm.).

photo: E Roycroft

Large amounts of vegetable waste is generated from markets in cities such as the one in Kumasi, Ghana

photo: E Roycroft

In Havana, Cuba, vegetables are produced organically within the city boundaries, placing great demand for organic soil fertility inputs

Unsegregated municipal waste undergoing preliminary composting at Accra composting site in Ghana

Final grading of compost at a large scale municipal composting plant in Accra, Ghana

In Malta the Sant'Antnin waste recycling plant was implemented in response to the island's pressing environmental and resource management problems (Short & Tricker 1994), in particular the growing volume of waste from urban areas, increasingly intense competition for water and a declining food trade balance. The compost produced from sewage sludge and urban waste is sold at a heavily subsidised price and is much in demand (Gauci pers. comm.) Wastewater is also sold to farmers, but at only 4% of its cost (Gauci 1993).

Several Indian cities established composting plants during the 1970s. Almost all have now closed (Jalan et al 1995), partly as a result of production costs exceeding the value of the product.

Similarly, Visker (1995) describes a composting plant in Accra which produced 4000 t of compost annually from a 3:1 mixture of refuse and nightsoil. The initiative failed for lack of markets, but also because the cost of production exceeded the value of the product and the Accra Municipal Authority could not afford to continue to subsidise production. A GTZ supported scheme described by Schweitzer (1989) found that the main market for the compost in Accra were expatriates rather than local people.

Where production costs exceed the value of the product, utilisation of the waste will occur only if other economic, social or environmental factors play a part. Such a situation exists in Europe where, although farmers are not prepared to pay a high price for compost, they will use it. Governments which have a legal duty to dispose of wastes, have to see compost making and utilisation as a waste disposal strategy rather than an income generating one.

The composting project in Jakarta, described by Furedy (1992) and Simpson (1993), found that the organic fraction of the waste, which amounted to as much as 70%, is bulky and of very low value, and as such it is only fit for use as compost. Private individuals tend not be interested in collecting, processing and trading such low value material which therefore will remain the responsibility of the city in which it is generated and municipalities will have to accept it as a waste disposal strategy.

In Japan a marketing campaign was conducted to promote sewage compost. Ishida (1989) reported farmers' reasons for buying sewage compost. Some bought it because it was cheap, some because of the difficulty of making or buying other organic fertilisers, while others bought it 'on recommendation'. Forty one percent of purchasers recognised the fertilising benefits of the compost, while 49% recognised its value as a soil conditioner.

A report from a study tour of composting initiatives in the Far East (The Urban Edge 1979) found the lack of a rural market. Farmers in both Thailand and Japan showed little interest in urban compost even when the price was reduced to 20% of the cost of production. Progressive farmers preferred to use inorganics, conservative ones, locally available manure.

Despite the uneconomic production of composts from organic wastes in many places, there are also documented cases of successful viable markets for composts.

In Egypt, compost produced by the zabaline, from pig manure and other organic waste, is sold to farmers up to 150 km from Cairo (EQI 1985, 1988). The situation in Egypt is unusual in that while soils lack humus, there is water available from the Nile and also sophisticated urban markets prepared to pay high prices for fruit and vegetables.

Lee-Smith & Memon (1994) reported that 25% of urban farmers in Kenya use compost and while most produce it themselves, compost is available in Nairobi markets presumably earning an income for the sellers and possible intermediaries.

The true value of compost utilisation is difficult to assess economically, particularly for more sophisticated varieties of compost, such as micronutrient fortified compost described by Nazareth (1994). Even an assessment of NPK values of a compost is not much use as these elements are mainly unavailable. Compost is probably undervalued.

2.3 Availability and use of alternatives

There are suggestions that urban wastes are most readily utilised in agriculture where alternatives are not available or are too expensive. Farmers may be prepared to buy bulk compost where soils are desperately short of organic matter and most alternatives are unavailable or impractical.

Similarly, in dry parts of the world, where water is highly valued and may have to be desalinised, the use of wastewater for agriculture is best developed (Cross & Strauss 1985).

Chemical fertilisers have a number of benefits. They are easy to transport, store and spread, have low costs per unit of fertiliser and crops react rapidly to them. However, they are also expensive and sometimes simply unavailable. Many farmers cannot afford to purchase fertiliser on a frequent and regular basis. In these circumstances use of organic waste materials, if these can be recycled, obtained free, or purchased at a sufficiently low price, may represent the only fertiliser option. Owusu-Bennoah & Visker (1994) report that, for these reasons, farmers in Ghana are very interested in using organic alternatives to chemical fertilisers.

The use of organic waste-derived fertilisers does not preclude the simultaneous use of inorganic fertilisers, although there are few reports of systematic studies of attempts to optimise organic and inorganic inputs in various combinations. Jansen et al (1995) reported that farmers neat Ho Chi Minh City in Vietnam used both organic waste and inorganic fertilisers on their vegetable crops, but there was no indication that farmers compensated the rate of one source with the rate of another. Similarly, Lewcock (1994) reports that farmers near Kano, Nigeria, use organic and inorganic fertilisers in combination, according to their availability.

2.4 Knowledge and perceptions

Although the availability of alternative soil fertility inputs influences the demand for and use of wastes in agriculture, farmers' perceptions and knowledge is of primary importance for utilisation.

A study carried out by HDRA (Harris et al 1998) found that in areas with a long history of agrochemical use such as around Nairobi in Kenya, organic fertilisers, mainly animal manures, are widely perceived to be better for long term soil fertility. Farmers in this area were generally aware of the potential benefits of using urban wastes for soil fertility and animal feed, and several sources were identified including fruit and vegetable wastes from market places, general town refuse and slaughter-house waste. However, there was little evidence of any use, in spite of high, and increasing, costs of artificial fertilizers and animal manures. A major reason for this was attributed to a lack of knowledge and appreciation of how to use them.

Similar preferences for organic fertilisers have been reported by Lewcock (1994). Farmers near Kano have perceived that organic wastes may have certain advantages over chemical fertilisers. For instance, chemical fertilisers can 'burn' plants when applied during periods of low rainfall, there being no such problem with most urban wastes. This is an important consideration in an area of erratic rainfall like Kano State. These farmers also favour urban wastes as fertiliser since they believe that their effect once applied might last for two or three years, whereas two or three applications of artificial fertiliser might be required during the growing season (Lewcock 1994).

Near the town of Thies in Senegal farmers load up donkey carts with untreated household rubbish from the town's waste tips, take it to their fields and spread it on their land. This practice has been going on since 1990, when farmers became convinced that 'things grow better with garbage', but there is no mention of what precipitated it (Haramata 1991).

Farmers near Ho Chi Minh City in Vietnam who use organic waste on their vegetable crops, have developed recommended annual application rates for different crops. Jansen et al (1995), found that bottle gourd received 50 t/ha, aubergine 80-200 t/ha, onions 50 t/ha, tomatoes 40 t/ha and brassicas 40-50 t/ha. Most leaf vegetables received only 10-20 t/ha of organic material and radishes only sawdust. Compost was considered less important for legumes where farmers applied animal wastes. Coconut and rubber cellulose was also used, most commonly at a rate of 1-2 t/ha to cucumbers, beans, cabbages, bitter gourds and aubergines. The basis for this 'knowledge' is unclear, particularly in view of the variable nutrient content of urban refuse, and some practices such as the supply of only sawdust to radish, which is nutrient poor, must be questioned. Taking into account application of both organic and inorganic nutrients and the fact that they did not reduce the rate of application of one source to compensate for the use of another, it was estimated that farmers were over-fertilising their crops.

Maxwell & Zziwa (1992) specifically asked farmers in Kampala if they made use of urban wastes, but none did. There was an unwillingness to use the wastes and a perception that they had no value in agriculture. Farmers also voiced the lack of technical advice as one of the most important constraints to use.

2.5 Priority of use

It cannot be assumed that agricultural use is the most economic or desirable use for all urban organic wastes. There is clearly competition for use of some materials, and a higher value for another purpose will affect the market price or availability of the product for agriculture. There may also be competition for a waste material for different agricultural purposes, with economic factors dictating whether a particular waste is used for fodder rather than fertiliser. Such decisions will affect different sectors of society differently and might be expected to favour the use of wastes by commercial farms over use by poorer individual farmers.

Some by-products are less 'waste' than others. Wastes that occur in a 'pure' form rather than as an element in domestic refuse are likely to have a higher value. Examples are copra cake, wheat bran and spent brewers grain used for livestock fodder in Ghana, and cocoa bean shells and cotton seeds which are exported to Europe from Ghana (Owusu-Bennoah & Visker 1994).

In most countries waste paper has a higher value for production of paper than for processing for livestock fodder or use as bedding.

In Dar es Salaam (Lopez-Real 1995) there are schemes to convert household, market, hotel, abartoir, leather working and pulp and paper wastes into biogas rather than into fertilisers and soil improvers. At present there are no intentions to integrate the solid residues into agricultural production although these would be of value. Some waste management schemes focus on using wastes for fuel. Two such pilot schemes, one in India and one in Dar es Salaam, are described by Jain (1994) and Lopez-Real (1995) respectively, where there are no intentions to integrate the solid residues into agricultural production although they would be of some value.

2.6 Socio-cultural factors

In China there is a well established tradition of using wastes in agriculture. In earlier times ancestral cults existed which included worship of the soil and water. An enduring theme in Chinese culture is that 'man belongs to soil and not soil to man' (Cross & Strauss 1985). This cultural view is likely to have facilitated the acceptability of soil improving techniques.

In Cuba, despite official efforts to encourage organic agriculture there are no initiatives, and little enthusiasm, for the use of human wastes in urban agriculture. Havana is a city of 2 million people and sewage is currently discharged directly into the sea without any prior treatment.

In many societies in sub-Saharan Africa, contact with human faeces is considered defiling and municipal workers responsible for collecting nightsoil are treated accordingly. Nightsoil is not much used for fertiliser in Africa (Muller & Rijnsburger 1994), and in the isolated examples when it is used, the practice is often not really socially acceptable. Examples of use include northern Ghana where municipal sewage trucks dump their waste on farmers' fields (Harris et al 1998) and Sierra Leone where pit latrines are excavated for use as fertiliser (Cline-Cole pers. comm.).

Koranic edicts prohibiting contact with all human wastes are widely upheld in Islamic societies. The use of human excreta in agriculture and aquaculture and the use of wastewater are not condoned in Islamic society. While Islamic law is quite clear in regard to contact with human wastes, resource constraints and religious, cultural and ideological variations lead to a variety of practices, not all in keeping with Koranic law. While the law is followed to the letter in Iran, in Indonesia Islam is grafted onto a strong indigenous culture. Nightsoil is collected and sold in Jakarta and in western Java it is used in aquaculture (Djadjadiredja et al 1979).

A more recent study on the use of composting latrines in Tanzania showed that users' prior held beliefs had little bearing on uptake. There was no significant difference in willingness to use the compost between Muslims and Christians. It seemed the compost was sufficiently different from faeces not to be taboo.

It has been suggested that cultural proscriptions on contact with excreta are more widely followed among urban middle and upper classes than among the peasantry.

In a number of countries in the Far East the production and use of compost was considered obnoxious and was rejected by many potential users (The Urban Edge 1979). In Bangkok hauliers refused to loan vehicles for the transport of compost because of this. In Malta there have been complaints from local residents about odour from a composting plant (Gauci pers. comm.).

2.7 Gender

Since the use of urban waste is predominantly in urban and peri-urban agriculture, the gender balance in urban waste use might be expected to reflect involvement in agriculture generally. Ratta (1993) reported that in Peru 80% of urban agriculturists were female, with a figure of more than 50% for Kenya. In contrast, in Senegal, China and Brazil they were mainly male.

It seems that the differences in the number of men and women involved in urban and peri-urban agriculture may depend on whether the agriculture is for subsistence, in which case women will tend to be involved, or to generate cash when it becomes a more 'male' activity. In Africa women constitute 60-80% of the agricultural labour force.

Scavenging is an activity often dominated by women. For example, 70% of scavengers in the municipal rubbish dump in Calcutta are women and children (Calcutta Social Project undated). In the system of non-municipal waste collection and recycling operated by the zabaline in Cairo, the collected household rubbish is sorted by the women and children of the family.

In the Philippines, the Metro Manila Council of Women Balikatan Movement organised the Linis Ganda Programme, which involved the separation of rubbish in the household into wet (organic) and dry components. The wet rubbish was collected daily by the government agency, the dry was collected and paid for by the Programme's collectors. Collectors sold what they gathered to junk shop owners who in turn provided the collectors with carts. The women's movement conducted meetings with housewives, civic, trade and religious organisations to inform people of the programme and researched markets for non-traditional recyclables such as broken bottles and batteries. They also organised the collection routes to ensure full coverage of the 21 villages within the San Juan area. Regular meetings were held with the collectors and junk shop owners and the programme provided the junk shop owners with loans as their businesses expanded. Recovery of solid waste has increased from 10% in 1983 to 35% in 1994 (Lardinois & van de Klundert 1994b).

More recently Linis Ganda has obtained World Bank money to start a composting plant. A World Bank/UNDP study of the programme attributed its success to three factors (Ullrich 1993):

- The use of the informal system in the collection of waste materials
- The educational campaign launched in the area regarding environmental issues
- The support of the junk shop owners, the government and the local community

2.8 Tenure and land availability

All around the world cities are expanding, often onto land that was formerly used for agriculture. Farmers on the edge of expanding cities may be less likely to invest in the use of soil improvers, such as urban waste, if they do not have legal title to the land they cultivate and are unsure how much longer they will be using the land. A rational farmer decision may be to 'mine' the land because it is destined for urban developments anyway.

Around Taipei, Taiwan, urban fringe farmland once provided 70% of the vegetables consumed by the city's population (Yeung 1986). By 1979 this proportion had already declined to 30% because of the reduction in agricultural holdings due to urban expansion.

The availability of land sites for processing of waste can also be a major constraint. The high cost of land was cited as one of the reasons why composting plants in several Indian cities had closed (Jalan et al 1995). In Bangalore there were problems in finding an area of land with water for composting (Rosario 1994).

Hardoy et al (1992) suggest that different solutions are required depending on: city size and type of refuse generated; the amount residents can, or will pay; the type of vehicle needed to reach buildings in different types of settlement; local possibilities for recycling or reclaiming part of the refuse; local traffic conditions; the resources at the disposal of local authorities for the collection and management of rubbish disposal; and not least, the availability of land sites for city dumps and processing plants.

2.9 Geographical factors

While some agroindustries are found worldwide e.g. breweries, others will have a more restricted distribution, e.g. coconut palms tend to grow best in maritime environments. In Brazil 500 million coconuts are produced annually and there is a significant industry in recycling the discarded shells for fuel (Wells 1995). Production of wastes of a single identifiable type will depend on the level of industrialisation of a country. For instance, while mangoes grow throughout the tropics it is only in some countries that they are pulped for juice extraction or dried, resulting in 50% waste production (Mahadevaswamy & Venkataraman 1990). In developing countries with their much lower levels of industrialisation, food processing and industrial organic wastes will be considerably less significant than in developed countries.

All processing of plant and animal matter results in waste. Levels of waste generated vary from country to country. Some salad growers in the UK market less than 50% of the crop (Lennartsson pers. comm.) whereas other observers have remarked on the paucity of wastes coming out of abattoirs in Africa because every part of the animal is collected and used, with the possible exception of some of the liquid wastes (Lopez-Real pers. comm.).

The types of waste available for peri-urban agriculture will be influenced by the fact that some agroindustries are more urban than others. Thus, sugar cane refineries tend to be found in the middle of extensive cane estates, since the raw cane is very bulky to transport. On the other hand, breweries tend to be urban, close to the source of supply of their, usually imported, raw materials and the major markets and centres of distribution for their products.

2.10 Institutional support

2.10.1 National government

Support for the utilisation of urban waste in agriculture can be from national or local government, from local NGOs and semi-official organisations and externally from international organisations, donor agencies and NGOs.

There are numerous reasons why governments should promote the recycling of urban organic materials and their integration into agriculture.

- Safe landfill sites are becoming increasingly rare and landfill causes pollution of the surface water and groundwater by leachates, odour and the proliferation of vermin which may spread disease
- Nutrients cannot be removed indefinitely from the soil of rural areas and concentrated in urban areas, without a decrease in soil fertility
- Urban and peri-urban agriculture provides a livelihood and source of food for many city dwellers. It provides the best hope for the urban unemployed in the future, relying as it often does on under-utilised land and under-employed labour

In some instances, governments contribute through supporting education campaigns. For example, McGarry (1976) reports increased use of nightsoil in China in the 1950s because of government campaigns to encourage nightsoil collection. The collection rate increased from 70% in 1952 to 90% in 1966 (Chao 1970). In Malta, the government is encouraging householders to separate inorganic and organic components by providing separate bins for the different types of waste.

2.10.2 Municipal responsibility for waste management

Waste collection tends to be the responsibility of municipal authorities. It is often one of the largest expenses on the municipal budget. In Bangalore, India, it absorbs 40-50% of the municipal budget (Rosario 1994) and Cointreau-Levine (1992) gives a figure of 20-50% for cities in developing countries in general.

In China the sanitation departments of local government are responsible for collecting and distributing nightsoil from latrines to storage tanks located in the suburbs (Bo Ling 1994). All fees including labour and costs of the vehicle and its fuel are paid for by local government.

In many instances, municipalities are prepared to subsidise the processing and use of organic wastes for agriculture as part of their responsibility for waste management. Examples of this have been reviewed above (e.g. McGarry 1976, Shuval 1995, Simpson 1993, Visker 1995, Foidl pers.comm.).

2.10.3 Municipal support for urban and peri-urban agriculture

Generally, links between city governments and agriculturists in and around cities are weak. There are probably a number of reasons for this. In the European model of city government adopted by many colonies at independence, agriculture has not traditionally been a concern of municipal authorities. Municipal governments in developing countries tend to be weak and urban agriculturists, who often exist as squatters, tend to be neither a highly vocal nor organised group (Maxwell & Zziwa 1992).

Agriculture may even be forbidden in urban areas. Streiffeler (1987) mentions how the Nairobi government, at one point, ordered the destruction of spontaneous agriculture in the city. Cities with such attitudes to urban agriculture are unlikely to implement the appointment of agricultural extension officers and mechanisms for encouraging the use of urban waste by local farmers.

One example of a city that actively encourages agriculture within its confines is Havana, Cuba. Support for urban agriculture only dates back to 1989 when Cuba's main trading partners, the Communist Eastern Bloc collapsed. This meant that Cuba was unable to maintain exisiting levels of agrochemical import. The United States has imposed trade sanctions on the island, greatly affecting Cuba's main export, sugar. Because of the lack of agrochemicals and environmental concerns, the Cuban government is encouraging people to adopt organic cultivation methods. The Ministry of Agriculture Urban Agriculture Department has 77 extension officers to provide free extension and training services to the organic farming sector, encouraging and advising on the use of organic urban wastes. The government provides other forms of legislative support for urban agriculture. Although the land on which crops are grown belongs to the state, co-operatives have guaranteed use of the land for ten years. Co-operatives are authorised to sell their produce at prices controlled by supply and demand.

There are other isolated instances of city governments supporting agriculture within their confines, but generally these are on a much smaller scale. In Lima and Manila governmental organisations have leased urban land, e.g. around hospitals, for agriculture (Smit & Nasr 1992). Yeung 1986 described how in Lae, Papua New Guinea the city government became concerned about the removal of forest from hillsides above the town for agricultural use. Allotment gardens were constructed on city lands and were assigned to low income residents by the city government. The crops were fertilised with locally produced compost and technical assistance provided by the city horticultural staff.

Schenkel (1982) reports that 80% of China's population work in agriculture and that connections between town and country are very close. The authorities in China have encouraged this synergy. Some of China's most productive agricultural land is found in the areas surrounding cities (Hardoy et al 1992). Eighty percent of the vegetables entering Shanghai city are produced within the boundaries of Shanghai city region.

The scale and value of food production reported from Chinese cities is probably due to the fact that production is considered within large administrative boundaries which include large rural areas in addition to the built up areas. Its potential in other countries is often lost or diminished as agricultural land on city peripheries is purchased as a speculative investment or developed illegally for housing. In Beijing, despite recent city expansion, the traditionally very important fields to the south of the city have remained agriculturally productive, and when cities in China are looking to expand, there is extensive dialogue with surrounding agricultural communes so that only wasteland or unproductive fields are given over to housing.

2.11 Technological and economic constraints

2.11.1 Processing

Most wastes require some degree of processing before they can be used safely and appropriately for agricultural purposes. In general this represents a major constraint, since those countries and communities which perhaps have greatest need for waste recycling for economic and agricultural reasons, often have the poorest provision of processing plants and equipment.

Organic wastes for soil improvers need processing to overcome problems of phytotoxicity, nitrogen immobilsation and bulk transport. Composting is the most commonly used technology, and can be done by very simple methods.

Wastewater, whether discharged or used in agriculture, needs to undergo treatment to avoid health problems and minimise environmental impact. There are quality standards which have to be met and a wide range of wastewater treatment technologies available and commonly used. The end use of the wastewater should govern the water quality target which, in turn, should determine the level of treatment required. Amount of sewage generated per capita is broadly similar for different countries. However, the method of disposal used for this material will influence its availability for recycling. Faecal material collected in a water-borne sanitation system is considerably easier to deal with than that accumulating in waterless latrines.

Ninety to ninety five percent of all wastewater in developing countries is discharged unpurified into lakes and rivers (Erbel 1995). Sanitation is unglamorous and has received a low priority by governments compared with road building, power schemes etc.

Agro-industrial wastes are an important component in livestock feed worldwide, but for reasons of toxicity or perishability, may require more processing than simply separation of edible components. The need to process oil seed residues, citrus pulp and chicken feathers, for example, is discussed in Sections 1.2.2 and 1.2.3. In developing countries it is, however, unlikely that subsistence farmers will have the means to process some types of waste into feed.

2.11.2 Cost of technology investment and maintenance

Centralised urban waste schemes are perceived by policy makers as being too expensive to implement in developing countries. Seventy percent of urban areas in developing countries are not on the public service network for drinking water, sewage or waste collection (Gaye 1994). This means that while systems for reusing wastes in agriculture are well established and documented, they are generally a feature of richer countries.

Programmes for Morocco (Maung 1982) have been examined. Plants in Morocco were built during the years 1962-1973 in Rabat, Marrakech, Tetouan, Meknes and Casablanca. By 1973 all the plants had broken down except the one in Rabat which was processing 160 t of rubbish per day, a third of its intended capacity. The reasons given for the failure of the projects were:

- Inefficient collection and transport of rubbish
- Incomplete facilities at the plant site
- Wrong choice of plant location
- Poor utilisation of equipment
- Poor plant engineering
- Unsuitable method of biological treatment
- Lack of skilled operating and maintenance personnel
- Generally inadequate plant management

Rio de Janeiro has three composting plants with the combined capacity to produce 800 t of compost per day, but are running at a fraction of this because of structural faults in the machinery (Wells 1995). These factors may limit the size and technological nature of processing plants.

2.11.3 Collection and separation

Waste collection tends to be the responsibility of municipal governments. While recycling of the waste starts as soon as it is generated, as door to door collectors may buy the more valuable items from housewives, the actual collection and transport of the waste is municipal. Schertenlieb & Meyer (1992) list the most frequently encountered problems in waste collection and disposal in developing countries:

- Inadequate coverage of the population to be served
- Operational inefficiencies in existing solid waste management systems
- Limited utilisation of the capacity of informal and private sectors
- Inadequate final disposal of municipal solid waste
- Inadequate collection and final disposal of hazardous non-industrial waste

Municipal waste management systems are typically based on the systems operating in industrialised nations where the emphasis is on technology. Large waste-compacting trucks are not really appropriate in developing countries as they are often unable to penetrate high density housing areas and they make sorting of the waste more difficult for waste pickers. Furthermore, in developing countries much of the waste is bulky organic material, not amenable to compaction to the same extent as is the paper- and packaging-rich waste of industrialised countries.

To some extent the municipal problems of collection and separation have been avoided in those cases where there is an informal, often traditional, waste recycling system. In most cities in developing countries an informal waste recycling system exists in parallel to municipal efforts. Informal waste recycling is often very important in terms of urban employment. Pacheco (1994) estimates that 1% of the Colombian population (>50,000 families) earn their living from urban rubbish.

Furedy (undated) reports that scavenging was the original method of disposing of accumulated rubbish in colonial Calcutta; licensed scavengers removed rubbish before the city established its own cleansing staff (Goode 1916 cited in Furedy undated). The municipal dump was created in 1867 and it became the main focus for scavenging. Around the dumps are established squatter villages (many of whose inhabitants are employed as sweepers and truck drivers by the Corporation of Calcutta). Scavengers await the 200-300 trucks arriving at the dump each day before descending to collect cloth, tin cans, pieces of paper, bone, wood, coal cinders, all metals, wire, rubber, rubber soles, old shoes, leather, broken glass and china, soaps and coconut shells. Recycling of higher valued materials can be very efficient. Simpson (1993) writing about Jakarta estimated that 88-98% of the higher value materials are recaptured.

In Cairo an estimated 40,000 families depend on waste recycling and collection for their livelihoods (Tollemache

1981). The wahiya, who originally came from an oasis in the Western Desert, control the rights to the domestic waste of Cairo and brokers compete for rights to collect the rubbish from new buildings. The commission varies depending on the quality of waste likely to be generared. The refuse brokers (wahiya) collect a monthly fee from flat owners and let the collection rights to the zabaline. The zabaline collect 10,000 m³ per day (Haynes & El-Hakim, 1978) or about half Cairo's waste (Tollemache 1981). Other household waste such as broken furniture is collected by another class of waste collector, the rukabikya, while public area waste is the responsibility of the municipality.

Although poor neighbourhoods have an urgent need for waste services, in Asia NGOs are finding it more effective to work in middle and upper class areas. Source separation and decentralised composting are more worthwhile and feasible in such areas because the wastes contain more recyclables, the householders better understand the purposes of waste separation, they can pay for collection services and there is space for composting (Furedy 1992).

Probably the greatest problem for producers of compost from urban waste all over the world is contamination with inorganic materials. If incoming organic waste is contaminated, even very expensive equipment is unlikely to improve the quality of the compost produced. Devising a collection system which minimises contamination is of primary importance. However, source separation has proven difficult to implement (Rosario 1994).

2.11.4 Transport

Among the most frequently cited constraints to the utilisation of urban wastes for agriculture are the cost and availability of transport either for collection or for distribution after processing.

In fact, the constraints of transport are cited as one of the advantages of centralised composting of municipal wastes to produce soil improvers. Although composting of municipal refuse before redistribution goes against one of the fundamental tenets of waste management, to handle waste once only, this second handling of waste may have to be accepted. It is possibly more practical than taking the waste from the city to farmers, expecting that they will separate the wastes, compost the organics and leave the non-compostables for recollection by the municipality. However, little information is available to support this view.

Even where organic wastes or compost are available, a market for these materials is not guaranteed. Compost is bulky and generally considered to be of low value and this can geographically limit the size of potential markets. Inadequate road systems further add to this constraint (The Urban Edge 1979). Lardinois & van de Klundert (1994b) reported that use of urban compost around Asian cities was limited to a range of 25 km.

On a local scale, even if suitable processed waste is available, farmers themselves may lack appropriate transport. Maxwell & Zziwa (1992) found that farmers in Kampala had no means of transporting the waste to their plots.

In Cuba, the single greatest constraint to organic urban agriculture is the lack of transport, because of the severe shortage of petrochemicals. There are very few draft animals within the cities, presumably because Cuba was able to rely on a cheap and reliable supply of oil for internal combustion engines until the collapse of the Soviet Union. Since then there has not been sufficient time to build up a sizeable national herd of draft livestock.

2.11.5 Cost of labour for collection, processing and distribution

Reutilisation of crop and livestock residues is labour intensive. Apart from burning which results in the volatilisation of many of the nutrients found in straw etc, or letting livestock consume crop residues in situ, composting or direct incorporation of residues into the soil are hard work. Clearly the effort and labour required is a major factor determining waste utilisation at the farm level.

The high cost of production was cited as one of the reasons why composting plants established in cities such as Calcutta, Madras, Delhi and Bombay during the 1970s had almost all now closed (Jalan et al 1995). Visker (1995) states that a composting plant in Accra failed partly because the Accra Municipal Authority could not afford to continue to subsidise production.

In a study carried out by HDRA in sub-Saharan Africa, it was found that labour constraints were not just related to availability of labour *per se*, but also to unwillingness to spend the necessary time. Views such as 'the practice is tedious and time-consuming' (Tanzania) were voiced (Harris et al 1998).

2.11.6 Seasonal variation in availability

Composition of waste, particularly the organic components will vary from season to season. Deelstra (1989) notes that in Bangkok a large proportion of waste during the mango season comprises mango pips and skins while Samsunlu (1982) notes that in Turkey there is much more ash in domestic waste during the winter, while in spring, vegetable waste tends to predominate.

Where a single type of waste is used as a livestock feed, the seasonality and reliability of supply may limit its value. For example, fruit wastes can become a main energy source, but supply may be highly seasonal. Wastes suitable for animal feed are often perishable, e.g. citrus peel and cocoa pods, and can therefore only be viewed as a valuable feed supplement.

Conversely, the demand for waste products may be seasonal. Ishida (1989) found that to be the case for the demand for sewage sludge compost in Japan, yet the supply was all year round.

2.11.7. Variability of quality

Because of the variable nature of urban refuse compared with farm waste, which typically contains a limited range of plant materials and manure, the quality of the compost is difficult to predict, particularly with respect to nutrient content. As such it may be difficult to estimate appropriate land application rates.

2.11.8 Health and safety

The availability of a particular type of urban waste, even in abundance, does not guarantee its potential for use, unless health and safety risks associated with certain types of wastes can be eliminated. This applies to:

- Human handling of wastes or waste derived materials
- Human and animal consumption of waste derived material or foodstuffs produced with the use of waste derived materials
- Any potential adverse affects on soil, plants or animals within the agricultural system

Wastes may contain potentially toxic materials such as cyanides, acids, lyes, mordants, bleaches and elements such as arsenic, cadmium, chromium, copper, lead, zinc and mercury, which may contaminate the soil and be harmful to plants, humans and animals.

There are clear risks associated with the use of wastewater for human/animal consumption and irrigation. Another concern regarding the use of wastewater for irrigation are pathogens, that have a faecal-oral transmission route, because it allows the cycle of infection to be completed. The greatest risk is associated with the irrigation of fruit and vegetables that are subsequently consumed raw.

A wide range of diseases may potentially be transmitted via food crops. The major groups are:

- Bacteria (typhoid, bacillary dysentery)
- Viruses (hepatitis, a wide range of gastro-intestinal diseases)
- Protozoa (giardiasis, amoebic dysentery)
- Parasitic worms (ascariasis, tape worms)

The main fear relating to wastewater use tends to be that it may contain various diseases and human parasites such as *Ascaris lumbricoides*, Taenia, viruses and coliform bacteria. The most important of these are parasitic worms and viruses, due to their longevity in the environment. However, appropriate treatment and utilisation of the water can minimise the risks.

Peri-urban health issues have been reviewed more generally by Birley and Lock (1997).

Even if toxic materials are not present at concentrations likely to affect humans, they could well be at phytotoxic levels which would limit their agricultural use. Therefore, repeated irrigation, even with small concentrations of heavy metals, may lead to phytotoxic accumulations and potentially, a risk to health. Pescod (1992) reports that >85% of the applied heavy metals are likely to accumulate in the soil, mostly at the surface.

There are also fears of an increase in soil salinity through the use of wastewater for irrigation (Gauci 1993). The risk of salinity build-up depends upon the ratio of the volume of water applied to the evaporative demand. For example, in Cyprus, the reuse of domestic wastewater decreased the level of soil salinity because the salt was effectively leached from the upper soil layers. In Jordan, Taha (1993) stated that although the domestic wastewater to be reused had moderate salinity, this would not cause problems if appropriate water management practices were employed.

Many wastes which nominally have a composition providing a valuable addition to the diet of livestock, are unsuitable for use because of toxic or anti-nutritional factors. Examples discussed in Section 1.2, are citrus seeds in pulp used as feed, over-ripe bananas and peanut husks.

A major problem with using municipal solid waste as an animal feed is the presence of heavy metals, particularly lead and mercury, and chlorinated hydrocarbons. One source of lead is from newspapers fed to animals (Silva 1993).

Animal feeds can be produced with high percentages of cow dung without processing or sterilisation, but there are concerns about the risks of diseases and drug residues being passed to the feeding animals, especially when manure is a component of feed to the same species. Similarly, using animal tissue wastes as feed is a somewhat dubious practice in the light of the 'BSE/CJD' concern in the UK.

One of the fears relating to compost use is that soils, and ultimately crops, will accumulate high levels of heavy metals, especially from urban composts. Drescher (1994) studying vegetable growing on an urban landfill site in Lusaka, Zambia found that vegetables did not accumulate heavy metals. Even in heavily contaminated soils, concentrations of metals in the vegetables remained considerably lower than soil concentrations.

Inappropriate use of wastes with high C:N ratios as soil improvers can also lead to reduced soil fertility due to nitrogen immobilisation that may occur when fresh organic material that contains relatively low amounts of nitrogen such as rice straw or sawdust is applied to soils (Garcia et al 1992). In some cases, urban waste as well as sewage sludge has severely inhibitory effects on seed germination (Garcia et al 1992).

One of the greatest problems for producers of compost from urban waste all over the world is contamination with inorganic materials. If incoming organic waste is contaminated, even very expensive equipment is unlikely to improve the quality of the compost produced. Waste sorting by hand picking is becoming increasingly hazardous in some countries as waste becomes more contaminated with broken glass, toxic materials and biomedical waste.

The presence of glass in the resulting compost was cited as one of the reasons why the products of composting plants established in Indian cities such as Calcutta, Madras, Delhi and Bombay were unpopular (Jalan et al 1995). Farmers found that compost prepared in Bangkok contained plastic and glass and barefoot paddy farmers were, unsurprisingly, not prepared to use it (The Urban Edge 1979).

3. Gaps in knowledge and recommondation for further research

There have been many projects which have adopted a top down, technological approach to waste management with the inclusion of some aspects of the potential utilisation of organic waste products in agriculture. These have principally been concerned with the use of municipal and/or agro-industrial solid wastes and to some extent with sewage and waste water. In many cases the technologies have been thoroughly studied, although for individual types of waste there are no doubt researchable topics concerned with detoxification, processing, storage and use. The main constraints identified in these technological projects seem, however, to be related to a lack of resources rather than a lack of research information, and included lack of suitable land, finance, transport and maintenance of equipment. Such projects often generate a product for which there is an insufficient market or use, in some cases justifying this on the grounds of waste disposal alone. There appears, therefore, to be a case for further research into small-scale and community or on-farm processing.

There have been far fewer studies starting from the basis of establishing the need for organic wastes in existing urban and peri-urban agricultural systems and investigating the potential to satisfy these needs within current resource, and institutional constraints. There are a number of significant gaps in knowledge on the value, processing, application rates, consistency of quality and efficacy of wastes at the farm level. To understand the system of waste use in peri-urban agriculture, an integrated approach is required.

Areas in which further research is needed have been identified as a result of this review. Research priorities were also identified by a working group on peri-urban interface production systems attending the workshop "Integrated nutrient management on farmers' fields: approaches that work", held at the University of Reading in September 1997 (Gregory et al 1997). The following research priorities are suggested:

For selected case study cities/regions research should be carried out with target farms and communities to:

- Develop an understanding, at the city/regional level, of the institutional perspectives of urban policy makers and urban planners/managers regarding both waste management and urban/peri-urban agriculture.

- Gain information on the current use of urban organic wastes. A calculation, from farm nutrient budgets and soil analyses, of the likely need and potential use of organic wastes. Emphasis is likely to be on the use of wastes as fertilisers and as soil conditioners, as soil fertility is perceived to be a major constraint to sustainable agricultural productivity in these regions. However, use of wastes for feed, fuel or aquaculture should not be ignored as evidence suggests that use of wastes in integrated farming systems is particularly effective.

- Establish baseline data on soil nutrient deficits in urban areas/peri-urban areas.

- Development of municipal waste collection systems which minimise contamination.

- Develop inventories of available nutrient resources, quality and accessibility, and assess the local availability, supply and cost of organic waste materials and their practical application in the chosen communities.

- Develop decision trees and choice pathways for nutrient management in relation to waste utilisation, for different kinds of farmers (e.g. intensive commercial vegetable producers, subsistence farmers etc.) under different circumstances (e.g. climate, soil type, land use rights, urban policies and infrastructures etc.), including research into:
  - The efficacy of waste utilisation in on-farm trials to determine application rates and methods in specific crops within the existing peri-urban agricultural systems encountered
  - The use of organic wastes in mixtures with inorganic inputs and mixtures of different organic wastes
  - Cultural issues including the farmers' attitudes and acceptability of handling and using different wastes
  - The economics and labour requirements of waste use at the farm level
  - The potential and methods for small-scale community or on-farm composting of wastes

Work initially needed in the use of wastewater in crop/fish production systems includes:

- For the selected case study cities/regions research needs to be carried out with target farms and communities to

establish baseline data on:
  - The current use of wastewater
  - The local availability, supply and cost of wastewater

- Evaluate whether small-scale local wastewater collection and treatment would allow the development of wastewater-irrigated crop or fish production by target communities in the peri-urban interface.

- Specific research projects within the city/region linked to existing wastewater collection and treatment schemes.

A number of these issues are currently being addressed by research within the Peri-urban Interface Production Systems of the Department for International Development's Natural Resource Systems Programme. The research is concentrating on the cities/regions Kumasi in Ghana (Blake et al 1997) and Hubli-Dharwad in India (Shepherd 1997).

4. Potential pathways for research uptake

No consistent pattern emerged from the literature review as to the main uptake pathways for research into urban wastes, but the following points may be of significance:

- Implementation of urban waste utilisation is frequently top down and involves municipal or other local government agencies. These are key motivators, to a greater extent than the conventional agricultural extension services, who may identify more with national agricultural extension strategies than local government initiatives. Local government departments responsible for environmental issues, waste disposal and health need to be involved as well as authorities responsible for urban agriculture and livestock. Where changes to attitudes and practices by the public are required, perhaps in the separation of domestic waste at source, then local or national governments with access to the media or other educational pathways are likely to be involved.

- There are few descriptions in the literature of NGOs playing an active role in waste utilisation projects. Although this may reflect the tendency to report larger and more formally organised projects, it probably also reflects that most reported projects are involved with the generation of wastes at a municipal or agro-industrial level and are on a scale which may be perceived a too large for individual, possibly quite small, local NGOs.

- There are a few examples of the traditional use of waste materials in agriculture by communities and some examples of relatively recent novel, unilateral adoption of 'self-help' utilisation of waste by communities. There would appear to be scope for further consideration of waste utilisation in integrated farming projects at the community level.

- A significant proportion of successful schemes reported, have included private sector activities and income generation. Dissemination of results to, and involvement of, the formal or informal private sector should be encouraged.

- There is significant involvement of major donor agencies from developed countries in urban waste management projects. This may reflect interest and expertise in industrialised countries which also face waste management problems. Existing European- and North American-funded projects offer a valuable pathway for possible uptake of future results.

5. Urban waste database

With the exception of articles obtained through personal communication with workers in relevant fields, the majority of information in this report was obtained by searching a range of databases.

For convenience, these references are electronically stored within the proprietary bibliographic software programme "Papyrus" (Research Software Design, Portland, Oregon, USA). This system allows owners of the full software programme to update and amend the database, and also to distribute the database free of charge with a restricted (read only) version of the software programme.

References are stored with all bibliographic details, including keywords where it has been practicable to include them. The data base is fully searchable on all fields, and reference lists of selected records can be saved to file and printed.

The full database and restricted (read only) version of the software programme have been packaged for distribution on 3.5 inch disks. Full installation details are contained in the file **papr.doc** which can be opened with any word processor or text editor. This text file also contains full instructions for using the programme. Anyone wishing to edit the database must purchase the full version of the software programme and obtain copyright permission.

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