3.1. Handling Systems

Manure handling systems vary among producers but, generally, they consist of four main components that include: collection, storage, treatment, and use/disposal (Smith, 1996). A similar summary of the components of manure handling systems for livestock production is given in Table 2. Manure collection systems are those components of manure handling systems that are used to collect and remove manure from the confinement facilities. Manure storage structures are components of manure handling systems that are used to store the collected manure from the confinements and put-together in structures such as deep pits, earthen structures, and above-ground or below-ground concrete tanks. Manure treatment can be perceived as the component of manure handling systems that is used to alter the original condition of the manure. An example is solid-liquid separation, mechanically or chemically, for the purpose of improving manure handling properties, producing manure solids for animal feeding, energy generation (for example, biogas) and compost production as well as reduction of odour and pollution potential of the manure (Zhang and Westerman, 1997). Currently, application of manure to cropland is the most common and practical method of manure utilization whereby benefits to the soil and plants of the organic matter and nutrients that are contained in manure can be derived. It is considered disposal, when manure is applied at a rate greater than which the soil and crops can use (Smith, 1996). Although it seems like a cheap manure handling system, it is a system in which producers use their fields as landfill sites, and is unlikely to be sustainable.

Table 1. Components of a manure handling system.

Operation	Solids	Semi-Solid/Liquids
Collection	Gutter cleaners Front end loaders	Slotted floors (complete with gutters) Scrapers cable hydraulic tractor
Transfer	Manure wagons Open tank spreaders Dump trucks Earth moving equipment	Pumps submerged, open impeller piston pneumatic Augers Vacuum tank wagon Pipeline Gravity Continuous flow gutters Large diameter pipes
Storage	Stock pile Bunk silo	Glass lined steel Concrete Earthen
Treatment	Aerobic compost dry incinerate Anaerobic	Aerobic pre-storage partial total Anaerobic Solid/Liquid separation
	Land application	Land application

Utilize/Disposal	Energy production (i.e. biogas)	Irrigation Energy production

(Source: MAF, 2001).

The major difference in manure handling systems is the use of solid or liquid systems (Schmidt et al., 1996). It is possible that producers may use solid manure handling systems or liquid manure handling systems exclusively, or both solid and liquid systems. However, selection between these two systems is not so simple, but challenging to producers because of the consideration that has to be given to two important issues: cost effectiveness and environmental safety (Barrington and Cap, 1991; Schmitt et al., 1996; Harrigan et al., 1996). Both solid and liquid manures have to be managed properly for the protection of the environment and optimum level of crop production. This may be achieved by the use of manure application management decisions. According to Schmitt et al. (1996), the form (solid or liquid) in which manure is handled and stored is implicitly related to some manure application decisions. The quantity of manure that has to be handled and the type of soil (due to compaction and leaching properties, etc.) on which manure would be applied also greatly determine the profitability of manure handling systems (Brundin and Rodhe, 1993).

A manure management survey of Minnesota swine producers, for example, indicated that the form in which manure was applied to fields was statistically ($P < 0.001$) linked to the size of the farms (Schmitt et al., 1996). They reported that, 52%, 21%, and 4% of the small, medium, and large farms, respectively, handled their swine manure exclusively as a solid whereas 15%, 23%, and 43% of the small, medium, and large farms handled their manure as liquid. The correlation of small farms and solid manure and large farms and liquid manure was attributed to financial considerations. The justification was that liquid manure handling and storage systems generally require more initial capital investment than solid manure handling and storage systems, which smaller farms could not justify but the larger farms by allocating the set-up costs over more hogs. Similarly, in a study that compared manure-handling systems under Swedish conditions, Brundin and Rodhe (1993) reported that solid manure handling systems appeared to be more profitable than slurry systems for small dairy farms of about 20 cows. In another study, conducted in Quebec, it was indicated that solid manure storage facilities that were accepted by environmental authorities were more expensive and less practical systems for dairy farmers as compared to the liquid alternatives (Barrington and Cap, 1991).

3.1.1. Liquid

Liquid manure can be defined as a mixture of excreta (urine and fecal matter) that is handled mostly by pumps, pipelines and closed tankers, and it typically has a total solids content of 3-6% (Turnbull, 1984; Fleming, 1986). Owing to ease of mechanization and low labour requirement, liquid manure handling systems are popular in various types of confinement animal operations including swine, dairy, beef, and poultry (Zhang and Westerman, 1997). Liquid manure handling equipment varies more than those used for solid manure due to the many different styles of liquid manure storages (Fleming, 1985).

Barrington and Cap (1991) listed several advantages that liquid manure handling systems offer over solid manure handling systems and indicated that there was a justifiable trend towards adopting liquid manure systems for dairy producers in Quebec. For example, use of gravity flow systems may allow eliminating all handling equipment and minimizing bedding (Midwest Plan Service, 1983). In spite of the consequently limited use of bedding material, adaptation of liquid manure handling systems in tie and stanchion barns can be made possible by installing grates over gutters to keep the cows clean. The manures can then be transferred to liquid storage facility, which can be built entirely of compacted soil at 25% of the cost that is needed to build a concrete tank (Barrington and Cap, 1991). When required, it is possible to remove the manure from the storage by using only one type of equipment and pumping it out from the reservoir with little problem.

On the other hand, however, Barrington and Cap (1991) caution that, from an ecological point of view, liquid manures tend to be more susceptible to causing problems of odors, soil compaction during disposal (land application), and nutrient leaching after soil incorporation. For example, they cited Sobel et al. (1988) to have reported that liquid dairy manure produced more offensive odors than solid manures during disposal. Liquid manure handling systems are causes for much environmental concern due to their inherent odor generation potential. In a study that investigated the presence, concentrations and distribution of manure gases in livestock housing in Sweden, Skarp (1975) found that liquid manure set in motion by pumping, mixing or cleaning-out released large amounts of gases, particularly H_2S which sometimes appeared in lethal concentrations whereas solid manure did not release gases in quantities injurious to animals or humans. Similarly, Klarenbeek (1985) reported a ten times greater odor emission from liquid poultry manure than the same manure handled in the solid form.

There are several types of liquid manure storage systems. Some examples include: circular concrete storage, rectangular concrete storage, above ground concrete silos, circular glass-lined steel storage, and earthen storage, and multiple storage systems (Hilborn, 1997). The round concrete structure in the circular concrete storage provides the most efficient use of concrete and reinforcing steel whereby the steel bars resist the outward force of the manure when the tank is full and the concrete wall resists the inward pressure of the earth when the tank is empty. This type of storage can be built completely below ground, partly below ground or fully above ground. Rectangular storages are suitable for conditions when constructing barns over top, the storages are roofed, or when the available area may not fit for a circular structure. The straight walls of rectangular storages must be supported so that they withstand the large stress on them and the most common ways of doing so are constructing of a roof or a slat support and designing the walls as retaining walls; i. e. using a cantilever or buttress design. Above ground concrete silos are smaller diameter limited capacity (about 200 kgal.) storages. Circular glass-lined steel storages are large diameter glass lined steel storages that are typically sold as part of a complete system including transfer, pumping, and agitation equipment. Earthen storages are usually rectangular in shape and posses 1:2 (rise:run) side slopes which increase the surface area of the storage as well as the liquid volume by allowing more precipitation to land in it. The resulting dilution makes it easier to handle the manure as liquid, however, added water increases the cost of application. Seepage loss is a potential problem associated with such storages and adequate testing and proper construction techniques must be used to ensure that sealing of the surface of the structures would take place to protect the environment. Figures 10 and 11 indicate different types of liquid manure storages that can be built of concrete, Figure 12 shows an example of earthen manure storage, and Figure 13 shows one way of surface covering of liquid manure in an earthen storage to control odour nuisance.

Figure 10. Above ground concrete liquid manure storage that can be used in places where soil conditions would pose risk to drinking water if earthen storages were used. (Source: PAMI, 1997b).

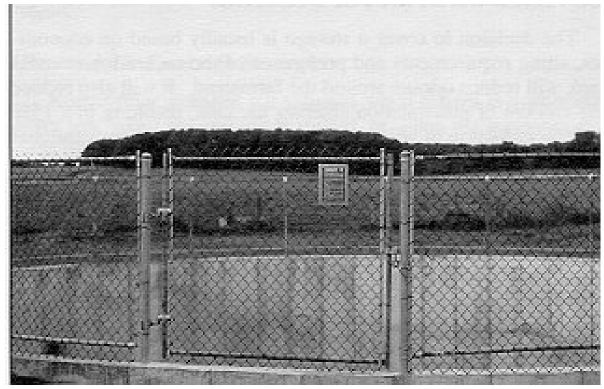


Figure 11. A concrete liquid manure storage tank with chain link safety fence. (After Hilborn, 1997).

Figure 12. Earthen manure storage (SAF, 1997).

Figure 13. Straw being applied to an earthen manure storage. (SAF, 1997).

Emissions of gases such as ammonia, methane, and nitrous oxide are potential problems associated with manure production and storages, particularly with liquid manures. Emissions of such gases can be detrimental to the environment, source of odour nuisance to the community around livestock operations, and may translate to economical loss due to the loss of important nutrients that could have been used for crop production (Hörnig et al., 1999). They reported that research has been conducted to examine the effect of reducing emissions while considering cost and durability. A study in Germany revealed that rigid covers over large lagoons are impractical and prohibitively expensive, however indicated the existence of alternative versatile and low-cost covers (floating layers) such as straw, granule, swelled clay, oils, peat, foams, foils, mesh, leka rock etc. (Hörnig et al., 1999).

Similarly, PAMI (1993) conducted a serious of studies on the effectiveness of the use of supported and unsupported floating covers on hog manure lagoons, with emphasis on cover durability, straw type, odour reduction period, and management problems in Saskatchewan. The result of these studies indicated that barley straw of good quality (i.e. fresh, unweathered, relatively dry, with as many whole stalks as possible) can give effective odour control over the entire season with only one or two reapplications to small areas of the lagoon surface to recover areas of straw sinkage. Moreover, it was reported that any type of cereal straw and even poor quality straw might work effectively when float systems are used to support the cover. In the same studies polystyrene sheets, 1 in (25 mm) thick, and plastic engine oil bottles were used as straw floatation devices and the polystyrene floats were reported to have kept the straw cover supported and dry for nearly the entire season, and resulted in excellent odour control. Figure 14 shows unsupported and supported straw covers applied over hog manure lagoons as demonstrated by PAMI (1993).

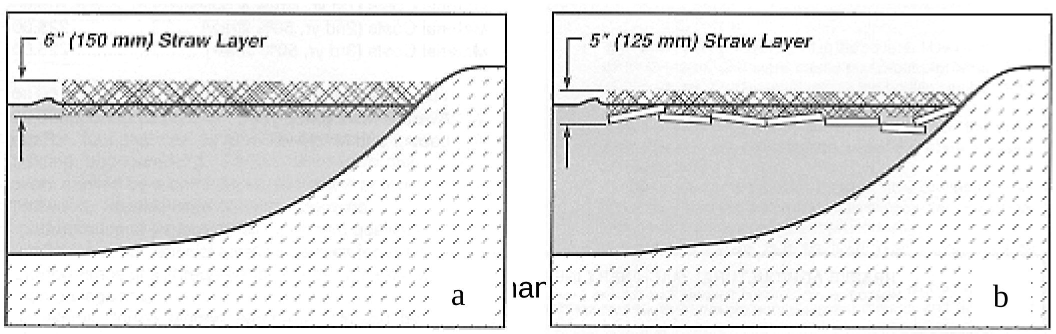


Figure nar

Removal of the manure from long-term storages is reported to be the operation that usually presents most of the problems, however, if the manure has proper moisture content and if correct equipment is used to complete agitation of manure within the storage, it can be done quickly and with little difficulty (Fleming, 1985). Gravity flow systems are very common and effective way of removing liquid manure from above ground storages as well as transferring it from the animal confinement to the storage. For example, in North Carolina, Vanotti and Hunt (1999) indicated that flushing systems are preferably utilized in many modern swine production systems for their simplicity and economy. In Ontario, Fleming (1985) reported a gravity system (Figure 15) to be a very simple and maintenance free approach to liquid manure removal from storage and Hilborn (1997) suggested gravity flow pipe system to be the simplest and most common approach of transferring manure from barns to storages.

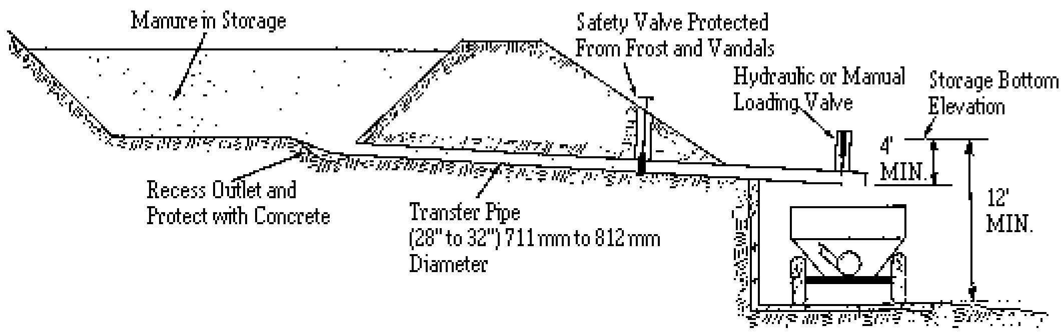


Figure 15. Gravity load out of manure from storage. (After Fleming, 1985).

Other methods of removal of manure from liquid storages include: use of vertical pumps, side mounted pumps, and earthen manure storage pumps (Fleming, 1985). Vertical pumps are used to remove manure from storages under barns or in outside storages where the storage is below the level of the tractor that is used to power the pump. Side mounted pumps are used to remove manure from storages that have vertical walls and above ground or partly above ground. Earthen manure storage pumps are used to remove manure from storages with earth wall and/or sloped concrete ramps.

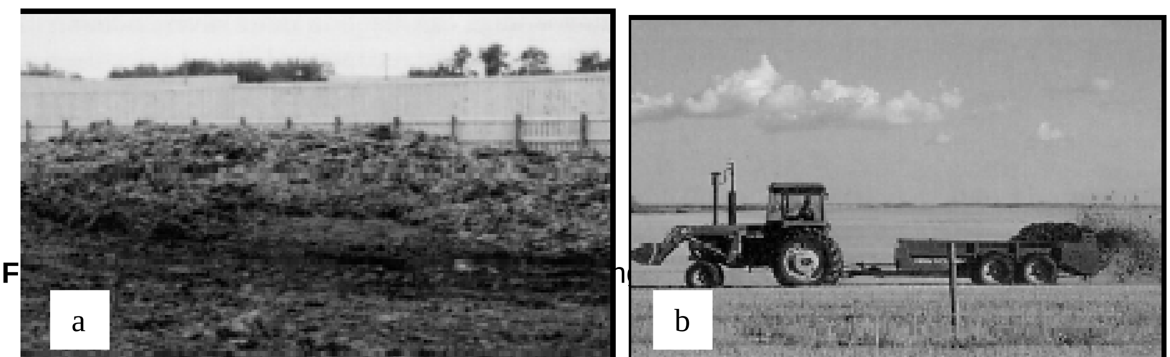
Most liquid manure storages on the prairies are earthen structures because of the advantages they offer such as cost per animal unit, ability to store large amounts of manure and/or runoff, and potential to handle manure with conventional pumping and irrigating equipment. However, some disadvantages, such as lack of appropriate soil materials for construction, the need for solid separation or sludge removal equipment if bedding or other nonbiodegradable materials are present, aesthetic appearance and/or public perception, may be associated with them (Manure Management Curriculum, 2002).

3.1.2. Solid

Solid manure can be defined as manure that contains a mixture of feces, urine, and bedding material with little or no water added to it and is handled mostly by mechanical conveyers, tractor-mounted fork or bucket loaders, and open box-type manure spreaders (Turnbull, 1984). According to Barrington and Cap (1991), handling of solid manure would require mechanization, a system which is not only costly but also subject to wear and breakage. They indicated other factors that contribute towards the costliness of solid manure handling systems. For example, the storage facilities require a hard concrete floor for the purpose of removal by means of a front end loader on farm tractor and the concrete floor makes the storage facility extremely expensive when compared to earthen reservoir. Further more, solid manure storage facilities must be designed to store liquids originating mostly from the contaminated rainfall washing off the manure pile and this necessitates two types (a liquid system for the contaminated rainfall and a solid system for the solid manure) of handling equipment when removing the manure.

Solid manures, on the other hand, represent a lesser volume of lower density (650 $kg{\cdot}m^3$) to handle at disposal than liquid manures (reaching 1000 $kg{\cdot}m^3$) and they are less likely to cause soil compaction problems during transportation as well as field application (Barrington and Cap, 1991; Midwest Plan Service, 1983). Barrington and Cap (1991) suggested that the use of manure pile covers made of an impermeable geotextile could be as economical and practical as liquid manure systems provided that enough bedding material can be used to curtail all seepage from the manure during storage. According to their design, the cover lies on the floor of the platform as well as the pile and this eliminates all structural components and the manure would be introduced under the cover by means of a pneumatic system.

Solid manure handling systems are usually used with cattle operations in feedlots and barns and these systems normally allow manure to accumulate over the entire area of the animal confinement until the time of cleaning (SAF, 1997). Bedding material, usually straw, is used to keep the animals warm and dry until the time of cleaning the barns or mounding the manure, which is a common way of storing solid manure until the time of use/disposal. Figure 16 shows examples of (a) piled solid manure that allows pens to dry and (b) how manure stored as such can be spread on the field. When solid manure is to be piled on coarse granular material such as gravel or sand, it may be required to construct impervious slab from materials such as compacted clay, concrete or asphalt to contain seepage. It may also be necessary to construct a perimeter curb to contain liquid runoff and sloping the slab to a corner opposite to the entrance ramp would enable collection of the liquid runoff for removal by vacuum tanker or transfer to a separate storage (MAF, 2000).



Handling manure in solid form has advantages such as less volume (high solids content), less odor (because of reduced bacterial action producing odorous compounds at lower moisture contents), less runoff potential, and relatively high nutrient retention. On the other hand, solid manure handling systems pose some disadvantages such as more labor requirement for manure collection and handling (i.e. mechanical handling as compared to hydraulic handling), run off management from storage areas, and labor/equipment requirements (due to the number of loads required to haul and spread the manure) for land application (Manure Management Curriculum, 2002).

3.1.3. Separation

Solid-liquid separation is one of the several manure treatment methods that can be used to improve manure handling properties and produce manure solids for animal feeding, energy generation, and compost production (Zhang and Westerman, 1997). They suggested that "effective solid-liquid separation that is capable of removing a substantial amount of organic solids from fresh liquid or slurry manure will potentially offer the benefits of production of nutrient-rich organic solids, odor reduction, in subsequent liquid storage pits (or tanks) and anaerobic lagoons, and improvement in the economics of subsequent liquid manure treatment processes due to reduced organic loading rates on an annual basis." They also indicated that the separated solids may be used on farms near animal operations or may be economically exported to other areas as fertilizer and soil conditioning products.

Typically, liquid manure has a total solids concentration of around 5%, however, in some cases it may be handled with over 10% solids and Fleming (1986) attributes this range of moisture content in liquid manure due to such factors as method of storage, type of livestock, feeding program, and type and amount of bedding used (if any). High solids content can make manure difficult to pump. One way of reducing the ratio of solids to liquids is adding more diluting liquid, which, however, only increases the volume of the material to be handled, but does not reduce the size of the particles. For example, Vanotti and Hunt (1999) reported that such high dilution results in wastewaters that have very low solids concentrations, which are often in the range of 0.2 to 1.5% total solids content. According to Fleming (1986), if the size of particles can also be reduced, this helps avoid plugging of transfer pipes from build up on rough surfaces inside a piping system due to larger solid particles. Reduction in size of particles in manure can be achieved by a solid-liquid separator. He listed several advantages and disadvantages to reducing the amount of solids in manure and reducing the particle size of the solids, as well. The advantages include: 1) less possibility of plugging transfer pipes, 2) less power needed to pump the same volume of material, 3) much easier to irrigate, 4) reduced agitation time, 5) other uses for the solids, such as recycling for bedding material, 6) other uses for the liquid, such as for in-barn flushing systems, and 7) odor control. The disadvantages include: 1) relatively high cost when considered on its own, 2) regular maintenance is required to avoid breakdowns on mechanical systems, 3) need extra space to accommodate the system, 4) two separate manure handling systems are needed, one for liquid and one for solids, 5) some systems have high energy costs to operate, and 6) there is an increased management requirement.

Hill and Tollner (1980) reported that most of the organic nutrients in swine wastewater effluents are contained in fine suspended particles that are not separated by available mechanical separators. Similarly, Sievers et al., (1994) indicated that separation of suspended solids from animal wastewater using screens and presses is very inefficient, and requires chemical coagulation to bind together the small particles of solids in manure into larger clumps. For example, in a study that was conducted in North Carolina, Vanotti and Hunt (1999) reported that only 5-13% of the total suspended solids (TSS) was removed with 1-mm opening screen. However, when they used polyacrylamides (PAM, high molecular weight, long chain, water-soluble polymers), higher (>90%) TSS removal efficiency was obtained. As a result, they suggested that use of PAM polymers has a potential for efficient separation of manure solids and nutrients and such technology can provide an attractive alternative to existing liquid manure management methods, promoting the transportation of nutrients from nutrient-rich to nutrient deficient areas.

The design and selection of proper solid-liquid separation equipment requires understanding of the particle size distribution of manure solids and distribution of various chemical constituents among the particles of different sizes in different types of animal manure (Zhang and Westerman, 1997). After reviewing previous research findings, they concluded that fine particles in animal manure decompose faster than the coarse particles and most of the reduced carbon compounds, protein, and nutrient elements (especially nitrogen and phosphorous) are contained in the fine particles. Having considered such compounds to be the precursors for odor generation, they suggested that solid-liquid separation processes should be designed to remove fine particles (smaller than 0.250 mm) effectively, as well as coarse particles, to cause a significant impact on reducing odor generation potential.

Solid-liquid separation techniques involve physical separation with sedimentation basins (by using the effects of gravity) and mechanical devices and chemical treatment to facilitate the physical separation process (Fleming, 1986; Zhang and Westerman, 1997). While the separation processes include sedimentation, screening, centrifugation, and filtration (pressing), sedimentation and screening are the most commonly used techniques for solid-liquid separation of liquid animal manure. Sedimentation (gravity separation) involves a settling pond or basin whereby the flow of the liquid is slowed down to a point where solid particles settle and is considered a fairly simple and most effective means of separating the solids from liquid manure (flushed manure or feedlot runoff). Figure 17 shows an example of liquid-solid separation using sedimentation in 2-stage storage.

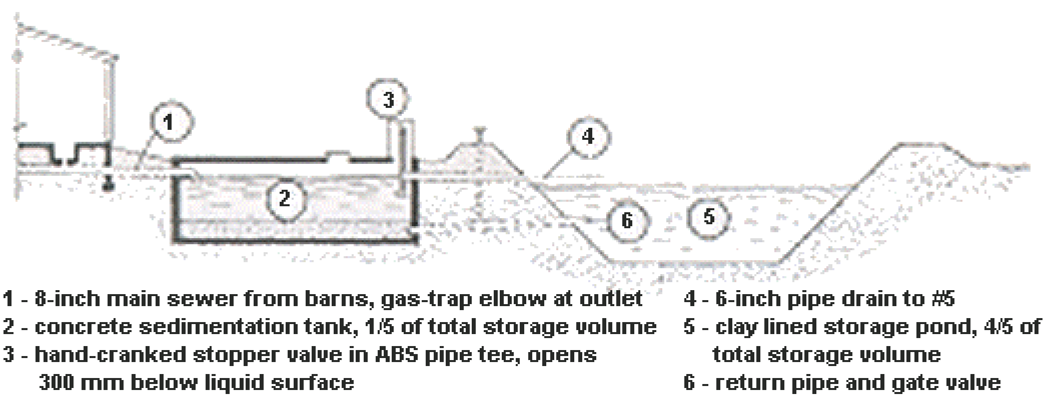


Figure 17. Solid-liquid separation using sedimentation in 2-stage swine manure storage (Fleming, 1986).

Solid-liquid separation can be performed mechanically in two ways: a) size separation by screening and b) size separation by centrifugation. The use of mechanical separators has the following advantages (Fleming, 1986):

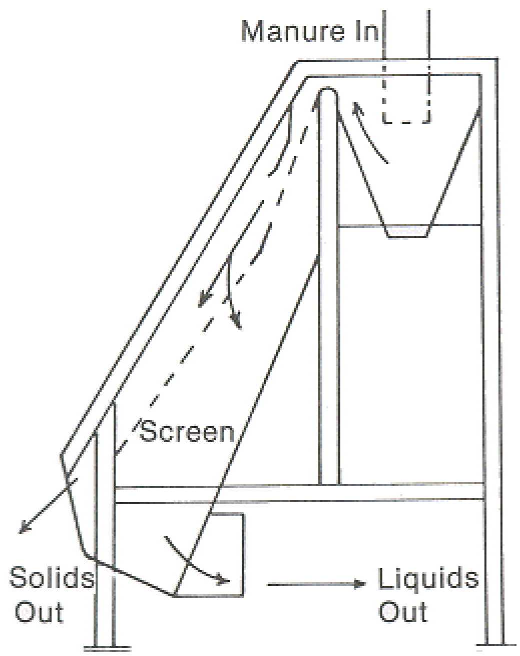
1. The separated solids portion has lower moisture content and can usually be handled as solid manure.

2. Most systems are better equipped to remove large floating or suspended particles.

3. Less space is needed.

It is expected that the amount of solids removed by such mechanisms varies from about 40 to 80%. Both Fleming (1986) and Zhang and Westerman (1997) presented detailed discussion of the solid-liquid separation techniques and equipment. Following is a brief description of the different types of techniques and equipment taken from their work.

The mechanical separators used for solid- liquid separation include: stationary screen, vibrating screen, rotating screen, and centrifuge separators. The stationary rundown (inclined) screen (Figure 18) is considered the least expensive mechanical separator which uses slow relative motion between the manure and the screen whereby the liquid manure flows (pumped) onto an inclined screen by a force of gravity. The separation



process takes place by the liquid passing through the holes of the screen whereas the solids movie down the inclined face of the screen to a collection area. Absence of moving parts and the resulting low maintenance and no power requirement is the most attractive feature of the stationary screen separator.

Figure 18. Stationary rundown separator (Fleming, 1986)

As opposed to the stationary screen, vibrating (Figure 19) and rotating (Figure 20) screens employ continuous motion of the screens to aid in the separation. As the names imply, the vibrating screen separator uses a rapid vibrating motion whereas the rotating screen uses a rotating motion of the screen to facilitate the movement of the separated solids across the screens and reduce clogging of the screens. There is a power requirement involved with these separators.

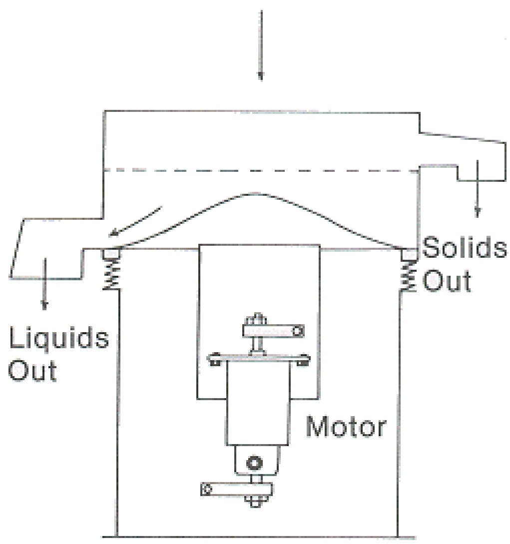


Figure 19. Vibrating screen separator (Fleming, 1986).

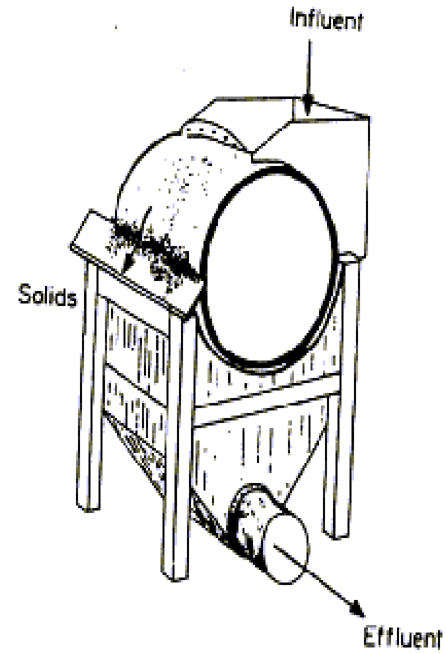


Figure 20. Rotating screen separator (Hegg et al., 1981).

Centrifuges as well as hydrocyclones employ centrifugal forces (forces that help to speed up the gravitational separation) resulting from spinning the manure to cause separation. Figure 21 shows an example of a centrifuge that uses a closed cylinder of continuous motion in which an auger turning at a slightly higher speed than the cylinder moves the solids to the conic part where they are discharged. Contrary to centrifuges, hydrocyclones do not have moving parts and the liquid itself performs the required vortex motion. Figure 22 depicts a hydrocyclone that consists of a cone tangentially to the circle near the top. These systems can be very effective in separating the solids form the liquids, however, they require high initial cost and energy as compared to other systems. Several other mechanical separators, such as vibrating screen with screw press, cyclone, roller press, brushed screen, rotary screw press, and porous belt press, are available on the market and individual assessment of the merits of each of these separators is imperative when making selection and use of any particular separator. In their conclusion, Zhang and Westerman (1997) suggested the need for chemical treatment of manure prior to physical solid-liquid separation due to the relatively low efficiencies of the available equipment. According to them, the purpose of the solid-liquid separation and the intended use of the separated solids are the main factors to be considered when selecting a separation unit. The screens alone may be sufficient for the purpose of removing coarse particles for easier manure handling. For the purpose of odor control and nutrient removal, separators that are capable of removing fine particles, perhaps coupled with chemical treatment, are needed.

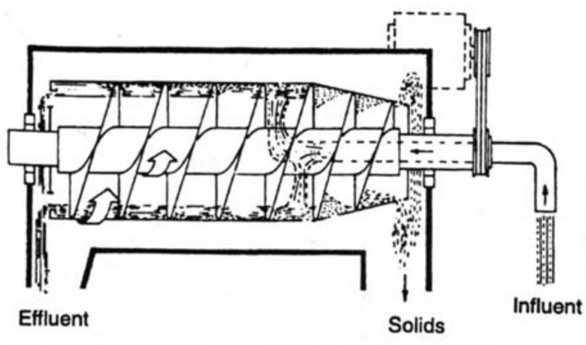


Figure 21. Horizontal decanter centrifuge (Glerum et al., 1971).

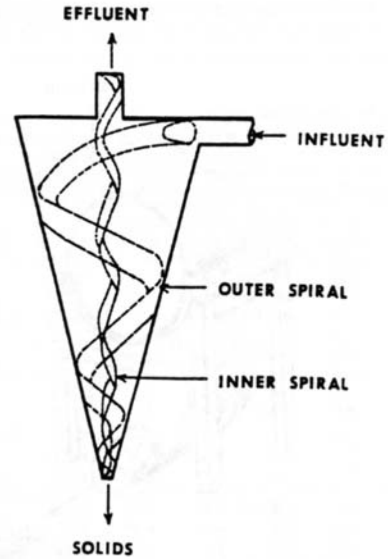


Figure 22. Hydrocyclone (Shutt et al., 1975)

3.1.4. Composting

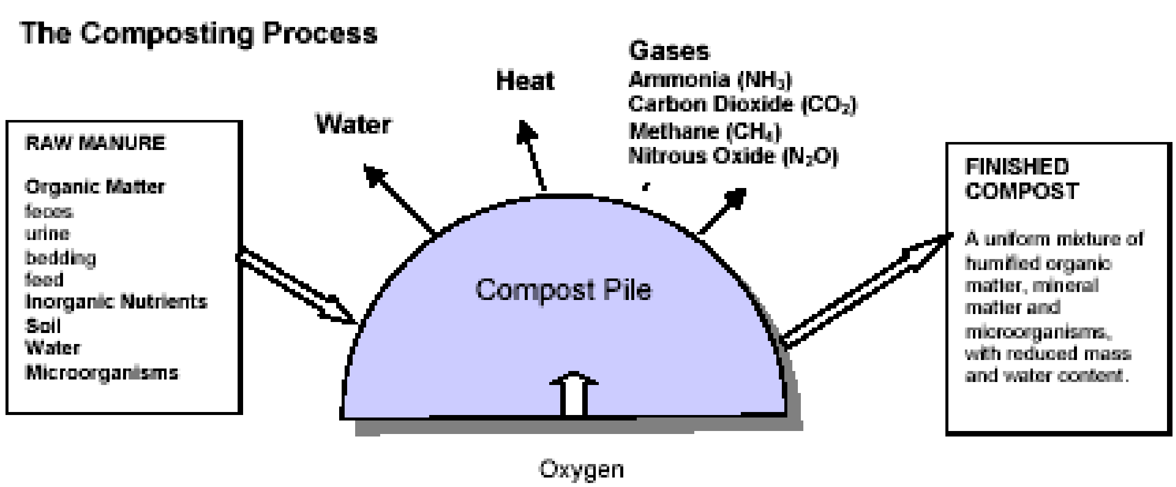
Composting is a biological manure treatment in which organic materials such as fresh manure, sludge, leaves, paper, and food wastes are converted to a more stable soil-like material called compost by the action of micro-organisms (Rynk et al., 1992; Larney, 1999). Composting involves aerobic decomposition of the organic material to produce the humus-like material known as compost (SAF, 2002), which is relatively resistant to further decomposition (Foth, 1990). The process of composting animal manure results in conversion of the manure into an easily manageable, nutrient rich soil conditioner and soil amendment (Chaw and Abiola, 1999). Implementation of composting in manure management tends to shift the focus from disposal to resource management. Eghball (2000) indicated that composting is a useful method of manure treatment whereby a stabilized product is produced that can be stored or spread with little odor or fly breeding potential. Therefore, composted manure can be applied to the soil as an odourless and relatively dry source of nutrients compared to non-composted manures (Eghball et al., 1997). Well finished compost has been reported to have a pleasant, earthly odor that generally varies from dark brown to black in colour (SAF, 2002).

Haug (1980) stated three main goals of composting: 1) to serve as a source of organic matter for maintaining or building supplies of soil humus, which are necessary for proper soil structure, moisture holding capacity and fertility, 2) to improve the growth and vigor of crops in commercial agriculture or home related uses, and 3) to reclaim and replace certain valuable nutrients in the soil including nitrogen, phosphorus, and a wide variety of essential trace elements. Other more recent studies have shown that composted manure can be effectively used for crop production. For example, in a study conducted in south-central Nebraska, application of composted beef feedlot manure resulted in corn silage yield that was similar to the yield from commercial fertilizer application (Ferguson and Nienaber, 1995). Schlegel (1992) reported that application of composted manure plus fertilizer resulted in greater sorghum grain yield than either source applied alone.

Composting manure occurs through biological activity and chemical reactions which provide the heat required for composting the manure (Eghball and Power, 1994). Normally, composting begins as soon as appropriate materials are piled together whereby initial mixing of the raw materials introduces enough air to start the process (Rynk et al., 1992), the same way as decays of leaves and other organic debris take place in nature. When it occurs naturally, the process of composting takes a very long time, however, with the development of new technologies it has been made easier, faster and it is possible to do on a much larger scale. Artificially, this can be achieved either by passive air exchange (natural convection and diffusion) or by active (forced) aeration (blowers/fans) that provide aeration continually to recharge the oxygen supply required (Rynk et al., 1992). Thus purposeful composting as such is merely controlling the conditions that favour faster decomposition of the raw materials of compost. The composting process, as illustrated in Figure 23, is most rapid when conditions that encourage the growth of the micro-organisms are established and maintained (Rynk et al., 1992) and does not stop until the material is completely consumed. However, because the compost becomes relatively stable and ready for use before complete consumption of the material, it should be judged to be "done" based on the characteristics related to its use and handling such as C:N ratio, oxygen demand, temperature and odor.

Figure 23. The composting process (SAF, 2002).

In a study that compared active vs. passive composting of feedlot manure in Alberta, Larney (1999) reported that active composting performed better than passive composting. When cutting the passive windrows, he found that a large portion of the centre of the windrow had the appearance of fresh manure indicating that the manure was only partially composted, perhaps due to limited supply of oxygen. Besides forced aeration, the use of mechanical equipment to agitate or turn the composting material on a regular basis in the active composting secures the necessary amount of oxygen for complete composting. However, active composting involves large overhead cost and may be justified only for large operations.



The physical changes that occur during composting include reduction in volume, moisture content, concentration of nutrients and a decrease in the carbon/nitrogen ratio (Larney, 1999). This allows for storing and transporting the composted manure with greater ease and lesser negative impact on the environment as compared to fresh manure. Moreover, the lower C/N ratio reduces immobilization of N in the soil following land application of the composted manure. A summary of some of the benefits and drawbacks of composting is presented in Table 3.

Table 2. Benefits and drawbacks of manure composting

Benefits of composting	Drawbacks of composting
• Destroys weed seeds and pathogens • Decreases bulk of raw inputs (estimated shrink factor 50 – 75 per cent) • Finished compost has a consistent soil like quality that makes it easier to handle and apply • Stabilizes nutrients as organic compounds • Stable organic nutrients release more lowly, providing plants with a more sustained source of nutrient for growth • Results in an odourless, potentially marketable product	• Emissions of ammonia, carbon dioxide, methane, nitrous oxide and volatile compounds, especially in the early stages • Runoff from the compost piles must be controlled to prevent movement of nutrients to ground or surface waters • Aeration and moisture must be managed throughout the composting process • Time, equipment and land required • Some additional fertilizer may be needed to meet crop requirements

Source: (SAF, 2002).

There are several methods of composting. Rynk et al. (1992) generalized them into four groups: passive composting, windrows, aerated piles, and in-vessel composting. Passive composting is done by simply stacking the raw materials of compost in piles to decompose over long time of period with little agitation and management. In contrast, windrow composting involves placing the mixture of the raw materials in long narrow piles (windrows) and agitating or turning them regularly. In passively aerated windrow methods the need for turning is eliminated by supplying air to the composting materials via perforated pipes embedded in each windrow. In aerated static pile methods blowers are used to supply air to the composting material, which is a step beyond the piped aeration system. In-vessel composting methods consist of a group of methods that confine the composting materials within a building, container, or vessel and they rely on a variety of forced aeration and mechanical turning techniques to speed up the composting process. A summary of the advantages and disadvantages of three composting methods are given in Table 4.

Table 3. Advantages and disadvantages of three composting methods**.**

Method	Advantages	Disadvantages
Windrow	Able to handle large volumes. Low capital investment. Rapid drying with high temperatures. High degrees of pathogen and weed seed kill. Drier product, resulting in easier handling of material. Good product stabilization.	Not space-efficient. Equipment (varies greatly in price) and labor is required for turning and monitoring. Vulnerable to climate changes (rain, snow, and drought). Odors released with turning. Bulking agents might be required.
Aerated Windrow or Static Pile	Able to handle large volumes. Low capital costs. Relatively space-efficient. High degree of pathogen and weed seed kill. Good odor control. Good product stabilization	Not space –efficient. Operation and maintenance costs for blowers and fans Loading and unloading equipment required. Placement of aeration system may present operational difficulties Vulnerable to climate changes (rain, snow, drought, and cold).
In-vessel	Space-efficient. Good control of composting process with confinement and automation. Predictable, uniform product. High degree of pathogen and weed seed kill. Potentially good odor control. Protection from climate. Potentially not visible. Can be designed as a continuous process rather than a batch process	High capital cost for sophisticated units with automated tuners, forced air and monitoring systems. Careful management required. Less flexibility in operation than with other methods.

Source: (SAF, 2002).

3.2. Composition

Manure is a natural by-product of animals that contains complex organic compounds originating from the undigested and wasted feed as well as simple organic and inorganic compounds produced in the gastric intestinal track of animals (Zhang and Westerman, 1997). Manure varies highly in its chemical and physical properties. There are several factors responsible for the high variability in properties of animal manure such as the physiology of the animal, the feed ration, and the environment (Hermanson and Kalita, 1994). The type of animal (ruminant versus monogastric) and age are important physiological factors. Sex, breed, and activity of the animal also affect the manure properties by way of partially determining the feed conversion efficiency under a given environment. Manure quality also varies with handling and storage systems (Lindley et al., 1988) and temperature plays an important role in such systems. For example, up to 66% losses of N from hog manure during collection and 15% losses of N from dairy manure during storage have been reported (Schulte et al., 1985; Welty et al., 1985).

The feed ration is an important factor in determining the characteristics of manure. Variability in feed digestibility, protein content, fiber content and other feed elements affect the composition of manure (Hermanson and Kalita, 1994). Highly digestible feedstuffs in rations can effectively reduce excretion of nitrogen and other nutrients whereas low quality protein sources (such as hydrolyzed hog hair meal) and high levels of crude fiber can increase nitrogen excretion (Kornegay and Verstegen, 2001; Kornegay, 1978a; Kornegay, 1978b). For example, in Australia, the starch content of the manure produced by cattle fed on dry-rolled sorghum rations was five times that of manure produced by cattle fed on steam-flaked sorghum, dry-rolled barley and steam-flaked barley rations (Tucker and Watts, 1993). The average ash content of the manure from cattle fed on barley and steam-flaked sorghum rations was about 32% greater than the ash content in the manure from the cattle fed on the dry-rolled sorghum ration. The average volatile solids content of the manure from the cattle fed on the dry-rolled sorghum rations was about 40% higher than the manure from the cattle fed on the barley and steam-flaked sorghum. The average pH of the manure produced by the cattle fed on the barley rations was about 21% higher than that of the manure produced by the cattle fed on sorghum rations. Feed waste is another potential factor that may greatly contribute to the variation among manure properties. For example, 5% feed waste can bring about an increase of up to 40% total solids in manure (Barth, 1985).

Kornegay and Verstegen (2001) reported that much of the phosphorus contained in corn-soybean meal diet is excreted because two thirds of the phosphorus in the meal is bound as phytic acid and is poorly available to pigs (Cromwell and Coffey, 1991). Lindley et al. (1988) reported that large differences in phosphorus concentrations occurred between samples of animal manure (hog and cattle) that were the results of different rations of feed. Feed rations containing barley and soybean oil meal resulted in the highest phosphorus concentration (4.3 $kg \cdot m^{-3}$ P_2O_5) in the manure as compared to an overall mean of 1.6 $kg \cdot m^{-3}$ P_2O_5; and feed rations containing barley and sweet clover gave the lowest phosphorus concentration (0.6 $kg \cdot m^{-3}$ P_2O_5). They did not observe any differences in total solids, nitrogen concentrations and potassium concentrations. There are some current researches going on such as low phytate barley and use of phytase enzyme in pig diets in order to reduce the amount of phosphorus concentrations in excreted manure.

Characteristics of manure from various animals have been reported in different publications (ASAE Standards, 1999; Midwest Plan Service, 1985; SAF, 1999; Schoenau et al., 2000). Generally liquid hog manure and solid cattle manure differ in their dry matter, nitrogen and carbon content as well as in their influences on microbial activity and physical and chemical changes in the soil (Ndayegamiye and Côté, 1989).

The characteristics and composition of cattle (dairy and beef) and hog manure are shown in Table 5. Such values could be used for estimating nutrients in a given manure. However, owing to the variation among manure, it is suggested that site specific data are preferred to “average value” data. According to the values in Table 5, generally per unit weight of animal, hogs void greater amounts of fecal and urine nutrients (for most of the nutrient elements) as compared to dairy and beef cattle manure. This could be due to the differences in digestibility of the feedstuffs fed to the animals because it influences the excretion of nutrients. For instance, reduced excretion of nitrogen and other nutrients is expected from the use of highly digestible feedstuffs (Kornegay and Verstegen, 2001).

3.2.1. Physical

In terms of physical composition, liquid manure such as hog manure is a mixture of excreta (urine and fecal matter) which is composed of undigested and wasted feed components, endogenous components, and products from the activity of indigenous microorganisms along with the biomass of those microorganisms (Kornegay and Verstegen, 2001). In addition to these components, water is added to the manure following excretion in systems that use some type of water conveyance such as flushing for collection of the manure. Solid manure such as cattle manure is composed of both fecal matter and bedding material, such as straw, and hence has a higher dry matter content than liquid manure. Manure can be classified into three types, as shown in Table 6, based on its physical state (moisture content).

Table 4. Characteristics of different types of fresh animal manure per 1000-kg live animal mass per day (wet basis). Typical live animal masses are: dairy, 640 kg; beef, 360 kg; and hog, 61 kg.

Parameter	Units	Animal type		
		Dairy	Beef	Hog
Density	$Mg{\cdot}m^{-3}$	0.99	1.00	0.99
Total manure[†]	kg	86	58	84
Urine	kg	26	18	39
Total solids	kg	12	8.5	11
Volatile solids	kg	10	7.2	8.5
pH		7.0	7.0	7.5
Total N	g	450	340	520
NH_4-N	g	79	86	290
Total P	g	94	92	180
Orthophosphorus	g	61	30	120

Potassium	g	290	210	290
Calcium	g	160	140	330
Magnesium	g	71	49	70
Sulfur	g	51	45	76
Sodium	g	52	30	67
Chloride	g	130	NA	260
Iron	g	12	7.8	0.33
Manganese	g	1.9	1.2	1.9
Boron	mg	710	880	3100
Molybdenum	mg	74	42	28
Zinc	mg	1800	1100	5000
Copper	mg	450	310	1200
Cadmium	mg	003	NA	27
Nickel	mg	280	NA	NA
Lead	mg	NA	NA	84

SOURCE: ASAE Standards (1999).
† Feces and urine as voided.
NA denotes data not available.

Table 5. Classification of manure by moisture content.

Type of manure	Moisture content	Ease of pumping
Liquid manure	>90%	Easy to pump
Semi-solid manure	80-90%	May be difficult to pump
Solid manure	<80%	Cannot be pumped

Source: SAF (1999).

3.2.2. Chemical

Suspended solids (SS) and dissolved solids (DS), the sum of which makes the total solids (TS), constitute the chemical composition of manure (Zhang and Westerman, 1997). Each solids fraction is in turn composed of a volatile solids (VS) fraction, that is a measure of the amount of organic matter present in that solids fraction, and a fixed solids (FS) fraction, a measure of the amount of inorganic matter present (ash content). Accordingly, there are corresponding volatile solids fractions and fixed solids fractions of the TS, SS, and DS.

Zhang and Westerman (1997) indicated that the amount of organic matter that is present in manure could also be determined by two other means: chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Chemical oxygen demand is the quantity of oxygen required to chemically oxidize the organic matter in the manure whereas biochemical oxygen demand is the quantity of oxygen required to biochemically oxidize the organic matter in the manure, which is the measure of the amount of biodegradable organic matter. It is typical to do five-day biochemical oxygen demand measurement (BOD_5); however, COD is usually preferred to BOD_5 due to a lesser time requirement for the laboratory analysis procedure for COD.

3.2.3. Salts

Salts are among the chemical constituents of manure. Some of the soluble salts include: Na, Ca, Mg, SO_4-S, Cl, NH_4-N, and NO_3-N (Chang et al., 1991). As is the case with other constituents of manure, the levels of these salts in manure varies depending on factors such as the type of feed the animals are fed. Manure from animals fed on feedstuff with higher salt concentration would have higher levels of salts and the vice versa. For example, Sutton et al. (19984) reported that dietary salt (NaCl) levels of hog ration directly affect Na concentrations in manure. Increases in salt levels of soils that received manure have been reported in several studies (Chang et al., 1991; Assefa, 2002).

3.2.4. pH

Manure also exhibits variation in its pH value. For example, Malley et al. (1999) reported the pH value of the hog manure from various types of hog operations in south-eastern Manitoba ranged from 6.8 to 8.1. The pH of the cattle manure Assefa (2002) used in the Peace River Region of Alberta was around 9 whereas Chang et al. (1991) reported an average pH value of 7.2 for the cattle feedlot manure they applied annually for 11 years in southern Alberta. The pH of manures, that were used in a study conducted over a four-year period of time in east-central Saskatchewan, were in the range of 7.7-8.1 for cattle manure and 7.6-8.1 for hog manure (unpublished data). Bate et al (1988) reported that pH values in liquid hog manure would be affected by the loading rate during collection and temperature. Under high loading rates or low temperature, manure tends to be more alkaline due to inhibition of metabolism of the microflora under conditions in which populations of nitrifiers would be less and hence the mineralized nitrogen remains in the form of ammonia.

3.2.5. Nutrients

The nutrient contents and forms of animal manure vary considerably depending on the type of livestock, manure handling systems and the type of ration used to feed the animals. For this reason, although tables of typical manure nutrient contents (such as Table 5) are available, to date only a laboratory analysis of a representative sample of manure from a given source will give the best indication of the nutrient value of the manure. In general, animal manure contains macro and micronutrients required by plants such as nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, copper, manganese, zinc, boron, iron etc. as indicated in Table 5. However, some of the nutrients in manure exist in the organic form and need to decompose or mineralize into inorganic form to be rendered plant available and as such animal manure is a more slowly available source of plant nutrients as compared to commercial fertilizers.

Typical nutrient contents in liquid hog manure and fresh cattle pen manure as studied in Saskatchewan are indicated in Table 7. The studies have revealed that 30% to 90% of the total N contained in the liquid hog manures existed as ammonium whereas the rest of the N existed in organic form of which 20% to 30% would be mineralized to plant available form in the year of application (Schoenau et al., 2000). In cattle manure, in contrast, only 10% to 20% of the nitrogen is present as ammonium while the rest of the N is present in the organic form. The study also indicated that 10% to 50% of the total P in the liquid hog manure was present as readily soluble inorganic phosphate, and of solid manures poultry manure has the highest P content. Potassium in manure is present in a readily plant available form and hence manures are effective sources of potassium for plant growth. Manures also contain considerable amount of sulfur however, manures like liquid hog manure tend to be low in their sulfur content.

Due to the complexity of micronutrients chemistry in manures, there is limited information on the forms and availability of micronutrients in manure, however, it is well known that manures also contain micronutrients. Schoenau et al. (2000) indicated that micronutrient metals may be present in manures as soluble free and complexed cations.

Table 6. Typical nutrient contents in liquid hog manure and fresh cattle pen manure samples in Saskatchewan.

Nutrient	Liquid hog manure (feeder hogs) Pounds per thousand gallons	Fresh cattle penning manure (with straw bedding) % on dry weight basis
Nitrogen (N)	15-50	0.5-1.5
Phosphorus (P)	1-20	0.5-1.5
Potassium (K)	8-20	0.8-1.5
Sulfur (S)	0.1-3	0.08-0.15
Copper (Cu)	0.05-0.5	0.01
Manganese (Mn)	0.05-0.5	0.02
Zinc (Zn)	0.05-1.0	0.02
Boron (B)	0.01	0.005

Source: Schoenau et al. (2000).

3.3. Gaps

Some gaps identified are as follows:

- Manure is traditionally viewed as a low value commodity to be disposed of at lowest possible cost. However, there are opportunities for adding value to manure through various treatment methods to increase the nutrient concentration and ease of handing and application. Technologies associated with composting, nutrient amendment and biochemical treatments should be further explored to make manure an economically exportable commodity to farther locations. Furthermore, the agronomic, environmental and economic performance of such value added manure products should be rigorously investigated.
- Further work is required in animal feed formulation aimed at reducing nutrient excretion and producing desirable proportions of each nutrient contained in manure to meet crop requirements. Undesirable constituents of manure such as high content of sodium in relation to calcium and magnesium could be addressed through feed management or manure treatment.

- There is limited information on appropriate rehabilitation practices for decommissioned manure storage, handling systems. While this is not a current concern, such issues may arise in the future and there is a need to have best management practices established for such aspects as excavation and fill of old storage units. This may also impact on the design of new storage units that should have decommissioning consideration as part of the overall design and construction criteria.