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Media and Media Mix Evaluation for Dairy Barn Compost Bedding Systems

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Seena Changirath, Thomas R. Halbach and Rebecca Dorff

Department of Soil, Water and Climate

1991 Upper Buford Circle

St. Paul, MN 55108

Phone: (612) 625-3135

Fax: (612) 625-2208

E-mail: thalbach@umn.edu

URL: http://www.soils.um.edu/

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EXECUTIVE SUMMARY

According to the 2009 Minnesota Dairy Industry Profile from the Minnesota State Department of Agriculture, there are about 4,700 dairy farms in the state producing about 8.8 billion pounds of milk each year. The state is home to about 470,000 head of dairy cows. Dairy housing systems have a substantial impact on the overall health and longevity of dairy cattle. Lameness in cows is a major welfare problem in the dairy industry today, as well as a large source of economic loss to the industry. Compost dairy bedded-pack systems (CDB) might be an economically and environmentally sound alternative for housing as well as an effective animal manure system.

This study evaluated alternate media as well as media mixes that could be used as bedding for compost barns. The goal is to help dairy farmers expand the number of alternative media and media combinations that could be potentially more economically used in dairy compost bedded pack systems. The study includes literature review, laboratory analysis of the media and media mixes, demonstration study at four production farms as well as the development of a computer model that is designed to help farmers decide what media(s) works best for their purpose.

Laboratory analysis was done for eleven different media, six media mixtures and for the existing media from the demo farms. Media that were studied are; green tamarack, Lonza tamarack, norway pine, southern yellow pine, jack pine, ash, soybean straw, corn cobs, white pine, poplar and anaerobically digested manure solids. Media mixtures were; tamarack and white pine, tamarack and jack pine, tamarack and wheat straw, tamarack and norway pine, corn cobs and soybean straw, green tamarack and soybean straw. Existing media from the demo farms included: window millings, ground pallets, wheat straw and very fine cabinetry dust (VFCD). Lab analysis was also done on the compost samples from the demonstration farms that used the above mentioned media mixtures on their farms. Each farm used and evaluated two different media mixes during the summer of 2010.

Both the laboratory results and the demonstration farms evaluations showed that most of the wood products as well as the mixtures could be used in the compost bedded pack barn as bedding materials. Various parameters such as initial moisture content, water holding capacity, and particle size distribution plays an important role in selecting a media for the bedding. It would be ideal to select a media that is: 1) initially dry, 2) economical, and 3) consistently available. Considering a media mix with different particle sizes would help in improving the water holding capacity of the mixture while, also maintaining acceptable levels of gas exchange in the tilled media. There is a cost for mixing two or more different media, but overall performance of the media mixtures often work better than a single media alone. This added cost has to be balanced against the improvement in media performance on the specific farm.

There may be significant cost savings to the farmer by negotiating three to four years contracts with media suppliers as compared to buying individual truck loads of media.

INTRODUCTION

Today's challenge in manure management results directly from developments in economics and environmental concerns. Nuisances such as odor, dust and pests as well as potential air and water pollution from Confined Animal Feeding Operations (CAFOs) have sensitized society and regulators towards better approaches for managing manure (Bickert 2003; Randall et al., 2006). Manure management is no longer just of concern to the agricultural community, but is a social issue as well. For housing facilities such as free stall barns, it has been difficult to reconcile cow comfort and udder health with manure handling and storage.

Dairy production and processing industry remains a powerful force in Minnesota. According to the 2009 Minnesota Dairy Industry Profile from the Minnesota Department of Agriculture, there are about 4,700 dairy farms in the state producing about 8.8 billion pounds of milk each year. The state is home to about 470,000 head of dairy cows, about 5 percent of the nation's herd. The state has grown its dairy cow numbers for the past five years while other, larger dairy states have decreased cow numbers. The state's dairy industry includes both dairy production and processing with a combined total annual output of $4.6 billion and the creation of almost 40,000 jobs in the state. (Schlosser, 2010)

Dairy housing systems have a substantial impact on the overall health and longevity of dairy cattle. Lameness in cows is a major welfare problem in the dairy industry today, as well as a large source of economic loss to the industry. To make the state's dairy producers more competitive, especially in the labor intensive management activities such as feeding, milking, and manure handling, economical modernization is needed. Developing dairy housing facilities that address these points will help increase herd size without increasing labor costs, thus resulting in a higher income. However, before changes are undertaken, the society and the farmers in particular, need to get to the point where manure is regarded foremost as a resource rather than waste material and potential pollutant (Bickert, 2003).

Compost dairy bedded-pack systems (CDB) might be an economically and environmentally sound alternative for housing as well as an effective animal manure system. By its typical design it reduces or eliminates outside feedlots and the problems with feedlot runoff. The roof diverts storm water and snow melt from coming into contact with the manure. The compost media and microbial degradation help to chemically stabilize the manure until it can be applied to the fields with lower loss of plant nutrients as compared to most alternative manure management system. Furthermore, CDB have the potential to generate additional income. Once the bedding is removed from the barn, it can be more fully composted and sold or used by the farmer as a soil conditioner. Compost used as a soil conditioner has the potential to result in higher crop yields and reduced erosion (Hoitink & Keener, 1993).

Bedding is a very costly component of compost dairy bedded pack system. Compost Dairy Bedded pack systems have significant implications for herd health as well as the environment especially surface water quality. The cost and availability of bedding fluctuates and good consistent bedding can be hard to find and is often expensive. Since 2001, the supply of sawdust and shavings has become more and more limited and expensive, hence alternative bedding options are needed if this practice is to be more widely adopted (Barberg et al., 2007b). One of the reasons for this increase may be renewed interest in "renewable energy resources" including wood products like shavings, shredded bark and sawdust. The bedding material of choice so far for the CDB has been wood shavings or wood sawdust (Barberg et al., 2007b).

This study, sponsored by the Agricultural Utilization Research Institute (AURI) evaluated the alternate media as well as media mixes that could be used as bedding for compost barns. Study results will help dairy farmers expand the number of alternative media and media combinations that could be potentially used in dairy compost bedded pack systems. The study comprised of literature review, laboratory analysis of the media and media mixes, demonstration study at the farms as well as the development of a computer model that is designed to help farmers decide what media(s) works best for their farm.

OBJECTIVES

The main objective of this study was to investigate the use of media by themselves and in blended mixes with the wood products in order to expand the number of alternate media and media combinations available to the dairy farmers who use the compost bedded system for manure management.

The first objective was to review and summarize on what has happened in the world of research since AURI/University of MN's previous study (2005) on compost bedded pack system. The literature review focuses on the alternative bedding media especially media that might have a lower cost and could be possibly used in a compost bedded pack barn. It also focuses on the physical and chemical characteristics of the plant materials that could be potentially used in compost dairy barns. The second objective is the laboratory analysis of the old and new media as well as the media mixes. Laboratory analysis included determination of the physical and chemical characteristics of the media and the media mix. The lab samples that were considered for this study are: green tamarack, Lonza tamarack, norway pine, southern yellow pine (SYP), jack pine, ash, soybean straw, corn cobs, white pine, poplar and anaerobically digested manure solids (ADMS). Media mixes that were considered for this study are – tamarack and white pine, tamarack and jack pine, tamarack and wheat straw, tamarack and norway pine, corn cobs and soybean straw, tamarack and soybean straw. Existing media that are used by the farms were also studied. The reason tamarack is considered for this study is because it was identified by the Minnesota DNR in 2005 as an underutilized tree species that grows well in Minnesota. It is a durable wood that can go through many wet dry cycles with minimal reduction in cell wall strength, which is an important parameter of the media that could be potentially used in a compost bedded pack system. Tamarack shavings have been priced 5% to 11% lower than other conifer species of wood shavings (Woodline Sawmills, 2010). Third objective was the on-farm demonstration study which involved four compost dairy barns in Minnesota. Different media mixtures were sent to all the four farms, tamarack shavings being the control in all the cases. Physical and chemical characteristics of the compost samples that were collected at various locations and depths from the demonstration farms were also analyzed. Samples were taken in July and August 2010.

Finally an optimization tool was developed to help the farmers evaluate different media and media mixes that could be in a compost dairy barn. This evaluation was based on the physical characteristics such as moisture content, water holding capacity, bulk density, and C: N ratio.

LITERATURE REVIEW

In the Midwest of the U.S., dairy housing systems have shifted from pasture-based to indoor housing with restricted outdoor access (Barberg et al., 2007a). The two main dairy housing systems are free-stall and tie stall barns. In free-stall barns, the cows can move freely throughout the barn and have access to stalls to lie down. Outdoor pens for exercising might be available depending on the season. The bedding of choice is often sand, which is said to offer good cow comfort and mastitis control (Barberg et al., 2007a; Barberg et al., 2007b). Wood products such as shavings and sawdust can also be used. In tie stall barns, cows are tied by the neck in individual stalls. Outdoor exercise may be scheduled by the farmers depending on the weather. Bedding material used includes different types of straw and wood products (Barberg et al., 2007a; Janni et al., 2005). Norring et al. (2008) compared straw bedded concrete stalls to sand stalls and concluded that the total lying for cows was longer on straw bedding (749 ±16 min) than sand bedding (678±19 min).

Dairy housing systems have a considerable influence on the overall health of the feet and legs as well as on the longevity of dairy cattle. Dairy cow lameness is a major welfare problem in the industry and leads to considerable economical loss (Barberg et al., 2007a; Gay, 2006). Concrete flooring, uncomfortable free stalls, or the combination increased the incidence of lameness and hock lesions (Weary and Taszkun, 2000; Somers et al.; Cook et al., 2004).

Another area of weakness in the current dairy system is manure handling which is expensive and must meet many requirements. The ultimate goal of a well designed manure handling system should be to improve management, provide positive environmental protection, and allow maximum utilization of manure nutrient use in crop production. There are several different manure management strategies – solid systems, slurry systems and liquid (lagoon) systems are the common choices (Van Horn et al., 1999). Manure nutrients are vital to plant growth and are also beneficial to the soil and soil organisms. However, if not applied correctly to the land, the nutrients, especially N and P, can severely pollute surface and ground water (Aillery et al., 2005; NDESC, 2005;

Bickert, 2003). Dairy farmers throughout the country face the challenge to find manure management strategies and technologies that comply with environmental regulations and are economically feasible (NDESC, 2005). Compost dairy bedded-pack systems might be such an alternative that will provide the farmers with the option to modernize their dairy herd facilities while minimizing capital cost (Gay, 2006; Janni, 2004).

Compost Dairy Bedded pack system (CDB) are an interesting alternative tool to the traditional loose housing systems for several dairy producers. CDB offer good cow comfort for lactating, dry and special needs cows. A well managed CDB provides a clean, dry surface for the cow to lay down thus providing excellent cow comfort levels and health (Barberg et al., 2007b; Gay, 2006; Janni et al., 2007; Janni, 2004).The bedded pack management system also provides an effective alternative to the traditional suite of best management practices: manure storage, barnyard runoff management system, and improved feeding area/heavy use area protection (Bedded pack management system: Case study – September 2009).

A complete housing system includes the design of a manure management system. This consist of manure collection and removal from the housing facility, necessary treatment, transport to storage facility, short and long- term storage, transport to the cropland and land application (Graves, 2007; Van Horn, 1999).Compost bedded pack can be an environmentally effective alternative to the existing manure management strategies.

The first compost dairy barn was built in Minnesota in 2001 by a producer with a goal of improving cow comfort, cow health and longevity and ease of completing daily chores (A.E. Barberg et al., 2007). Some of the producers also choose this kind of housing system because of the reduced initial investment costs primarily due to less concrete usage in the floor over free stalls (A.E. Barberg et al., 2007).Today it is estimated that over 30 CDB's exist in the State (Janni et al., 2007).

Compost bedded pack may have a lower initial capital costs when compared to other husbandry systems, however the on-going annual costs of the bedding material have to be considered.

Compost barn layout

Compost bedded pack dairy barns require proper design, location, and exceptional management to provide a well-ventilated, dry place for cows to lie down. Compost barns have a concrete feed alley, a composting bedded pack, a four foot high wall separating the pack and feed alley, and four foot high walls around the other three sides of the bedded pack area. Compost bedded packs typically consists of a large bedded pack area, which is considered as a resting area for the cows separated from a feed alley by a 1.2 m high concrete wall (Barberg et al., 2007). The bedded pack is sized to provide a composting bedded pack area of 7.4- 9.2 m^2 (80 – 100 ft^2) per cow. This allows all cows to lie down at the same time and still have space for a cow to get up to go and eat or drink.

Compost bedded pack management

Management of the compost bedded-pack is critical to the success of compost barns. A compost bedded pack is not a conventional bedded-pack where bedding (usually shavings, straw or corn stalks) is added periodically to cover the soiled surface. A composting bedded pack is a deep bedded-pack that is tilled and aerated to support active composting. The main effect of this surface management is to keep the bedded pack dry and clean for as long as possible. Composting is a natural aerobic (requires oxygen) process where microorganisms consume oxygen and produce carbon dioxide, moisture and heat. Cow manure and urine provide nutrients primarily carbon and nitrogen, moisture that the microorganisms use in composting. Composting effectiveness depends on environmental conditions present within the pack, including oxygen, moisture, and temperature, amount of organic matter and the size and activity of microbial populations. If any of these elements are lacking, or if they are not provided in the proper proportion, microbial activity will be hindered, and the compost will not generate adequate heat (Milkproduction.com 2008 edition).

Materials that can be blended with dairy manure in a compost dairy barn must possess certain chemical and physical characteristics to achieve active composting are as follows: (Northeast Dairy Business, April 2008 – Frank Vokey).

- Water holding capacity between 100% and 250% - This means that the material can hold from 1 to 2.5 times its own weight in water.
- If the moisture content in the pack increases, above 61%, it causes anaerobic condition in the pack which leads to odor, low temperatures and emission of nitrogen compounds as well as methane.
- Media porosity allows air to be entrained more easily during mixing. This provides oxygen to the microbes.
- Bulk density is important parameter. Materials with low bulk densities can be more expensive per unit of weight to haul than higher bulk density materials.
- The manure and bedding carbon-to-nitrogen ratio and the pH should be in a range necessary for composting.

The compost bedded pack is actively managed to rapidly compost the manure and urine. Composting generates temperature between 55 ˚C (130 ˚F) and 65 ˚C (150 ˚F) within the compost materials; these temperatures will be helpful to inactivate the pathogens and the viruses. Composting also requires sufficient moisture for active microbial activity but not too much, which hinder aeration. Urine, wet manure, and moisture from microbial activity are the moisture sources in a composting bedded-pack. Rain and snow blowing can also wet the pack and should be avoided to the extent possible.

The bedded pack area is aerated or stirred to a depth of 18 to 24 cm at least two times a day or at each milking to facilitate composting process. Stirring is done typically using a modified cultivator on a skid loader or tractor. (Barberg et al., 2007) Stirring facilitates the mixing of urine and manure on the surface into the bedded pack resulting in a dry surface for the cows when they return from milking. It also helps in incorporating oxygen into the pack allowing a faster aerobic decomposition which is important to optimize the composting process. Furthermore, through the mixing manure is incorporated into the bedding material providing the microorganisms present the necessary nutrients such as N and P (Barberg et al., 2007b; Gay, 2006; Janni et al., 2007; Janni et al., 2005). Good ventilation helps dry the freshly turned bedded-pack surface which helps to retard bacterial growth on the surface and keep cows cleaner since dry bedding does not stick to the teat or leg surfaces (Source: Milkproduction.com, 2008).

Clean bedding is added when the bedded pack becomes moist enough (usually greater than 61%) for it to adhere to the cows. Typically, a semi-truck load of clean material (approximately 18 tons) is added every 1 to 5 weeks, varying by season, weather conditions, barn size, ventilation efficiency, breed and area available per cow. Some dairies prefer to add a smaller bedding amount more frequently, such as once weekly (Compost Bedded Pack Barns – Can They Work for you? Marcia I. Endres).

Composting is also becoming a more popular alternative manure management method for dairy farmers. This process results in manure stabilization, mass and moisture reduction, and the reduction of pathogen levels (Willson and Hummel, 1975; Hong et al., 1983; Rynk et al., 1992; Haug, 1993; Lufkin et al, 1995; Lopez Real and Baptista, 1996; Keener et al., 2000; Wright and Inglis, 2002; Michel et al., 2002; Changa et al., 2003). Parameters such as oxygen, carbon content, moisture content, nitrogen content and the microbial community in the pack are important factors to attain the targeted temperature of 50 ˚C to 55 ˚C (122 ˚F to 131 ˚F) needed for good composting (Barberg et al., 2007b). Barberg et al., (2007b) measured bedding temperatures and chemical characteristics in 12 CDB barns throughout Minnesota in 2006. The authors stated that the pack was biological active but conditions were not optimized for composting (Barberg et al., 2007b).

Compost Bedded Pack Media

Compost bedded pack could be a good alternate housing system for the cow if a reliable bedding source is available. Researchers have also studied the effects of bedding quality on the lying behavior of cows. Dairy cows show a clear preference for a dry lying surface and they spend more time lying down in well-bedded stalls that in those with little or no bedding (Tucker et al., 2003; Wagner – Storch et al., Tucker and Weary, 2004). Frehonesi et al. (2007b) found that cows spent 5h/d less time lying down when they only had access to stalls with wet bedding compared with when they had access to stalls with dry bedding. Previous studies have also shown that cows preferred bedding that contained less moisture than a high moisture bedding in both summer and winter.

In addition to providing a well bedded surface for the cow, it is also important to properly maintain the bedded surface. Drissler et al. (2005) has documented how bedding levels decline in deep bedded stalls that are not maintained and how these declines have a dramatic effect in the stall usage. The lying time declined by approximately 10 min/day for every 1 cm reduction in sand bedding (J.A. Fregonesi et. al., 2007). In addition to the decrease in the bedding quantity, the bedding quality also declines as it becomes wet, either from exposure to the elements or from feces and urine entering the stall. Moisture content increases with the use by cows, resulting in increased bacterial counts on both the bedding and the teats (Zdanowicz et al. 2004).

Dry bedding material not only provides cow comfort but also helps reduce the somatic cell count; which is an indicator of mastitis. Mastitis results in reduced milk production. Barberg et al. (2007) reported a somatic cell count of 325,000 with a range of 88,000 to 658,000 cells/ml. Reduction in mastitis infection rates was observed for 6 of 9 farms analyzed for historical change from the previous housing system. Fulwider et al. (2007) found no hock lesions on cows housed in compost barns with the exception of purchased cows previously housed on freestalls. Barberg et al. (2007) reported that the body condition score was 3.04 ± 0.11 and hygiene score was 2.66 ± 0.19 for cows in compost barn yards using sawdust as bedding material. They also found that 7.8% of cows were clinically lame and no hock lesions were observed on 74.9% of the cows. The effect of sawdust bedding dry matter on the lying behavior of Holstein cows was studied. The results of the study confirmed that the wet sawdust bedding reduces the amount of time cows spend lying down and supports previous studies (L.J. Reich et al., 2010).

A wet bedded pack is more vulnerable to compaction. The compaction may be caused by the machinery that is used for stirring. Lower ground pressure tillage machinery should help reduce media compaction. Compaction in turn reduces air flow and oxygen in the bedded pack and thereby makes the pack anaerobic. An anaerobic pack shows lower temperatures which leads to reduced pathogen kill, and more pest and odor problems (Gay, 2006; Janni et al., 2005; Graves, 1999).

Weather, mainly temperature and humidity, or the Temperature-Humidity Index (THI) has an impact on the lying time of the cows. The THI is used to estimate the level of heat stress in dairy cattle. A study that investigated the association between THI and lying behavior of cows housed in compost dairy barns found that the lying behavior had an inverse relationship with the THI during the monitoring period of the study (M.I. Endres et al., 2007). Cows in the compost barns laid down fewer minutes per hour and increased the number of steps taken, which indicated restlessness and stress, as the THI increased. It was seen that the cows were able to move freely on the bedded pack.

Parameters that influence the bedding material performance are moisture content, bulk density and porosity (Wright & Inglis, 2002). Increasing bulk density, moisture content and depth of the pack can result in decreased permeability, especially for oxygen. If the moisture content in the pack increases, particles get wet resulting in reduced strength of the media (Ahn et al., 2004; Wright & Inglis, 2002). This can cause anaerobic condition in the pack which leads to odor, low temperatures and emission of N-compounds as well as methane. Materials that absorb too much water or urine are not suitable as bedding material as this high moisture content can rupture the cell walls which results in additional free water. In addition wet bedding also contributes to dirtier cows.

Media particle size distribution is an important factor influencing the bedding moisture content, compaction and bulk density. Sawdust, serves as a good carbon source. It has a fine particle size and provides poor air circulation. When fine materials like sawdust are used as a bedding media, they will need to be turned frequently in the pack. (http://cwmi.css.cornell.edu/compostfs5.pdf). It has also been suggested that the amount of fine particles in the bedding has an effect on the bacterial population on the teat ends; the finer the material, the more likely it will stick to the teat ends, and therefore they will have a higher population of bacteria (Use of Dried Manure Solids as Bedding for Dairy Cows: Cornell Waste Management Institute). The finer the media, the more time is required to clean the udder before milking.

Studies have also shown the effect of moisture content, particle size, vibration and compaction pressure on bulk density. Bulk density decreases with increase in particle size. As the particle size becomes larger, the gap between the particles increased keeping more unoccupied space. This resulted in the lower mass of the particle in the same container i.e. lower bulk density. The effect of compaction pressure on bulk density was also studied. It was observed the effect of compaction pressure on bulk density for larger particles was more in comparison with smaller particles, because smaller particles are closely packed leaving less space among the particles. For example, bulk density of 6 mm straw increased from 54.4 to 206 kg/m^3 while for 50 mm size it increased from 23 to 260 kg/ m^3. The maximum compaction pressure used for the experiment was 630 kpa. (Mozammel H et al., 2006)

The microbiology of the CDB pack depends on the media, weather conditions, temperature and moisture content, as well as the number of animals on the pack, which influences the amount of manure. Green et al. (2004) examined and compared the microbial community composition of sawdust and straw amended cow manure composts and found highly similar bacterial community profiles in both mature composts. However, there were significant differences in the composting process. For example, the peak heat temperatures, the length of the heating phase and the pH were different, depending on the initial C: N of the start media (Green et al., 2004). This can be explained with the different requirements of bacteria and fungi to C: N availability. Higher C: N ratios were found to favor fungi development in the pack (Eiland et al. 2001). The C: N ratio also influences the release of nutrients such as N (Villegas-Pangga et al., 2000). The authors found an increased N release with increased N content whereas increasing concentrations of polyphenols and lignin, as found in wood, decreased the release of N (Villegas-Pangga et al., 2000). Organisms that decompose organic matter use carbon as a source of energy and nitrogen for building proteins and enzymes. They need more carbon than nitrogen, in part because they respire carbon dioxide as they ‘burn’ these carbon foods. Furthermore, microorganisms have optimal pH ranges for their growth. In general, fungi tolerate a wider pH range than bacteria do. Where most bacteria have a pH range of 6.0 to 7.5, fungi can grow between 5.5 and 8.0 (BioCycle, 1991). However, bedding is not solely responsible for differences in microbial community structure. Miller et al. (2003) stated that more parameters of the manure (salts, total P, available P, total C, NO_3-N, and NH_4-N) were significantly influenced by season compared to bedding. Furthermore, bedding showed no significant effect on four bacteria groups (E.coli, total coli form, total aerobic heterotrophs (27˚C) and total aerobic heterotrophs (39˚C) compared to seasonal changes (Miller et al., 2003).

Different Media that have been used for the bedded pack

The most commonly used bedding material is dry sawdust (E.M. Shane et al. 2010), but the cost, availability and dust from the saw dust are growing concerns among the producers and the farmers. Kiln dried wood shavings or sawdust has been widely used in compost dairy barn throughout Minnesota with different success (Barberg et al., 2007a; Barberg et al., 2007b; Janni et al., 2007; Janni et al., 2005). Dry, fine wood shavings or sawdust are recommended for CDB. The fine particles improve handling, mixing, surface area, and composting. Straw and corn stalks do not work as well as wood shavings. Green or wet sawdust or shavings are not recommended because moisture levels are too high, leaving little capacity to absorb more water.

A descriptive study was conducted from June to September 2005 on 12 compost barns in Minnesota in order to describe the building layout, collect building dimensions, characterize the bedding material and observe barn management practices that were used on these dairies. The compost barns in this study were bedded with dry fine wood shavings or sawdust. The bedded pack was aerated twice a day while the cows were milked. The average bedding temperatures across all the depths, across all the pack barns was reported to be 42.5 ˚C (±7.6) (108.5 ˚F). The minimum temperature was 24.4 ˚C (75.92 ˚F) and the maximum was 58.9 ˚C (138.02 ˚F). The temperatures were greater in the areas of the pack that were fluffier, that was not heavily soiled or packed by the cows.

The bedding temperatures and chemical characteristics indicated that the bedding material used for this study was not composting, although the aerated pack was biologically active. (A.E. Barberg et al. 2007). The largest concerns among the farmers in this study were the cost and availability of the bedding material. The study also emphasized the need to identify best management practices or bedding characteristics that could result in more effective composting and possible reduction of bacteria counts in the bedding.

Alternative bedding media

The rising costs of the bedding material and the dust from fine bedding media are growing concerns among Minnesota Dairy farmers. Scarcity and economical reasons have pushed the farmers to explore different bedding strategies that could be used in the compost bedded pack.

A recent descriptive study considered various alternate bedding materials such as saw dust, wood chips, flax straw, wheat straw, oat hulls, straw dust and soybean straw for their study. The study was conducted on six Minnesota dairy farms having compost bedded packs. Chemical and bacterial analysis was done on these bedding materials. Results of this descriptive study showed that the alternate bedding materials that were used in the barn appeared to work similar to the sawdust. Pack temperatures for all the bedding materials were measured and it was seen that temperatures were high enough to support the microbial activity and produce heat (E.M. Shane et.al, 2010). Cow comfort measurement such as lameness and hock lesion prevalence were also similar to the previous study using sawdust as the bedding material. The paper highlights the importance of good pack management and suggests that the bedding material used in the farm is an important measure for the alternate housing system to work. This study also brings out the need for excellent ventilation to keep the surface dry and to remove the excess heat from the pack. The study concludes by stating that any of the bedding materials that were evaluated for the study can be used as an alternative bedding material for sawdust and would work well provided the pack is consistently well managed by tilling twice daily, providing proper ventilation to keep the surface of the pack dry, and adding new material when it is visually adhering to the cows. The study highlights ventilation as very important to the keep the surface of the bedded pack dry and to remove the excess heat from the pack (E.M. Shane et.al, 2010)

Cornell Waste Management institute has studied the use of Dried Manure Solids (DMS) as one of the alternated bedding for the dairies. Farm records of mastitis and somatic cell count (SCC) were recorded and an economic analysis of the cost savings from using manure solids was done on six farms using the dried manure solids as bedding media (Mary Schwarz and Jean Bonhotal et.al, 2010 – Cornell Waste Management Institute). Samples were collected from both the used and unused bedding material to determine the bacterial count. Bedding was also analyzed for the moisture content and particle size. Average moisture content in the unused DMS ranged from 64% to 73% and fine particles less than 2 mm in size ranged from 31% to 74%. This study also discusses the possibility for the spread of Johnes disease in a herd which is caused by Mycobacterium avium paratuberculosis – MAP. Since these bacteria are shed in the manure, using the dairy manure solids as bedding may spread the disease throughout the herd if the bacterium remains viable in the DMS (Mary Schwarz and Jean Bonhotal et.al, 2010 – Cornell Waste Management Institute)

Previous studies also indicate that the compost dairy barn manure behaves more like a mixture of bedding and manure rather than a well composted mixture. This was also substantiated by recent work that showed the stratified bedded pack manure can be further composted in managed piles (Shane et al. 2010). To avoid high C: N ratio in the applied manure and to reduce the bedding costs, farmers should avoid excess bedding (Michael P. Russelle et al., Crop Management 2009).

Table 1: Summary of the compost bedded pack characteristics as reported by the authors in their study.

Table 1. Summary of CBP Characteristics				
	Units	**Barberg**	**Janni**	**Russelle**
Barns in Study		12	6	8
Moisture (wet basis)	%	52.7 in SL[1]		61 in SL*
		56.7 in CL2[2]		64 in CL*
Total Nitrogen	%	-	0.99	1.09
Phosphorus (P205)	%	-	0.36	0.28
Potassium (K20)	%	-	0.7	0.74
pH	Units	8.5	8.45	7.5
Carbon nitrogen ration (C:N)		19.5	15.5	11.2 to 20.9
Temperature	Degrees C	42.5	-	-
Density	lb/ft^3	-	-	55.3
Bedding Use	lb/cow/day	-	193	-

1 SL - surface layer top 3 to 8"
2 CL - compacted layer >8"

Source: Harold House - Engineer, Dairy and Beef Housing and Equipment/OMAFRA – Calculating Fertilizer value of compost bedded pack

Table 2 lists the characteristics that various bedding materials should have for maximum performance efficiency. Table 3 lists different media and their composition. As observed from the table soft woods and hard woods have higher lignin content when compared to the straws. The amount of cellulose and lignin has an important impact on the availability of carbon, thus will also influence the microorganisms which are able to use them.

Table 2: N, C/N ratio, moisture content and bulk density of possible bulking agents (Rynk, 1992)

Material	Type of value	% N (dry weight)	C/N ratio (w/w)	Moisture content % (wet weight)	Bulk density (lb/cubic yard)
Corn cobs	Average	0.6	98	15	557
	Range	0.4-0.8	56-123	9-18	N/A
Corn stalks	Typical	0.6-0.8	60-73	12	32
Cattle manure	Average	2.4	19	81	1,458
	Range	1.5-4.2	11-30	67-87	1,323-1,674
Straw general	Average	0.7	80	12	227
	Range	0.3-1.1	48-150	4-27	58-378
Sawdust	Average	0.24	442	39	410
	Range	0.06-0.80	200-750	19-65	350-450
Woodchips	Typical	N/A	N/A	N/A	445-620
Hardwood (chips, shavings, etc.)	Average	0.09	560	N/A	N/A
	Range	0.06-0.11	451-819	N/A	N/A
Softwood (chips, shavings, etc.)	Average	0.09	641	N/A	N/A
	Range	0.04-0.23	212-1,313	N/A	N/A

Table 3: Chemical composition of selected lignocellulosic fibers

	Composition a (%)			
Fiber Type	**Alpha Cellulose**	**Lignin**	**Ash**	**Silica**
Rice straw [b]	28-36	12-16	15-20	9-14
Wheat straw [b]	38-46	16-21	5-9	3-7
Oat straw [b]	31-37	16-19	6-8	4-7
Bagasse [b]	32-44	19-24	2-5	1-4
Kenaf [b]	31-39	14-19	2-5	N/A
Cotton stalks [c]	N/A	22	5	3
Rice husks [d]	38	22	20	19
Softwoods [b]	40-45	26-34	<1	--
Hardwoods [b]	38-48	23-30	<1	--

[b] Source: Kocurek & Stevens, 1983; [c] Source: Fadl et al. 1978; [d] Source: Govindarao 1980

MATERIALS AND METHODS

Potential bedding materials that were examined for this study were: green tamarack; Lonza Corp. Inc. tamarack; norway pine; southern yellow pine (SYP); jack pine; ash; soybean straw; corn cobs; white pine; poplar and anaerobically digested manure solids (ADMS). Lab analysis was performed on the above mentioned media. A mixture of these media was send to the farms for the on-farm demonstration study, tamarack being the control for all the four farms of this study. Lab analysis was also performed on the media that were used by the farmers in their compost barn yard.

Physical and chemical analyses were performed on these materials. Moisture content, bulk density, water holding capacity and sieve analysis were the physical parameters that were measured using the original loose media. The following chemical analyses were carried out: pH, electrical conductivity, ash content, total nitrogen, carbon, potassium, phosphorus and ICP extractable elements. For most of the chemical analyses, dry ground media samples were used. The media were ground to a particle size of 2 to 3 mm. For the pH and electrical conductance tests, 250 ml of as-is media was used. Lignin content measurement was also done on the media. Lignin content measurement was measured using air dried media which were ground to a particle size of less than 1mm.
On farm testing included the measurement of the bedding pack temperatures and oxygen content at six different locations in the barn. Compaction at different locations and depths on the bedded pack was measured by a penetrometer (FieldScout SC 900 Soil Compaction meter).

MOISTURE CONTENT

Weight of an empty aluminum tray was recorded. Tare the aluminum tray. 100 grams of the as-is media was then transferred to this tray. This is the net sample weight at as-received moisture. Place the tray with the media in the oven preheated to 70±5 °C (158 ±5 °F) for 1-24 hours until there is no weight change. Place the oven-dried sample in desiccators and cool to ambient laboratory temperature, approximately 23 °C (73.4 °F). Weigh and record the gross weight of the aluminum tray with the dried media. Subtract the weight of the aluminum tray from the gross weight to determine the sample's net oven dried weight. Moisture content is then calculated using the following equation:

> M = 1 – [dW/A] * 100
> Where M = Percentage moisture in the sample, calculated on a wet basis.
> dW = net dry weight of the sample, g
> A = net sample weight at as-received moisture, g

BULK DENSITY

The bulk density was determined using the drop method, where the weight of a specific volume is measured after the sample was systematically packed. The tare of a 2 liter container was measured. The loose media (original) on a 70±5°C (158 ±5 °F) dry weight basis was transferred to the container and filled to two liter container. To obtain a representative compaction, the container was dropped ten times from 10 cm to acquire a drop distance of one meter. Throughout that process, it was assured that the 2-L volume of media was accurate. The container and the media were then weighed. The bulk density was calculated using the following equation:

$$Bulk\_Density = \frac{(weight\_containerwithmedia) - tare}{container\_volume}$$

WATER HOLDING CAPACITY

One of the functions of the bedding material in the CDB barn is to retain liquid. Therefore, the water holding capacity was determined using the following method. Twenty grams of dry media was weighed. Weight of the saturated coffee filter #6 was recorded. Five hundred ml funnel with the saturated filter paper was taken and the bottom of the funnel was plugged with a rubber stopper. Weighed media (20 grams) and 350 ml of de-ionized water were added into the funnel. The funnel with a beaker at the bottom was allowed to sit for 24 hours. Bottom of the funnel was unplugged after 24 hours and water was allowed to drain for 2 hours. Weight of the filter paper with the media was recorded. Dry water holding capacity was then calculated using the following equation.

Gain in weight (grams) = Weight of the filter paper with the media – Weight of the wet filter paper – Original dry weight of the media.

$$\text{Water Holding Capacity} = \frac{\text{Gain in weight}}{\text{Original dry weight of the media}} * 100 = \text{\% of dry weight moisture}$$

SIEVE ANALYSIS

Sieve Analysis was done using five different sieve sizes; the sizes of sieves used depended on the particle size of the media or compost tested. If the media/compost appeared to be very fine, smaller sieve sizes were used and if the media/compost appeared to be shaved into large particles, larger sieves were used. The sizes of sieves used throughout the experiment were 25 mm, 12.5 mm, 6.3 mm, 2 mm, 1 mm, 425 µm and 250 µm. A representative weighed sample (approximately 50 grams of oven dried media or compost) was poured into the top sieve which had the largest screen openings. Each lower sieve in the column had smaller openings than the one above. At the base was a round pan, called the receiver. The column is typically placed in a mechanical shaker (RO-TAP, RX-29). The mechanical shaker was turned on for 10 minutes. After the shaking was complete, the media/compost retained on each sieve was weighed. The weight of the sample of each sieve is then divided by the total weight to give a percentage retained on each sieve. It should also be noted that for some media, only 20 grams was used due to less dense but large particle sizes and due to the less availability of the media.

Chemical analysis of the media and the compost samples for pH, EC (electrical conductance), total ash, total Phosphorous, total potassium, total Carbon and total Nitrogen were conducted by the University of Minnesota Soil Testing and Analytical lab. Lignin content measurement for the samples was performed at Kaufert lab at the University of Minnesota on the St. Paul Campus.

pH

pH is a measure of hydrogen ion activity in solution and is a measure of alkalinity or acidity. pH has a major influence on the microbial growth and on ammonia emission from the bedding (Misselbrook & Powell, 2005; Tiquia et al., 2002; Lory et al., 2002; Eiland, 2001; Jeppsson, 1999; Anderson, 1995). The pH of the different bedding media was determined using ground sample in a 1:10 solid to liquid slurry ratio. The flasks with the 1:10 slurry were placed in a shaker for 1 hour at 180 rpm. The pH of the slurry was determined using a pH electrode (Page et al., 1984).

ELECTRICAL CONDUCTIVITY

In soils, soluble salts refer to dissolved inorganic solutes that can be measured in an aqueous extract of the media using a conductivity meter (Page et al., 1984).Electrical conductivity (EC) is the measure of the ability of the extract to conduct an electric current between two electrodes. The measured value relates to the amount of salt in the extract and increases with concentration. EC was determined with a conductivity meter using the same 1:10 solid to liquid slurry used to measure pH.

METALS

Metals are elements whose concentrations are regulated by law due to potential harm to humans, animals, plants or soils. Therefore, the media were tested on their metal concentrations (US-EPA-503). The testing was done at the Department of Soil, Water and Climate's Soil Testing Lab on the St. Paul Campus. These elements were measured using the Inductively Coupled Plasma (ICP) method (Munter, 1990). The ash content was also measured in the Soil Testing Lab through high temperature combustion (485 °C ashing temperature).

LIGNIN CONTENT

The procedure for the measurement as performed at the Kaufert lab was:
Weigh out 250-300 mg of the extracted wood/pulp meal to the nearest 0.1 mg in a 250-mL beaker. At the same time weigh another specimen for moisture determination. Add 3 mL of 72% H_2SO_4 in small increments while macerating the material with a glass rod. Place the beaker after addition of the acid in vacuum desiccators for 15 minutes to facilitate wetting and dispersion (keep the glass rod in the beaker). After dispersion, cover the beaker with aluminum foil and place it in a water bath at 30 °C for 60 minutes. Stir frequently with the glass rod during this time. Add 84 mL deionized water to dilute the concentration of H_2SO_4 to 3.0%. Prepare at least 4 different calibration solutions containing the 5 monosaccharide (glucose, xylose, galactose, arabinose and mannose). Add 3 mL of 72% H_2SO_4 to each solution and dilute with deionized water to 3.0% H_2SO_4 as described above. Boil all solutions (samples and calibrations) in an autoclave at 1.2 atmospheric pressure and 120 °C for 60 minutes. Time zero is considered to be at the end of preheating period. After interrupting the hydrolysis, allow the beakers to cool to room temperature (~23 °C). Pipette 5 mL of an internal standard solution into each one of the cooled solutions (500 mg cellobiose weighed to the nearest 0.1 mg and dissolved in deionized water to a volume of 50 mL). Filter off through a previously weighed glass microfiber filter paper (Whatman GF/A, diameter 4.7 cm) using a 3-part filter funnel. Wash the precipitate with 5 mL warm deionized water. Transfer the filtrate to a 100-ml volumetric flask. The precipitate on the filter paper is the acid-insoluble lignin (Klason lignin). Wash the lignin free of acid with hot water. Verify neutral pH with a suitable pH-indicator paper. Dry the filter paper with lignin in an oven at 105 °C overnight or to a constant weight. Cool in desiccators and weigh.

ON-FARM DEMONSTRATIONS

Introduction

The demonstration part of the study included four dairy farms from central and western Minnesota. We wanted to get real world experience with the alternative media and media mixes. The farms that were chosen as demonstration farms met the following criteria: 1) They had 3 or more years of experience with CDB; 2) their herd average in milk production per cow was in the top 10 % of Minnesota dairy farms; 3) they like the overall performance of their CDB; 4) they were each located in different counties and 5) they wanted to be a part of this study. The dairy farmers selected were all very busy people. They see their main job as providing excellent care to their cows. While manure system management is seen as important it is only one of many tasks that require the attention of the farmer each day. We thank them for their time and willingness to share their experiences, suggestions, and comments with this study.

Each farmer used different media and different management techniques making the operation and management of each pack very different. Farmers agreed to experiment with different mixtures of media and allow our research team to visit their farm during summer to take samples of their bedded pack. The objective of the farm demonstration was to test different types of media and get the farmer's opinion of how it performed in their pack. A set of questions were designed to gather information about the barn management practices used and the building layout, as well as the farmer's satisfaction and overall opinion of the study media and CDB in general.

Each farm was sent two loads of dry media; the first load was a mixture of 50% tamarack and 50% of another media, and the second load was a load of only tamarack. Each load of wood shavings contained 143 cubic yards of "thin" shavings about 19 mm (0.75 inch) wide at 10% moisture or less with most of the "fines", less than 2 mm 90% removed and fines between 2 mm and 6mm 50% removed. This practice of fines reduction lowers the dustiness of the media and is in common practice for poultry, horse and small animal bedding. It was used to see if in fact the dust of these media in handling and tillage would be reduced.

Farm #1

Farmer 1 has been dairy farming for 13 years and composting with a bedded pack system since June of 2006. The barn, a pole-barn building, is 210 feet by 84 feet and was built in 2005 and then renovated to accommodate the bedded pack system. The renovation costs totaled $25,000 including labor, fans & lights, and cement & lumber. The bedded pack is 53 feet by 200 feet containing 99-120 cows, allowing approximately 102 square feet per cow. Prior to dairy composting, the barn was a tie stall and 2 pits were used for manure management.

Recently, this farmer has been using window millings as main media source. However, in the past, meadow hay, corn stover, ground wood pallets, corncobs, and shredded paper have been used. The farmer did not comment further on the performance of these alternative types of media. For the study, Farm 1 received a load of 50% tamarack shavings and 50% white pine shavings in mid-July and a load of 100% tamarack shavings for their second load in early August.

Depending on the season, the farmer adds some amount of fresh media every week. During the summer months, ½ of a load is added per week. During fall and spring, 1/3 of a load is added 2 times per week, and during winter months 1/3 of a load is added 4 times per week. It is common for farmers to have to add more media in the winter due to the cold weather inhibiting airflow in the barn thus reducing the drying of the surface of the pack. Also during winter less moisture evaporates from the pack.

Tilling is performed twice daily using a chisel plow with 4-inch twisted shovels in the morning and a spring tooth with sweeps during the afternoon. The chisel plow tills to a depth of 25.4 cm – 35.6 cm (10-14 inches) and the spring tooth tills to a depth of 15.2 cm (6 inches). This keeps the bedded pack fairly loose, well aerated, and the surface dry. In fact, of the four dairy farms involved in the demonstration study, this bedded pack was the driest at surface to 15cm, 30cm, and 45cm depth. This farmer does not take any kind of measurements of his bedded pack, such as temperature or oxygen; however he does pay close attention by making simple look and feel observations, which gives him an idea of how often he needs to till. He commented on how airflow is the key to make compost work well, which is why he pays close attention to the temperature and firmness of the pack as well as on complete and thorough tillage each week.

This pack was very loose, when walking atop it, our boots sunk in up to our ankles in some spots. The cows' hooves sunk in about 15.2 cm (6 inches) and the farmer noted that after it is plowed they could sink into the pack up to 30.5 cm (one foot) deep. The farmer also noted that the tamarack/white pine mixture did not improve cow comfort in comparison to the window millings because the pack is always fairly loose. He also mentioned that the mixture did not seem to reduce dust in the air; however, it was less dusty than the other types of media he has used.

Farmer 1 has had no problems with high somatic cell count before or after composting with a bedded pack. He did express concern over *E-coli* infecting his cows, as one was lost to this disease while composting with a bedded pack. He also expressed concern over the tie-up of nutrients, especially nitrogen, when the compost is applied to the soil to grow corn.

Farm #2

This farmer has been dairy farming for 37 years and composting with a bedded pack system for 7 years. Prior to dairy composting, the cows were housed in a stanchion barn with gutters and the manure was hauled out of the barn daily. The current barn is 95.1 m by 30.0 m (312 feet by 98 feet) with four pens at each corner of the barn and the feed alley running down the center. The dimensions of the bedded pack are un-known however approximately 205-215 cows are kept in the bedded pack with approximately 50-60 cows in each pen. The barn, built in 2003, is a wood frame on top of 5-foot cement sides with curtains on 12-foot sidewalls. The airflow inside of this barn is great, there are 6 rows of 3 fans on each side of the feed alley, totaling 36 fans, which are caged short-bladed fans allowing for fast rotation speed. There are 10 lights inside the barn, 5 on each side of the feed alley. During the day, there is little need for these lights to be turned on as natural light penetrates through the open sidewalls lighting up the barn sufficiently. The construction of the barn cost $265,000 to accommodate the bedded pack system.

Farmer 2 consistently uses ground palettes, which costs him $1125 per load. A load of 50% tamarack and 50% jack pine shavings was sent to this farm in mid-July and a load of 100% tamarack shavings was sent in early August for this study. The study mixtures was said to have not increased dust in the barn and is also able to dry sufficiently after tilling. Tilling is done twice daily with a cultivator that turns over the compost 12.7 cm – 20.3 cm (5-8 inches) below the surface. Fresh media is added to the pack by the amount of one semi truckload per week in both summer and winter. Occasionally, in winter an extra load is needed somewhere in the month. The depth of the fresh media layer is approximately 15.2 cm (6 inches) when initially applied every week.

Farmer 2 thinks that the bedded pack system has reduced somatic cell count in the milk. When asked if time/money/energy is saved compared to traditional methods of manure management, he said it was difficult to answer, because of the lack of a lagoon system compared to his current CDB. It was also noted that the study mixture shavings improved cow comfort in comparison to the ground palettes due to the softer and fluffier texture of the shavings. When walking atop the bedded pack, the structure felt stable with very minimal sinking. The farmer commented on the stability of the pack stating that the cows' hooves sink in slightly when standing or walking on the pack. No measurements, such as temperature, oxygen, or moisture were taken in the pack; and no comments were made.

Farmer 2 expressed his biggest concern about bedded pack systems as the cost of the media. Overall, Farmer 2 was pleased with the performance of the mixture of 50% tamarack and 50% jack pine. He noticed that when the media was wet it stuck to the cows' legs more than the ground palettes that he usually uses. This was because the ground palette wood was thicker and larger in size than the study mixture shavings. He also mentioned that the study mix was easier to dig or stir; however, it was difficult to make good observations and notice differences with only two loads. With a study of similar objective lasting a full year, much more conclusive results might be seen. When auguring through the depths of the pack we could feel when our layer of media was reached as it was much easier to auger through, concurring with the observations of the farmer that it was easier to dig. The difference in airflow between the different media due in large part to the differences in particle size was noticed with oxygen and temperature measurements taken at the various depths.

Farm #3

This farmer has been dairy farming for 17 years and composting with a bedded pack system for 5 years. Prior to dairy composting, the cows were housed in free stalls and the manure was managed in the pit under free stall barn. The current barn is 97.5 m (320 feet) by 24.4 m (80 feet) with four pens at each corner of the barn and a feed alley of 320 feet. The dimensions of the bedded pack are 15.2m (50 feet) by 22.9 (75 feet). Approximately 200 cows are kept in the bedded pack. The barn, built in 2005, is a wood frame on top of 4-foot (1.2m) concrete walls around the bedding pack with curtains on 16-foot sidewalls. The airflow inside of this barn is great; there are 16 fans, 1.3 m diameter (52 inch) located along the south side of the bedded pack, blowing over the pack and two additional fans, 1.32 m diameter (52 inches) at the end walls peaks. The construction of the barn cost $240,000 to accommodate for the bedded pack system.

Farmer 3 consistently uses a combination of wheat straw and soybean straw, which costs him $55-$60 per ton or $1080 per semi load, ground and put into the barn. A load of 50% tamarack and 50% wheat straw was sent to this farm in mid-July and a load of 100% tamarack shavings was sent in early August for this study. This farmer also received corn cobs and soybean straw in December 2010.

The study mixture was said to have not increased dust in the barn and is also able to dry better than the grain straw. This farmer is trying to minimize the tillage to two or three times per week or less. The reason given was to lower labor and fuel costs with seeming little benefit to the bedded pack through drying or mixing. He is trying to find out how little tillage can be done and still have good cow comfort. Fresh media is added to the pack every day as needed to keep the pack dry. He mentioned more media is needed in winter compared to summer months. The depth of the fresh media layer is approximately 5.1 cm (2 inches) to 7.6 cm (3 inches).

Farmer 3 mentioned that initially the somatic cell count was 230,000 cells/ml, but within three years the count reduced to 160,000 – 180,000 cells/ml and now they are back to 225,000 – 230,000 cells/ml. When asked if time/money/energy is saved compared to traditional methods of manure management, he thought there are pros and cons to this.

The farmer believed there was no difference in the cow comfort as a result of the new media in the barn. He felt it seemed to firm the pack a little. When walking atop the bedded pack the structure felt stable with very minimal sinking. The farmer stated that the cows' hooves did not sink into the compost when standing or walking on the pack. They could walk atop the bedded pack. No measurements, such as temperature, oxygen, or moisture were taken in the pack.

Farmer 3 expressed his biggest concern about bedded pack systems as the cost and ability to obtain the bedding media. He mentioned the three parameters that he considered important considering the media in a bedded pack barn were low cost, performance of the media, especially water holding capacity and consistent availability and supply of the media to the cows.

Overall, Farmer 3 was pleased with the performance of the mixture of 50% tamarack and 50% wheat straw. He mentioned that the shavings were very user friendly and not really dusty, but they were very absorbent. He would consider using the wood shavings in a mix with the straw. This farmer has tried almost all types of wood product shavings, chips very fine straw dust. He also shared his experience and preference on these media – soybean straw ground to about 7.62cm (3 inch); he thought it was very dry, absorbent and easy for tillage. His second preference was small grain barley, wheat and oat straw followed by wood shavings or chips. He thought corn cobs that are dry would also work better, but are hard to obtain. His final preference was for the mixture of small grain straws. These straws work fine but are very dusty, hard to handle and require more tons to keep the cows dry. He mentioned that he did not observe any difference between the load of only tamarack and the mixed load in terms of the drying capacity and the moisture content of the bedded pack on the surface.

This farmer was sent a load of corn cobs and he tried corn cobs and soybean straw mixture. He said it worked well as a media for the bedded system. He used the mixtures of one volume of corncobs passing through 1 inch screen and two volumes of soybean straw that were cut 3-4 inches in length. He mentioned that the mixture worked better than the media by itself. Tilling was easy and WHC seemed to increase with the mixture usage. This farmer also tried layering the two media. In one of his pens, he cleaned the whole floor and laid a first layer of whole corn cobs. On top of it, the second layer of soybean and wheat straw mixture was added. He thought the top layer mixture stayed much drier than any other media used. So far he thought this layering system worked well for him, but did not know if it will continue. Additionally he mentioned that the corncobs do not work well by themselves, but the mixtures works great. He also commented on the particle size of the media. He thought it would be better to have a mixture of media with different particle sizes. With 2 mm or larger size, there was less dust. Wood or corncobs work better if the size is less than 25 mm. Farmer also felt that the mixing of media should be done outside the barn and then the mixture should be laid in the barn rather than layering or tilling in the barn.

Farm #4

This farmer has been dairy farming for 10 years and composting for 4 years. The barn has dimensions of 19.5 m (64 feet) by 60.9 m (200 feet) and holds approximately 120 cows. The barn was built in 2005 with 5-foot cement walls, 16-foot total sidewall height with curtains, 3.0 m (10-foot) centerboards, and a steel roof. The costs of the barn totaled $175,000. The dimension of the bedded pack is 15.2 m (50 feet) by 60.9 m (200 feet); therefore with 120 cows; there is 7.7 square m (83.3 square feet) per cow. There are three “Big Ass Fans” located at 9.1 m (30 feet), 30.5 m(100 feet), and 51.8m(170 feet) inside the barn. These fans have large blades that rotate rather slowly. Prior to dairy composting the cows was housed in tie stalls and the manure was managed with a barn cleaner and a pit.

The media choice of this farmer is strongly based on cost. Farmer 4 pays $300 for 30 yards of very fine cabinetry dust from a cabinetry factory. When the fresh dust is initially applied, fine particles stay suspended inside the barn for a long time, reducing the air quality and potentially issues for the cows and workers from the very fine dust.

Farmer 4 has never had a problem with high somatic cell count regardless of the bedding system. He believed that the bedded pack does not save him any time, energy, or money; however, he does it for improved cow comfort and health.

He tills his compost pack twice daily with a tractor-pulled cultivator going 15.2cm (6 inches) below the surface. One 30-yard load of VFCD is applied per week in summer and two 30-yard loads per week in winter. Each weekly load adds a 1.91cm -2.5cm (¾inch – 1inch) layer of fresh sawdust on the bedded pack. The farmer was asked to comment on the stability of the pack in relation to the cows’ ability to stand or walk across the pack. He claimed that the cows’ hooves sink into the pack about 10.2cm – 15.2 cm (4-6 inches); however, the cows have no problem with walking or running on the pack.

A mixture of 50% tamarack shavings and 50% norway pine shavings was sent to farm 4 in mid July and a load of 100% tamarack shavings was sent in early August. This was the first time Farmer 4 experimented with other types of media. He thought that the study mixture did not improve the cow comfort. But mentioned that there was no increase in the amount of dust or particulate matter in the air, and also sufficiently dried after tilling. However, he did mention that it took less time to clean and prep the cows because the media did not stick as much to the cow's udders as the VFCD does. The farmer also commented on the water holding capacity of the tamarack and norway pine mixture, stating that it does not absorb as much as VFCD does. The farmer does not take measurements of any kind, such as moisture content, oxygen, or temperature, on the bedded pack.

When our research team walked across the pack during our first visit in July, we noticed that the pack was moving beneath us. If we jumped the pack would bounce with us, almost like stiff jelly. We later discovered that the VFCD media has over 400% water holding capacity, which was over 2 times that of the wood shavings. This validates the farmer's comment regarding the absorption capacity of the sanding dust versus the wood shavings. In terms of moisture content, the compost samples taken from this farm had the highest values of all four farms' compost samples. Therefore, although the media has high water holding capacity, its ability to dry in the pack was the lowest of all four farms. Also the very small particle size of this media greatly restricted the movement of oxygen into the pack.

Conclusion

There are certain management techniques that most compost dairy farmers share such as, tilling two times per day, thereby mixing and aerating the pack. Mixing incorporates oxygen to enhance composting. Most CBP farmers remove their bedded pack media from the barn in summer or fall, and then immediately applying it to their fields. A few mix it and put it into a pile outside before applying it to crop land. The differences in media, barn structure and layout, the depth to which they till, and the amount and frequency of spreading new bedding reflect strongly in the composition of the bedded pack. Of all four farms' compost packs we worked with, not one was exactly like another. All our demonstration farmers expressed concerns over the high price of the media. Their primary reasons for composting with a bedded pack are to improve cow comfort and health. This seems to be a reoccurring theme found in dairy composting research. If a farmer is able to find an affordable and consistently available media source, they are likely to opt for the bedded pack system due to its pay-offs in cow health and comfort.

The farmers were all very cooperative and pleased to be a part of this study. Our research team learned a lot from working with them and we hope they learned from us as well.

RESULTS AND DISCUSSION

pH

pH is a measure of hydrogen ion activity in solution. It is a measure of alkalinity or acidity. pH of the media ranged from 4.3 for southern yellow pine to 7.4 for wheat straw. Tamarack, pine shavings, corn cobs, ash and poplar showed acidic pH value of below 6 (see figure 1). Anaerobic digested manure solids and soybean straw showed the highest pH values of 8.6 and 8.7. Similarly wheat straw had the highest pH when compared to wood based media that were used in the demo farms (Figure 2). Among the media mixtures, most of the mixtures showed acidic pH values, except for the mixtures that included corn cobs with soybean straw and green tamarack with soybean straw (Figure 3). Apparently, soybean straw has greater buffering capacity than the corncobs or green tamarack, both of which have pH below 6. These are the initial pH values of the media and media mixtures before composting

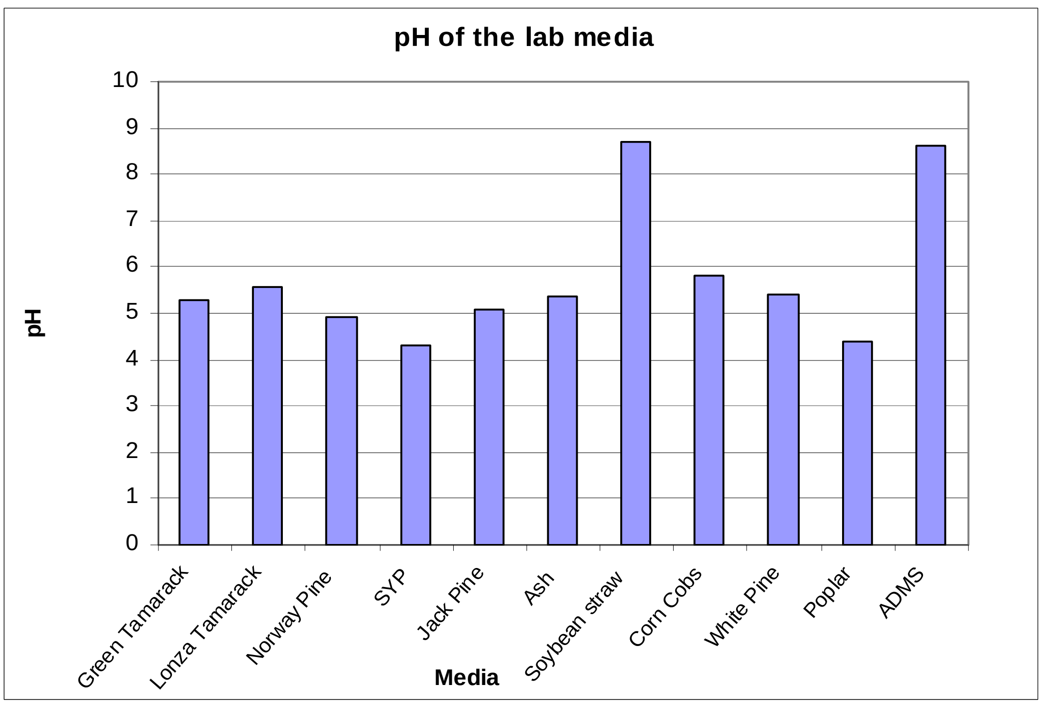

Figure 1: pH of the lab media

Compost microorganisms operate best under neutral to acidic conditions, with pH's in the range of 5.5 to 7.0). pH measurements that are outside the range of 5.5 to 7.0 affect the microorganisms in the pack; both pathogens and favorable organisms. pH controls the equilibrium between ammonium ions and ammonia in manure, so if pH is increased, the equilibrium is displaced towards the production of ammonia (Jeppsson, 1999).

During the initial stages of decomposition, organic acids are formed. The acidic conditions are favorable for growth of fungi and breakdown of lignin and cellulose (Cornell Composting). It also helps reduce the ammonia emission from the pack thereby conserving N within the bedding material. As composting proceeds, the organic acids become neutralized, and mature compost generally has a pH between 6.0 and 8.0. Larney et al. (2008) stated that a rise in pH occurs when microorganisms start to breakdown proteins and with the release of NH_4-N during the ammonification process. If anaerobic conditions develop during composting, organic acids may accumulate rather than break down. Aerating or mixing the system should reduce this acidity. An alkaline pH increases ammonia volatilization during the composting process (Peigne, 2004)

pH was measured for the existing media that were used by the farmers as well as for lab media mixtures. It can be seen that the wheat straw showed the highest pH when compared to the window millings, ground pallets and very fine cabinetry dust.

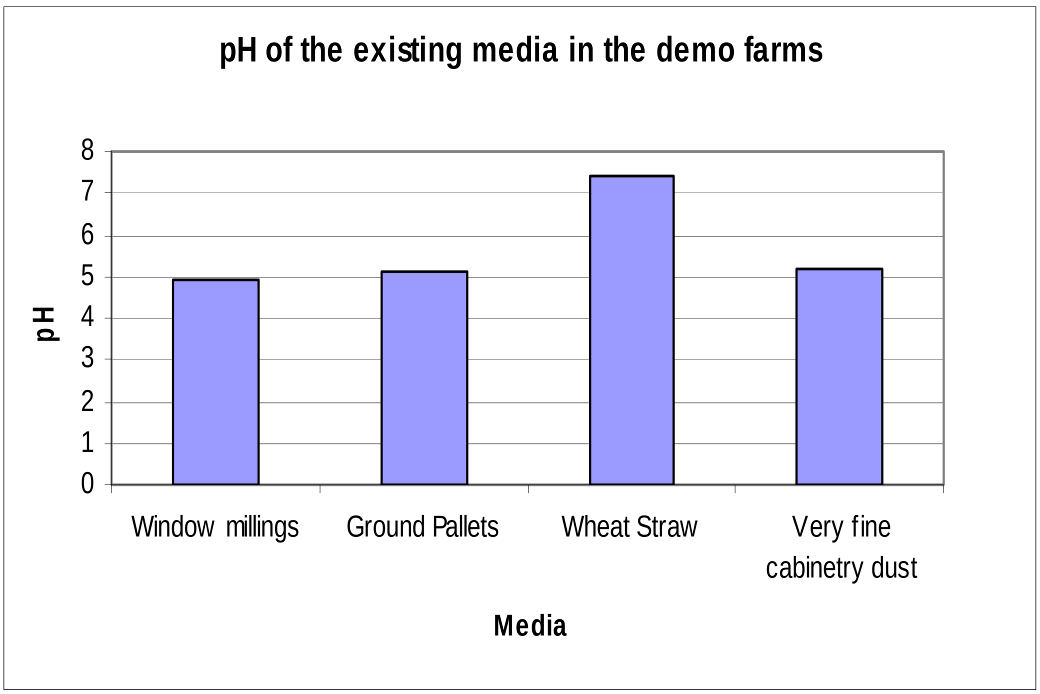

Figure 2: pH of the existing media in the demo farms

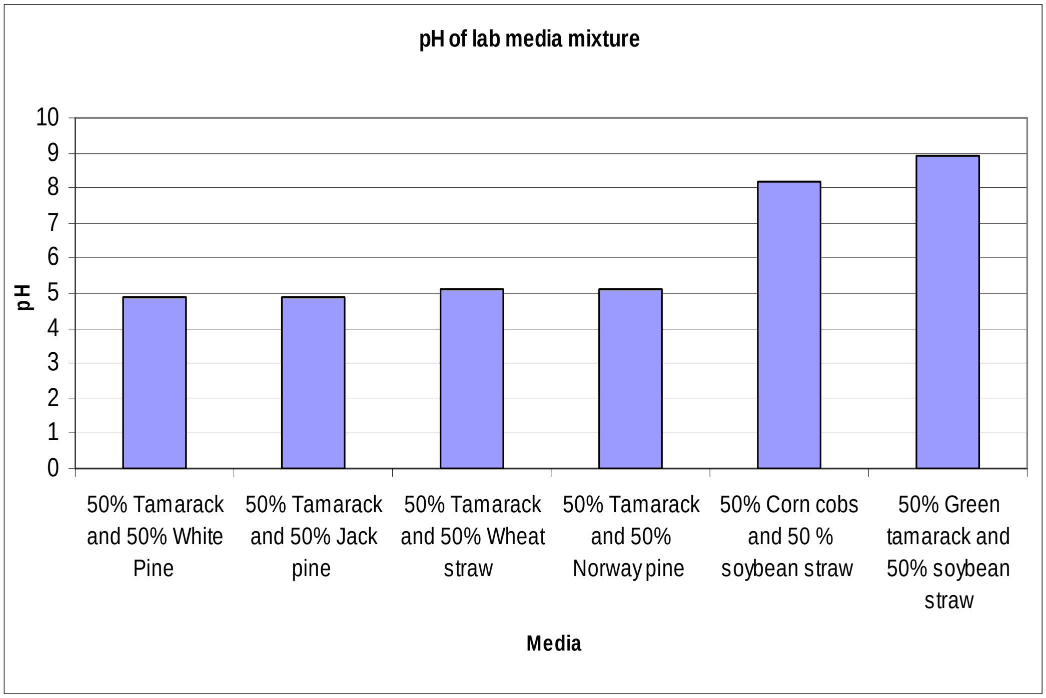

Figure 3: pH of the lab media mixture

It would be better to use media with an initial pH below 7 as it would help in composting. The average pH of the compost samples from the demo farms ranged from 8.1 to 9.6 (Table 15) slightly above the recommended pH levels for composting of 6.5 to 8.0 (NRAES – 54, 1992).

Electrical Conductivity (EC)

EC is a measure of soluble salts extracted from the media. Salts that become soluble and commonly found in compost are potassium chloride; sodium chloride; various nitrates; compounds involving sulfates, calcium, magnesium, and potassium carbon. The greater the electrical conductance, the greater the concentration of soluble salts in the compost (Maurice E. Watson – Testing Compost). Earlier studies have considered the soluble salt as one of the potential source for the environmental pollution of water, soil and air. High salinity can reduce seed germination and plant growth. Plant species differ in tolerance to salinity.

Cattle manure and urine contain soluble salts, so choosing a media that is initially lower in soluble salts will result in a larger potential dilution factor. This may result in a more useable finished compost product (Widmer et al., 2007).

The electrical conductance values ranged from 0.1 to 2.4 mmhols/cm. Straws had higher electrical conductance when compared to other wood shavings. Soybean straw showed the highest electrical conductivity with a value of 2.4 mmhols/cm. Apart from the soybean straw and anaerobic digested manure solids, all other media had the values below 2 mmhols/cm (Figure 4). Electrical conductance for the lab media mixtures remained below 2 mmhols/com; mixtures of corn cob and soybean straw and tamarack with soybean straw mixture had higher values of EC than the other mixtures (Figure 6). All of the EC measurements of fresh lab media, lab media mixtures and the existing media used in the demo farms were low to very low values in terms of potential damage to most crops grown in Minnesota.

The average electrical conductance of the compost samples from the demo farms was 9.64 mmhols/cm (Table 15), below the 10 mmhols/cm maximum concentration desired for composting (NRAES-54, 1992).

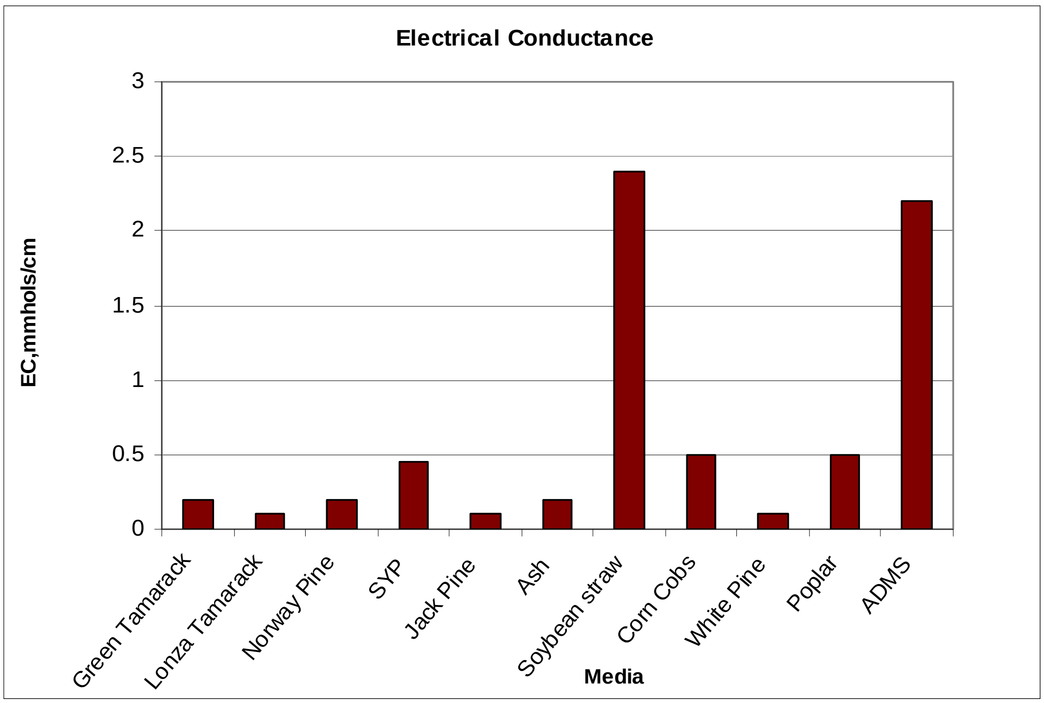

Figure 4: Electrical Conductivity of the lab media

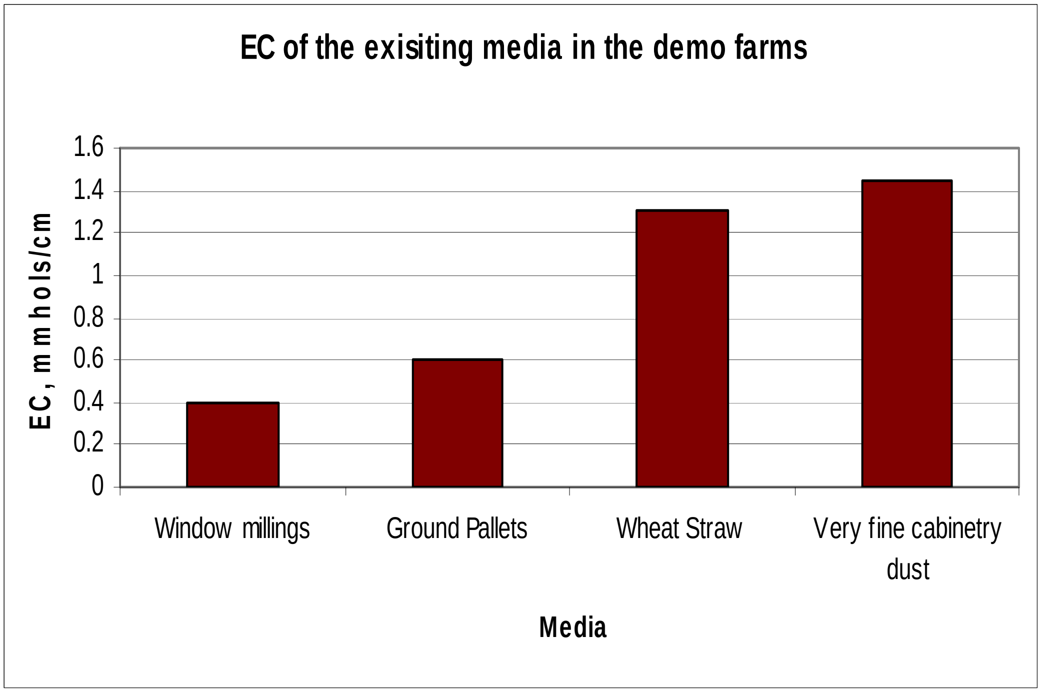

Figure 5: Electrical Conductivity of the existing media in the demo farms

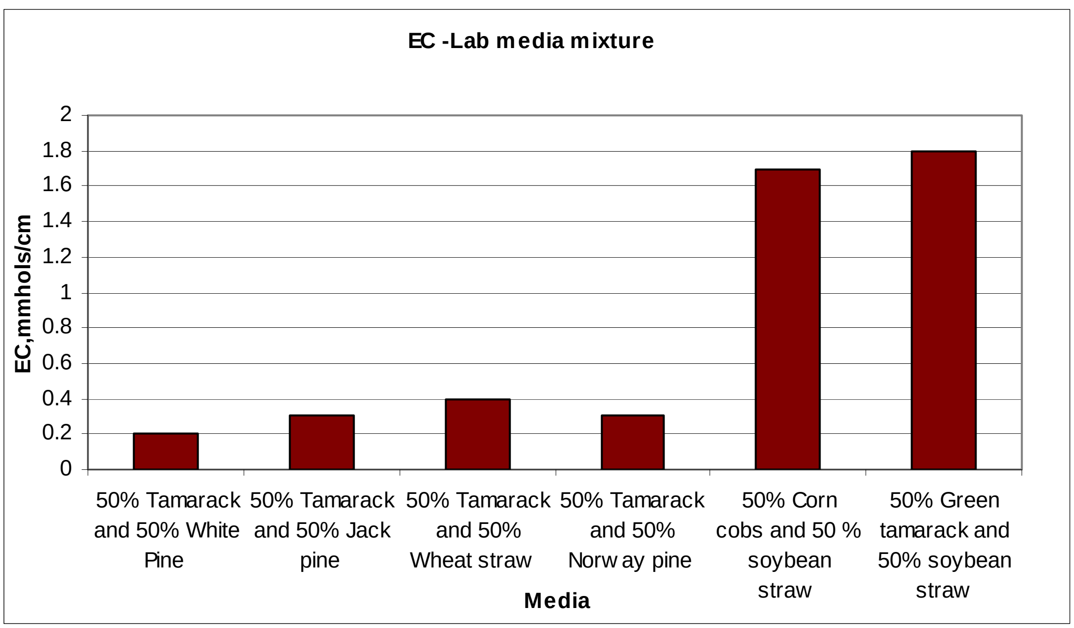

Figure 6: Electrical Conductivity of the lab media mixture

ASH

Ash represents the mineral fraction of the media after all the organic components are oxidized. The lower the ash content, the more organic carbon is in the media (Widmer et.al, 2007). Ash content ranged from 0.26 % for southern yellow pine to 12.25 % for anaerobically digested manure solids. Ash content for wheat straw was high (8.05%) (Figure 7). It should be noted that the ash content and electrical conductance for the wheat straw was high, which indicates a higher amount of silica and minerals in the original media. Ash content for media mixtures with straw as one of the mixes also showed higher ash content when compared to other mixes (Figure 9). Poplar, corn cobs and ash showed the ash content values of 2.5%, 1.38% and 0.74%.

Table(3)in the literature summary section reports values of ash content for soft woods, hard woods, and different types of straws. The authors further obtained values of < 1% ash content for hardwood and softwood. Table (3) reports the ash content for wheat straw to be in the range of 5-9%. Our tests showed the ash content for the wheat straw to be 8.05%, within the range of the reported values. The average ash content of the compost samples from the demo farms was 14.89%.

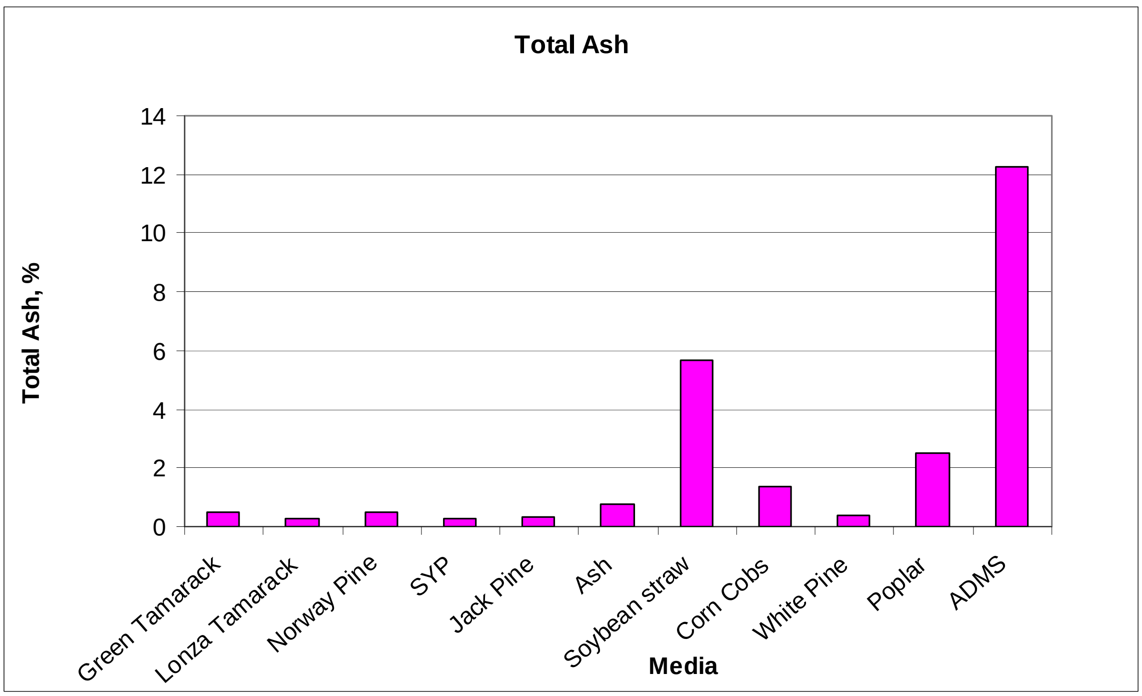

Figure 7: Total Ash of the lab Media

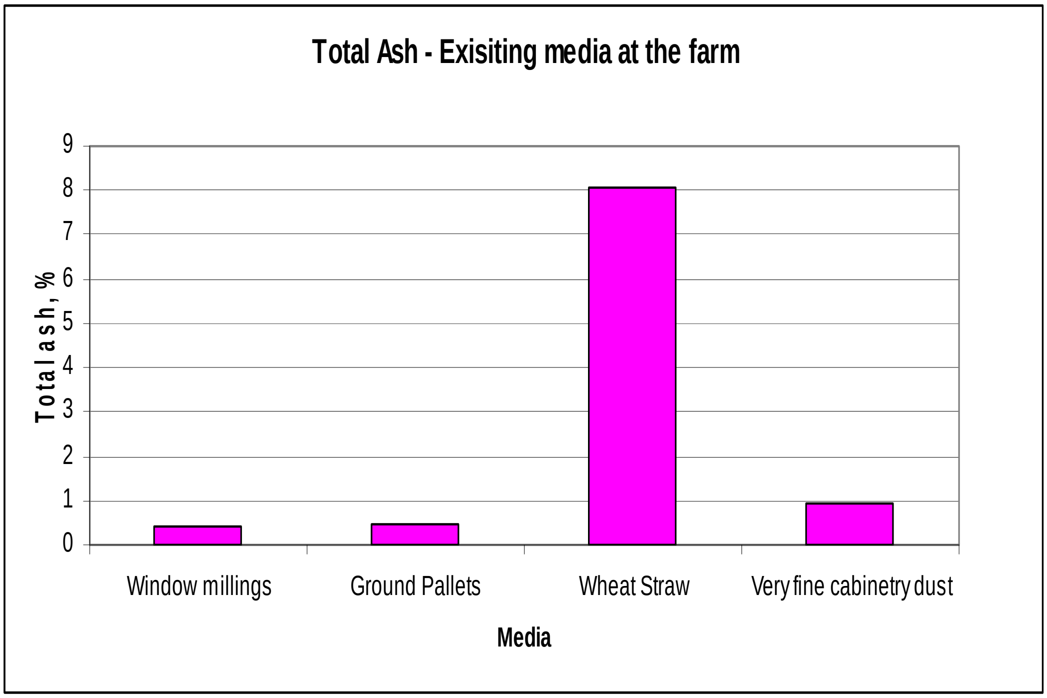

Figure 8: Total Ash of the existing media at the demo farms

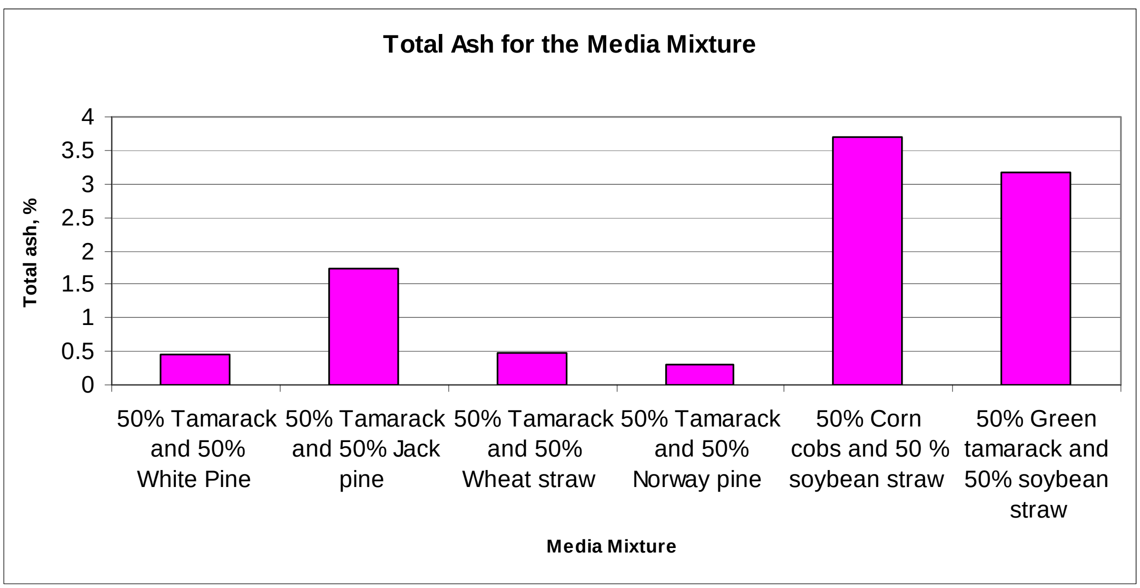

Figure 9: Total Ash of the media mixture

NITROGEN, CARBON AND C: N RATIO

Total nitrogen content for the media was relatively low, less than 2%. Anaerobically digested manure solids showed the highest N content of 1.49 % when compared to other media. The pine products and Lonza tamarack showed the lowest N content (Figure 10). Wood products in general have lower nitrogen content and relatively higher carbon contents, resulting in higher C: N ratios. On the other hand high nitrogen materials like grass will break down readily when compared to wood chips. Bedding with smaller particle sizes retained nitrogen better than bedding with wood chips, long fibers, or wood additives (NRCS Manure management). This was supported by our study, as the N content for one of the existing media in the demo farm (VFCD) showed a highest value of N content of 2.38% and a lower C: N ratio (Figure 13).

The carbon content for most of the media was in the range of 40-55%. Pine shavings and Lonza tamarack showed the highest carbon content, thereby having the highest C: N ratios. Among the lab media mixtures, tamarack with norway pine showed the highest C: N ratio when compared to the other mixtures (Figure 14). The course of decomposition of organic matter is affected by the presence of carbon and nitrogen. The higher the C: N ratio, the longer it will take for the breakdown to occur. Organisms that decompose organic matter use carbon as a source of energy and nitrogen for building proteins and enzymes. They need more carbon than nitrogen, in part because they produce carbon dioxide as they 'burn' these carbon foods. But if there is too much carbon, decomposition slows when the nitrogen is used by the microorganisms, leaving little for the crop (Wayne Schoper, 2008)

The average total N of the bedding materials in all the demo farms was 1.74%, with a range of 0.90% to 2.63%.The average carbon to nitrogen ratio for the compost samples from the demo farms was 26.39:1, which is at the preferred range of 25:1 to 30:1 for composting (NRAES – 54, 1992). Rosen et al., (2000) reported a C: N ratio below 25:1 may emit ammonia odor, which may influence the ammonia levels in the compost barns. When the C: N ratio is too low (too little carbon), nitrogen may be lost in the form of ammonia because the microbes do not have enough carbon to assimilate the nitrogen.

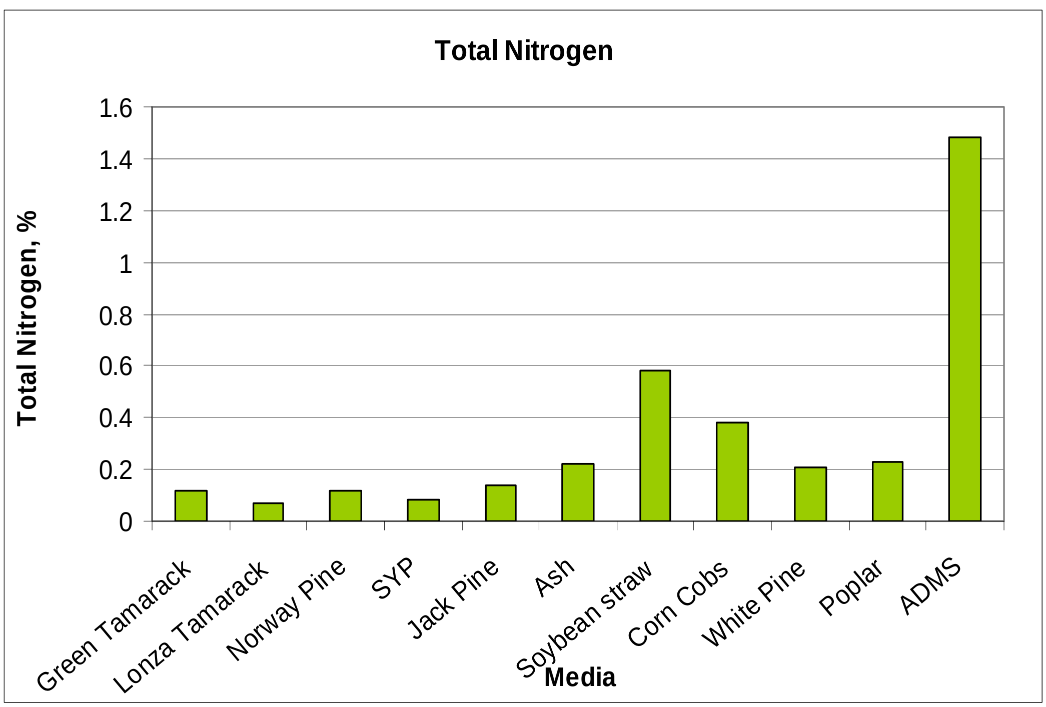

Figure 10: Total Nitrogen of the lab media

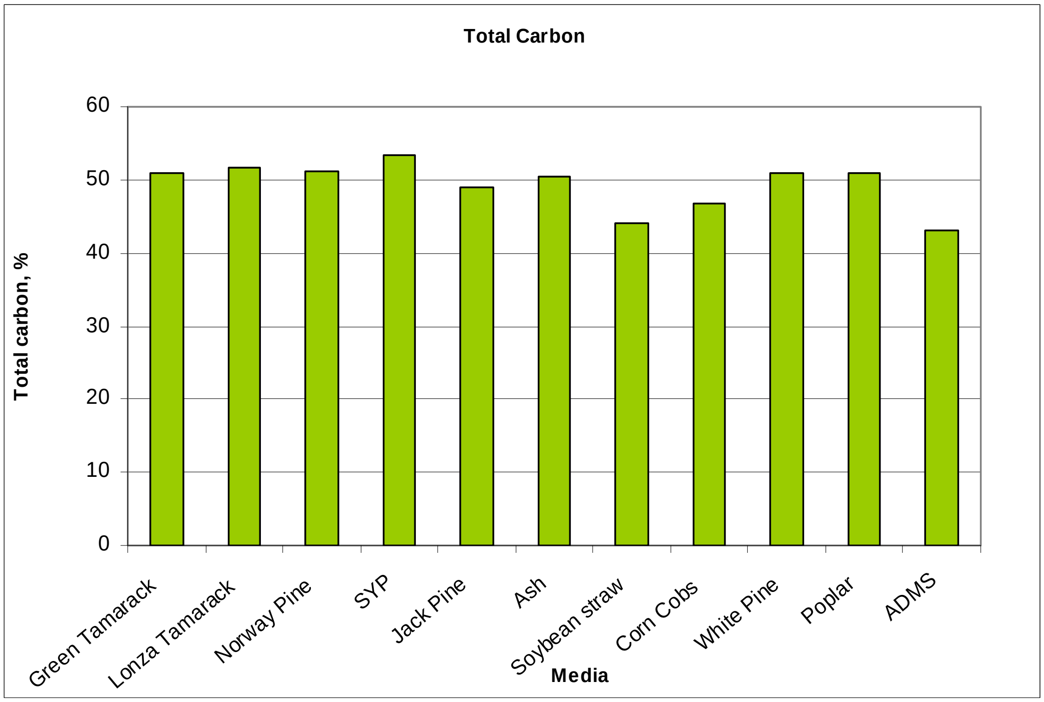

Figure 11: Total Carbon of the lab media

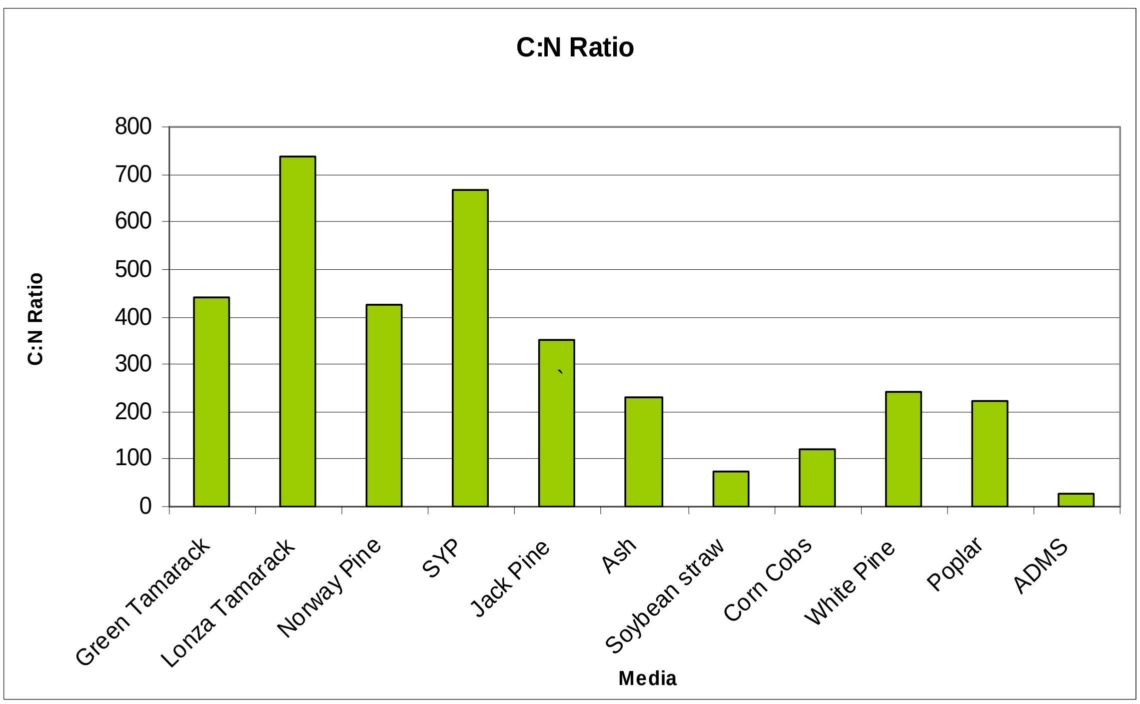

Figure 12: C: N ratio of the lab media

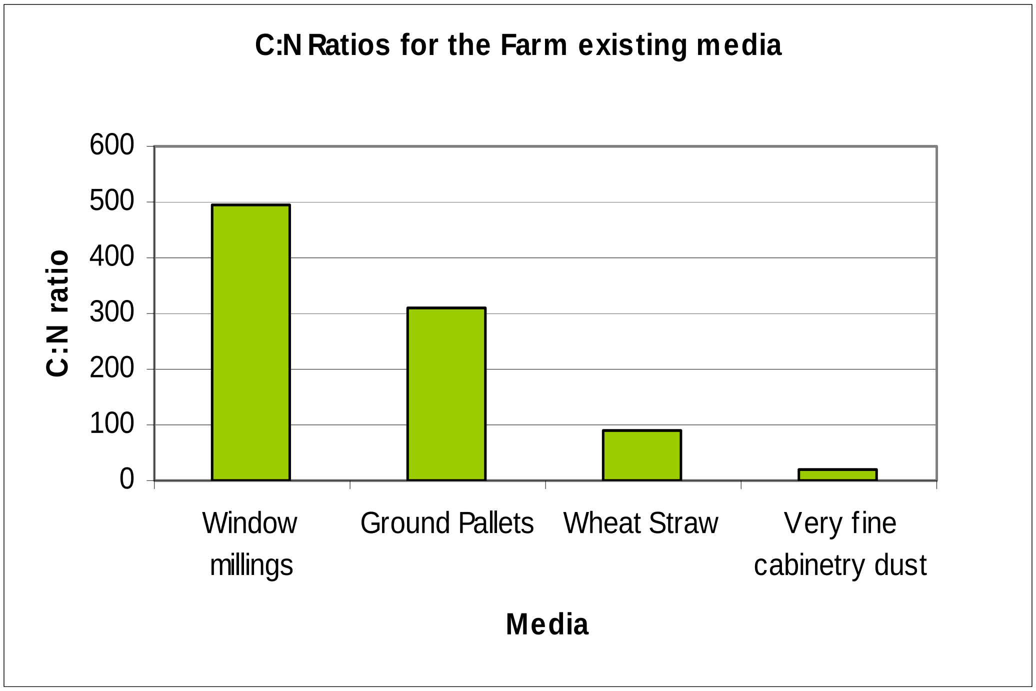

Figure 13: C: N ratio of the existing media at the demo farms

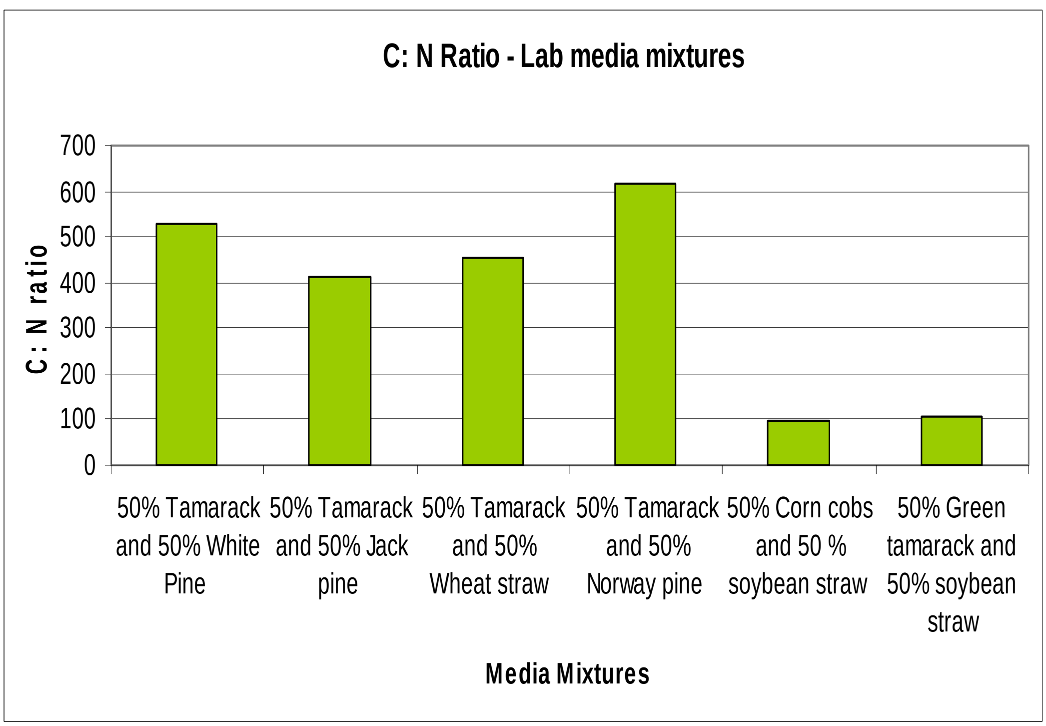

Figure 14: C: N ratio of the lab media mixtures

PHOSPHORUS

Phosphorus is one of the important nutrients needed for microbial growth. It is also considered as one of the primary macronutrients that are required in large quantities by the plants to grow. Phosphorus (P) enables a plant to store and transfer energy, promotes root, flower and fruit development, and allows early maturity. Much of the phosphorus in the finished compost is not readily available for the plant uptake, because it is incorporated in the organic matter.

Straws showed higher values of phosphorus when compared to wood shavings. Phosphorus and potassium was high in anaerobic digested manure solids. The average P of the compost samples from the demo farms was 0.31%, with a range of 0.22% to 0.4%.

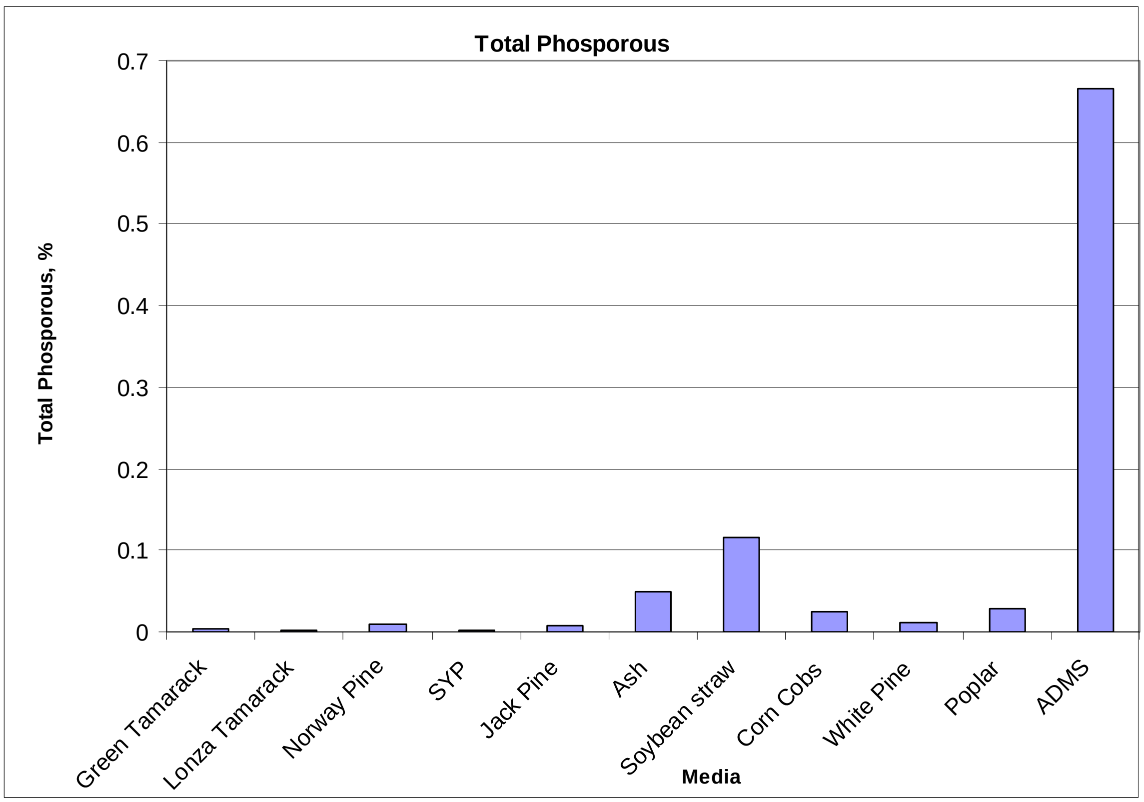

Figure 15: Total Phosphorous of the lab media

POTASSIUM

Potassium in finished compost is much more available for plant uptake than nitrogen and phosphorus, because potassium is not incorporated into organic matter. However, much of the potassium can be leached from the compost, because it is water soluble (Compost use and soil fertility – Frank Mangan et al. 2000).The average potassium of the compost samples from the demo farms was 2.01% with a range of 0.87 % to 3.73 %.

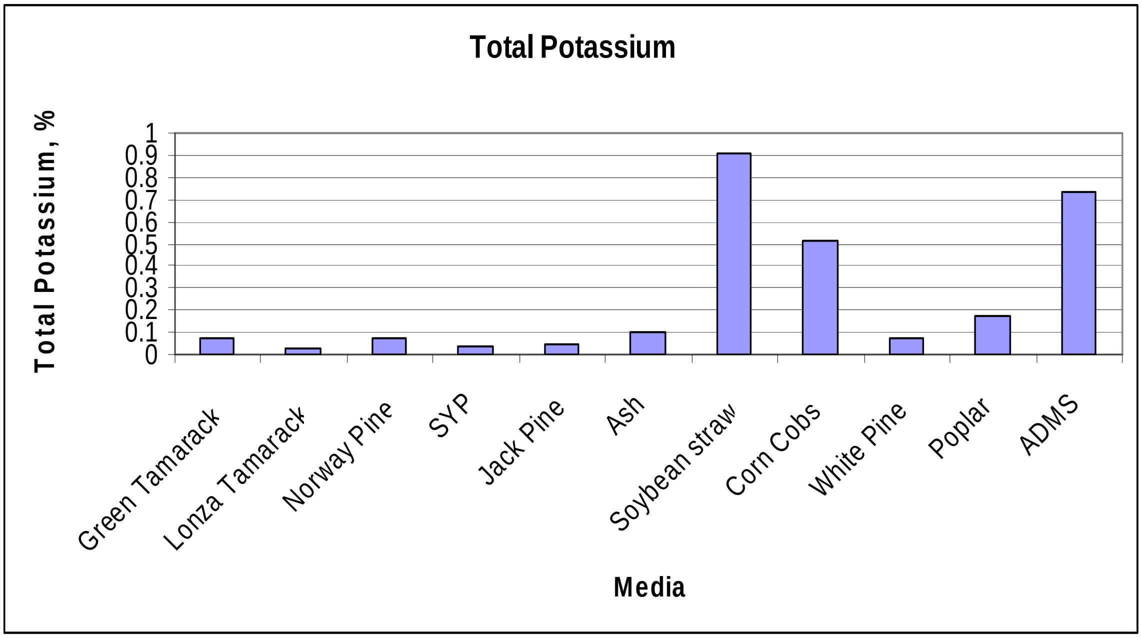

Figure 16: Total Potassium of the lab media

BULK DENSITY

Bulk density is an important characteristic that influences directly the cost of feedstock delivery and storage cost. It also impacts storage requirements, the sizing of the material handling system and how the material behaves during the subsequent processing. The engineering design and operation of transport equipment, storages, and conversion processes depend on bulk density and flow characteristics of feed stock (P.S Lam et al., 2008). One obstacle to agricultural fiber utilization for relatively low-value products is low bulk density. Low bulk density increases transportation costs significantly. A standard cord contains 3.6 m^3 of volume of which approximately 2.1 m^3 is wood. This yields a gross bulk density (dry basis) of 240 to 320 kg/m^3. The economics of processing and transporting small-diameter timber with such bulk density dictates a practical procurement radius of about 65 km. In contrast, stems of annual plants such as kenaf or small grain straw cannot be compacted much beyond 135 kg/m^3, which limit the feasible supply pool to a range of 25 to 35 km (Youngquist et al., 1993). The same is true for bedding material; the bulk density will affect the radius of an economical delivery.

Very fine cabinetry dust, used at one of the demo farms showed the highest bulk density, followed by ash, ground pallets (used at another farm) and southern yellow pine. The bulk densities were 296 kg/m^3, 258 kg/m^3, 207 kg/$m^3$and 188 kg/m^3 respectively(Figure 17). This implies that these can be transported longer distances than the lower bulk density media. Different straw, pine chips, tamarack, poplar and anaerobically digested manure solids showed lower bulk densities comparatively. The wet bulk density determined at two of the farms were 855 kg/ m^3 (Depth 15 cm) and 975kg/m^3 (Depth 60 cm). Dry bulk densities at the same depths were 405kg/m^3 and 325kg/m^3 respectively.

Earlier studies have seen that compaction played a significant role in increasing the bulk density of straw, which in turn helped in the transportation cost of the media. The effect of compaction pressure on bulk density for larger particles was more than the smaller particles, because smaller particles are closely packed leaving less space among the particles (Mozammel H et al., 2006)

Media mixture with 50 % soybean straw (6mm size) and 50% corn cobs (6mm size) had the highest bulk density (142 kg/m^3) than the other dry lab mixtures The remaining mixtures; tamarack and white pine, tamarack and jack pine, and tamarack with norway pine had comparatively lower bulk density and were similar. Mixture with 50 % tamarack and 50% soybean straw showed the lowest bulk density compared to the other media mixtures (Figure 18).

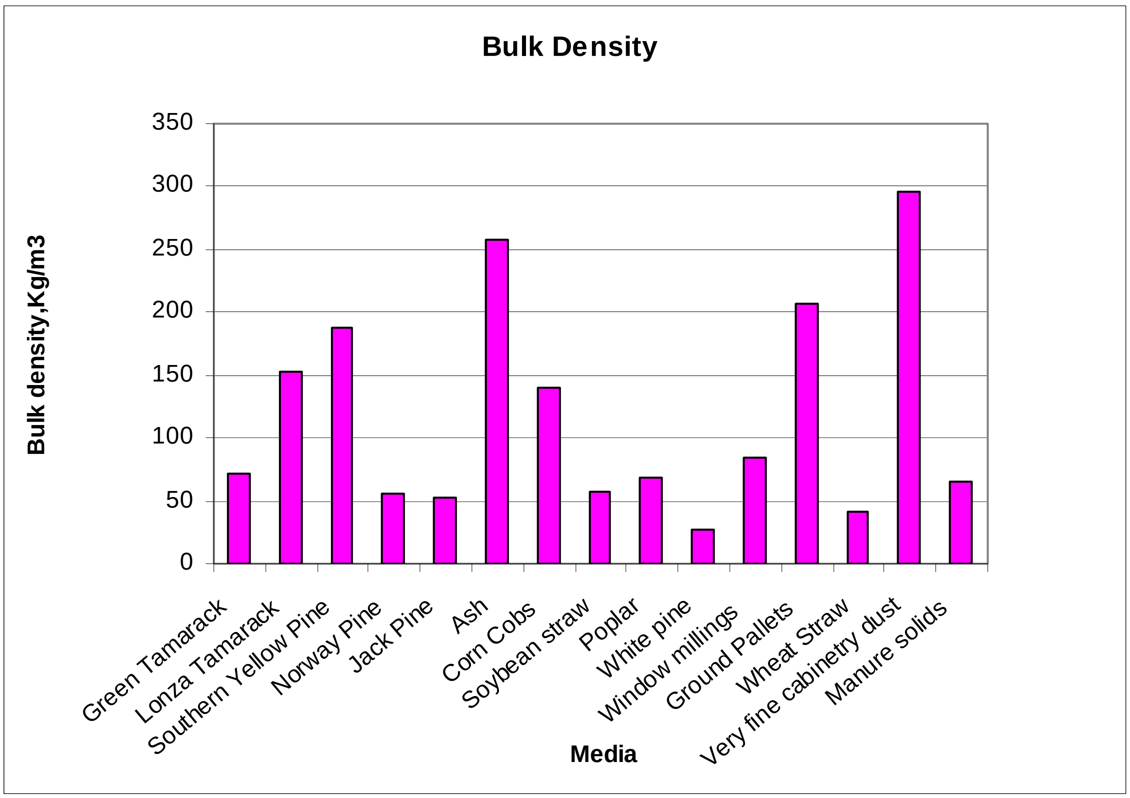

Figure 17: Bulk Density of dry lab media and the existing media at the demo farms

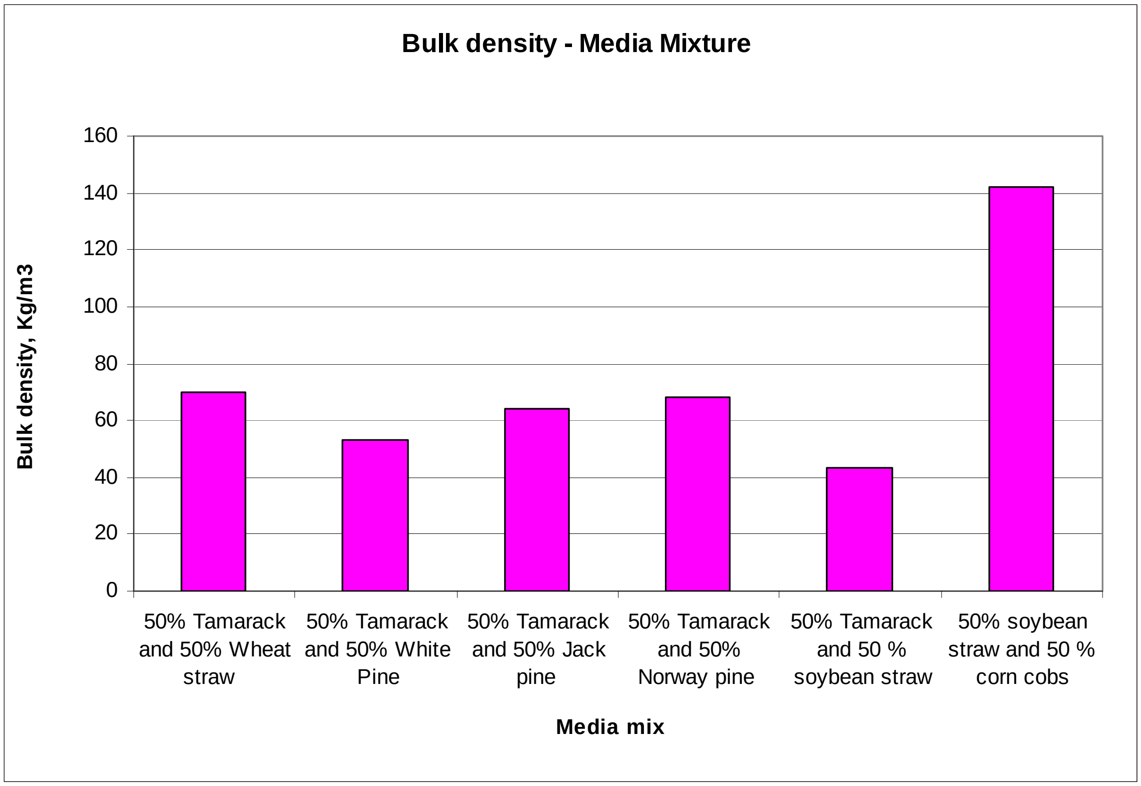

Figure 18: Bulk Density of the dry lab media mixture

WATER HOLDING CAPACITY (WHC)

Water holding capacity (WHC) provides information on the amount of water that can be absorbed by the bedding material. High water holding capacity allows the media to absorb water into the bedding. However, depending on the cell structure of the media, high water content in the cell can sometimes lead to rupture of the cell which results in the media releasing free water. This limits the media's ability to function as a bedding material for longer periods of time.

Anaerobically digested manure solids had the highest water holding capacity value of 572.4% followed by very fine cabinetry dust, wheat straw and white pine. 12.5 mm ash and ground pallets (existing demo farm media) had the lowest WHC of 52% and 102.2%. Current research focused on how mixing straw with other wood chips would affect the WHC. Media mixtures; 6mm Tamarack with 6 mm soybean straw and 6 mm tamarack with 6 mm wheat straw had WHC values of 102.4 % and 162.4 %; which is within the range of 100-250%. Mixing wood chips with the straw lowered the WHC when compared to using straw itself as a bedding media. Other media mixtures – 6 mm corn cob with 6 mm tamarack showed a WHC of 211%, 2mm southern yellow pine with 6mm tamarack – 221.5%,12 mm ash with 6mm tamarack showed a WHC value of 126.4% and 6 mm corn cobs with 6mm soybean straw showed the highest WHC of 242.3% as seen in the (Figure 20).

There appears to be a balance between the physical structure of the media and the WHC. If the cell wall breaks down too quickly free water is released.

Straws of all kind have a moderately high WHC and less physical structure to withstand compaction in the pack compared to wood chips (Frans Vokey, Pro-Dairy, 2008).
Water holding capacity for media with different particle sizes was also determined. It was observed that the WHC increased with decrease in the particle size of the media (as evident from the Figure 21). 0.425 mm size corn cobs showed the highest WHC when compared to 25mm, 12mm, 6mm, 2mm and 1mm corn cobs. Corn cobs had the highest water holding capacity in all different sizes followed by tamarack and ash. It can be seen from the graph corn cobs had the ideal WHC of 100 – 250% when its size was 25mm, 12mm, 6mm and 2mm. Although fine particles have higher water holding capacity, health issues for humans and animals due to dust as well as air quality issues in the barns should be taken into consideration. Particles passing a 1 mm screen are of concern as fines measuring less than 10 μm and particularly less than 2.5 μm have been reported to irritate and cause hyperactive airway disease conditions to both humans and animals. It is even important to avoid bedding materials that contain large amounts of fines (P.L. Ward et al., 2000)

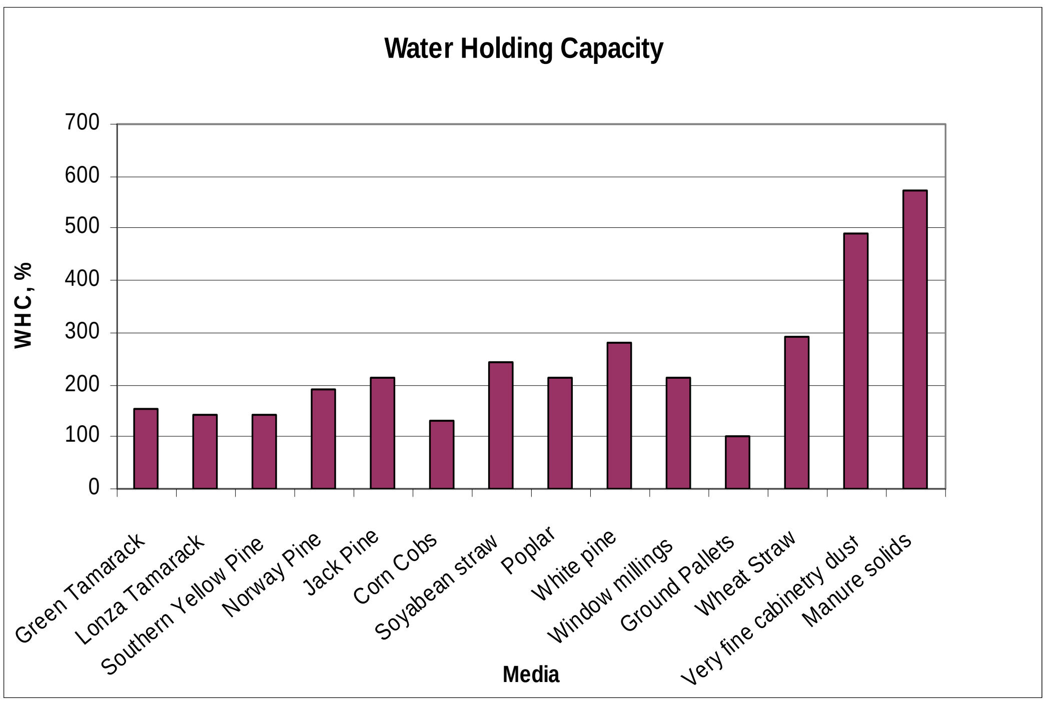

Figure 19: Water Holding Capacity of the oven dried media, not sorted to specific particle size.

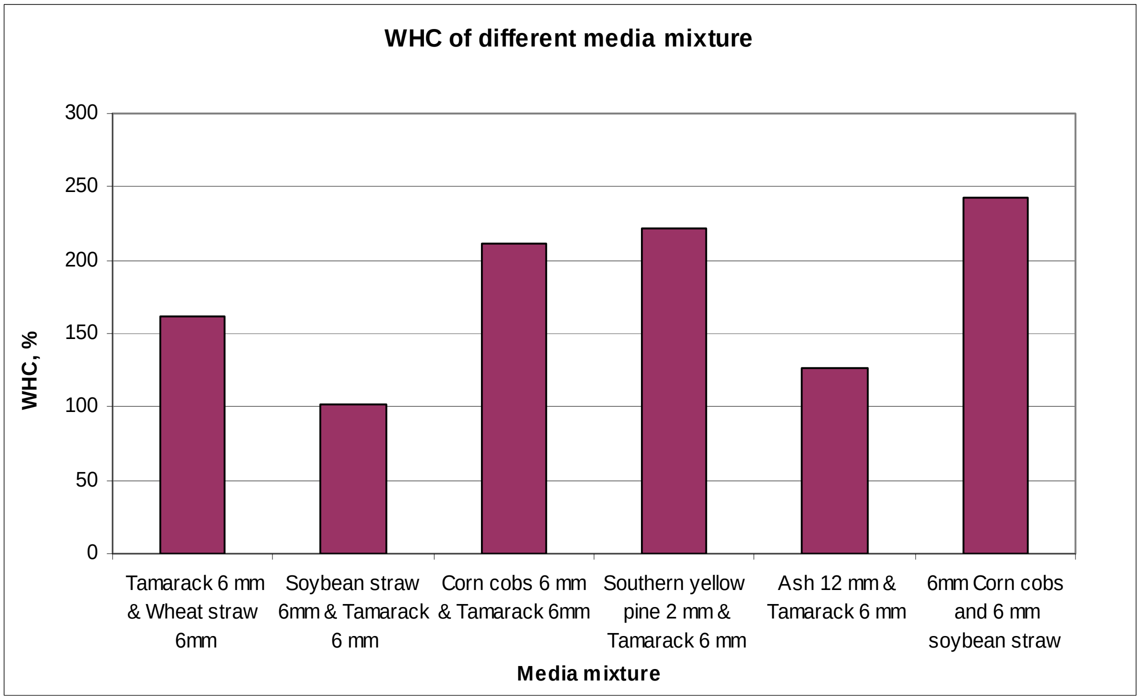

Figure 20: Water Holding Capacity of the oven dried lab media mixture

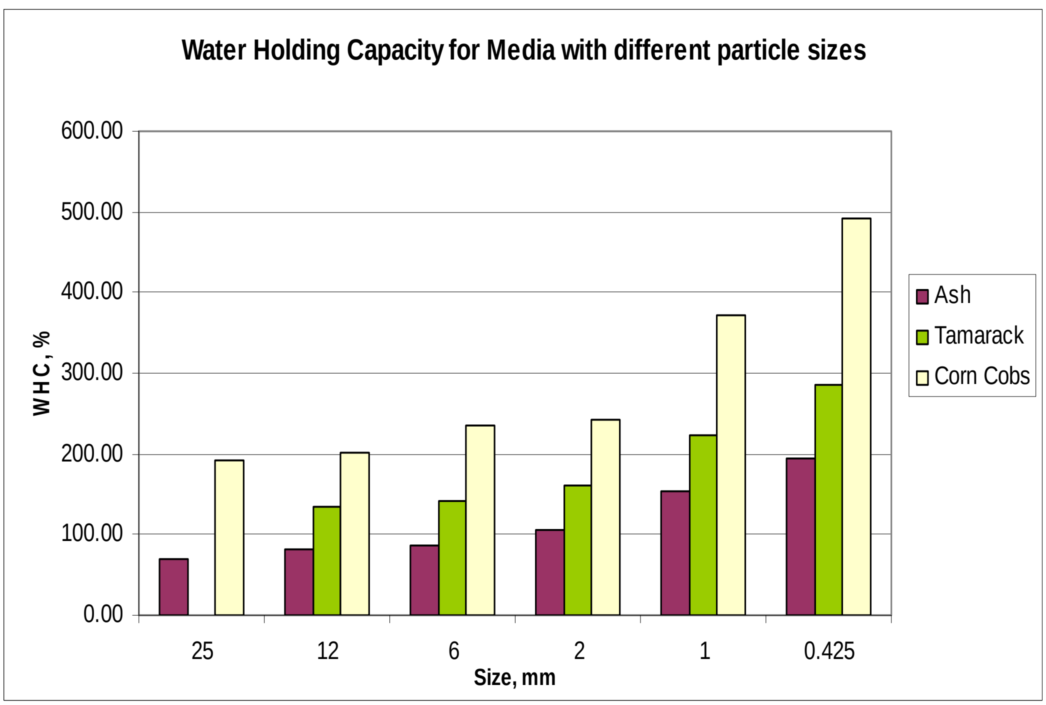

Figure 21: Water Holding Capacity for media with different particle sizes

LIGNIN CONTENT

Plant cell wall material is composed of three important constituents: cellulose, hemicelluloses and lignin. Lignin is one of the main constituents of plant cell walls, and its complex chemical structure makes it highly resistant to microbial degradation (Richard, 1996). Because lignin is the most recalcitrant component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate. The effect of lignin on the bioavailability of other cell wall components is thought to be largely a physical restriction, with lignin molecules reducing the surface area available to enzymatic penetration and activity (Haug, 1993).

Lignin content for most of the media ranged between 29-32%. Southern yellow pine showed the highest lignin content of 32%. Most of the pine shavings showed higher lignin content (Figure 22). Since they have significant amount of lignin, it will help resist microbial breakdown and would last longer than the other bedding materials. Corn cobs and soy bean straw had the lowest lignin content values when compared to other media and therefore are more likely to be microbially broken down more quickly than the media with higher lignin content.

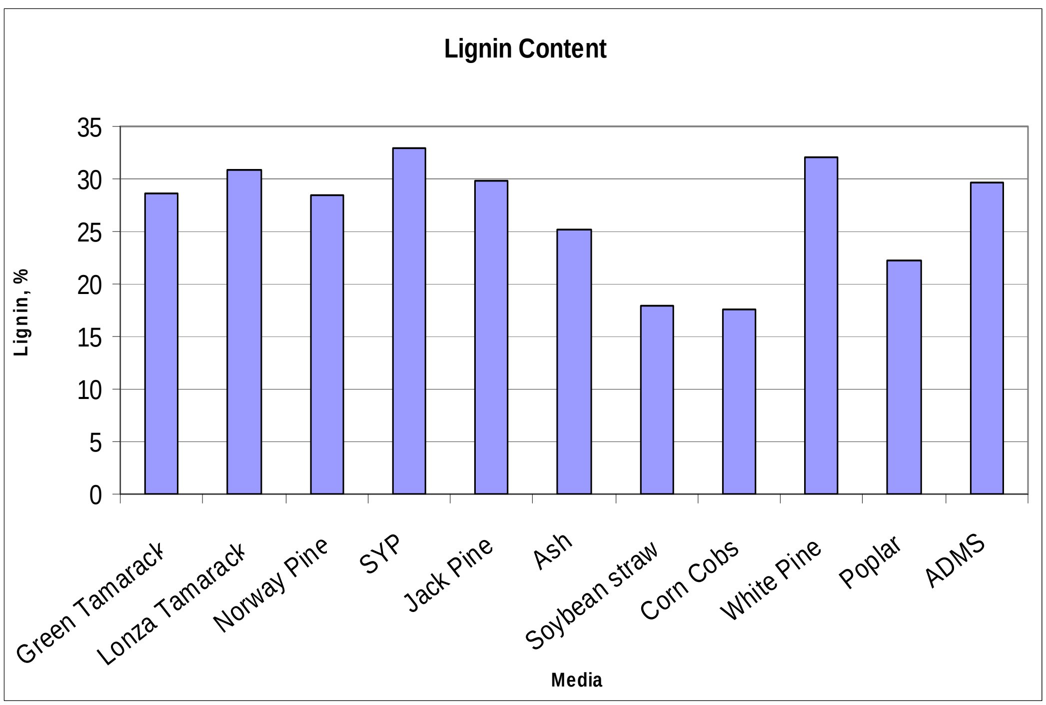

Figure 22: Lignin content for the lab media

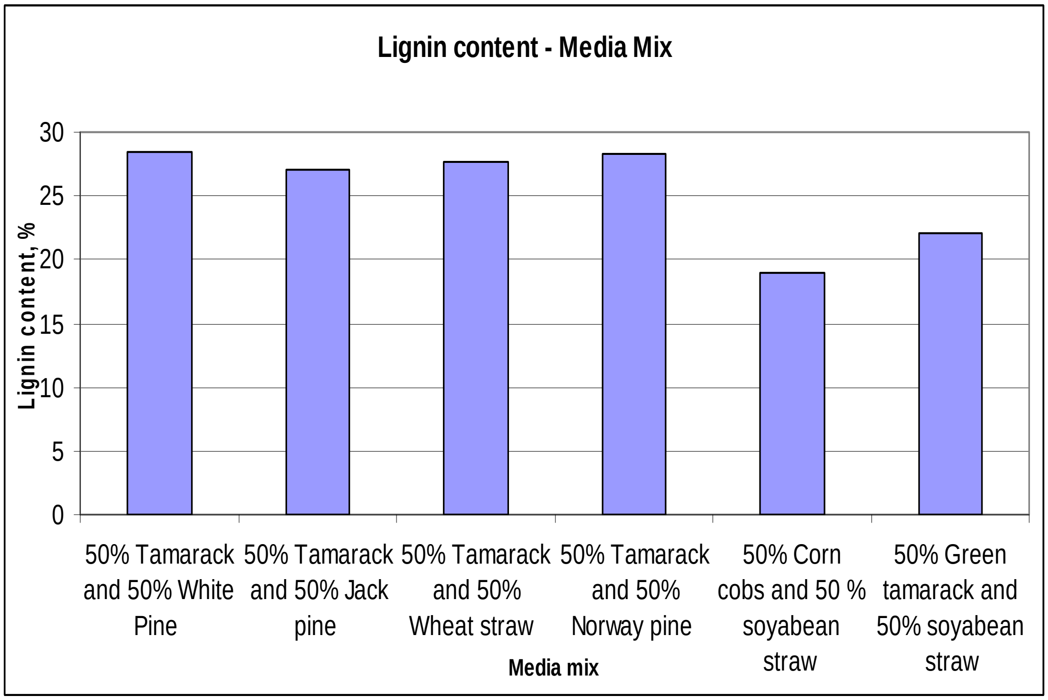

Figure 23: Lignin content for the lab media mixture

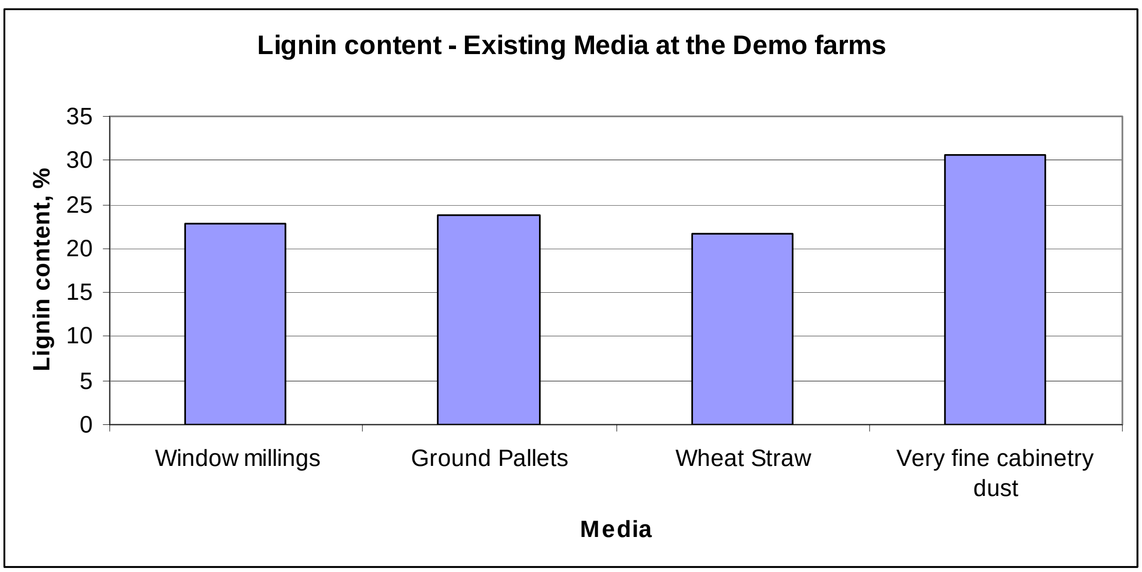

Figure 24: Lignin content for the existing media at the demo farms

Lignin content of the media mix was also determined. As seen from the figure, lignin content for the media mix also ranged between 20-30%. Corn cob and soybean straw mix showed a lower value when compared to other mixes. The average lignin content for the compost samples from the demo farms was 28.1% with a range of 21.3 % to 33.2%

METALS

Media was also tested for the US-EPA 503 metal concentrations. These elements were measured using the inductively coupled plasma (ICP) method (Munter, 1990). The media was tested for the following metals – Aluminum (Al), Boron (B), Calcium (Ca), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Potassium (K), Magnesium (Mg), Manganese (Mn), Sodium (Na), Nickel (Ni), Phosphorous (P), Lead (Pb) and Zinc (Zn). It was observed that these metal concentrations on the media tested were below the standard limit (USA-EPA, 40CFR– 503)

PARTICLE SIZE DISTRIBUTION

Microbial activity generally occurs on the surface of the organic particles. Therefore, decreasing particle size, through its effect of increasing surface area, will encourage microbial activity and increase the rate of decomposition. On the other hand, when particles are too small and compact, air circulation into and through the pile is inhibited. This decreases oxygen available to microorganisms within the pile and ultimately decreases the rate of aerobic microbial activity. Particle size also affects the availability of carbon and nitrogen. Large wood chips, for example, provide a good bulking agent that helps to ensure aeration through the pile, but they provide less available carbon per mass than they would in the form of wood shavings or sawdust (Cornell Composting, 1996). Optimum size is very material specific

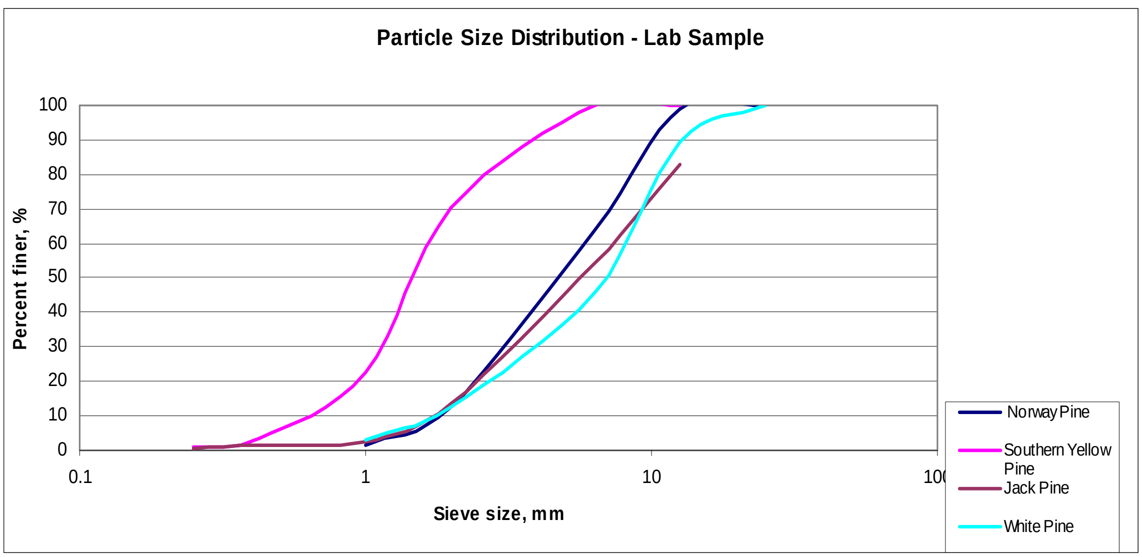

Figure 25: Particle size distribution for the lab media

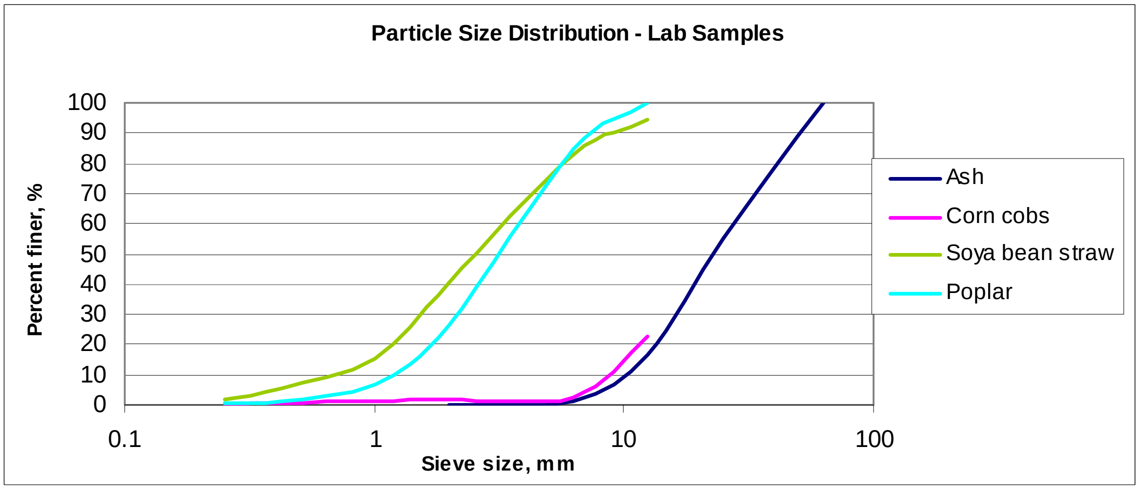

Figure 26: Particle size distribution for the lab media

Figure 27: Particle size distribution for the compost samples collected from the demo farm 1

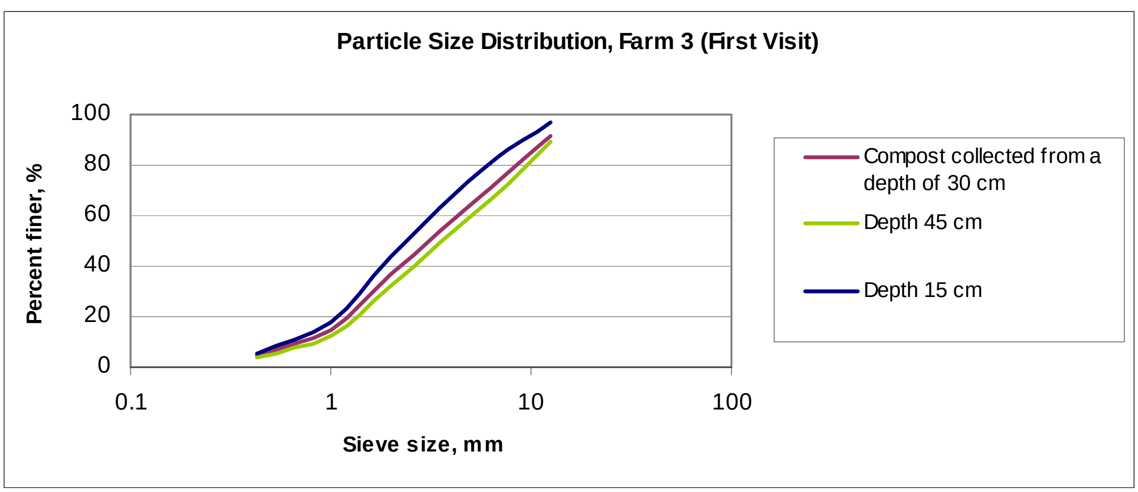

Figure 28: Particle size distribution for the compost samples collected from the demo farm 3

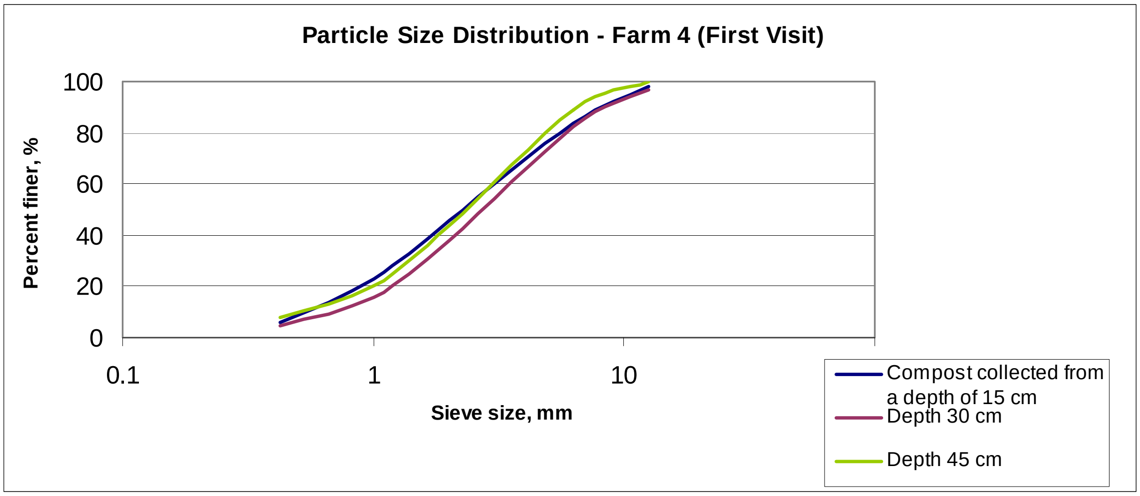

Figure 29: Particle size distribution for the compost samples collected from the demo farm 4

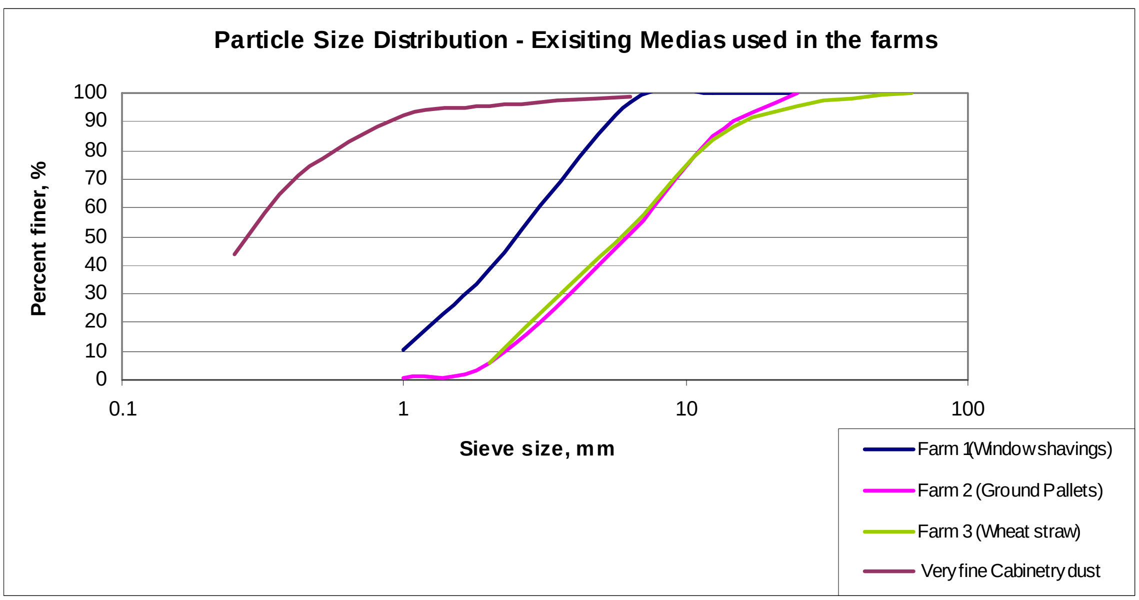

Figure 30: Particle size distribution for the existing media used in the demo farms

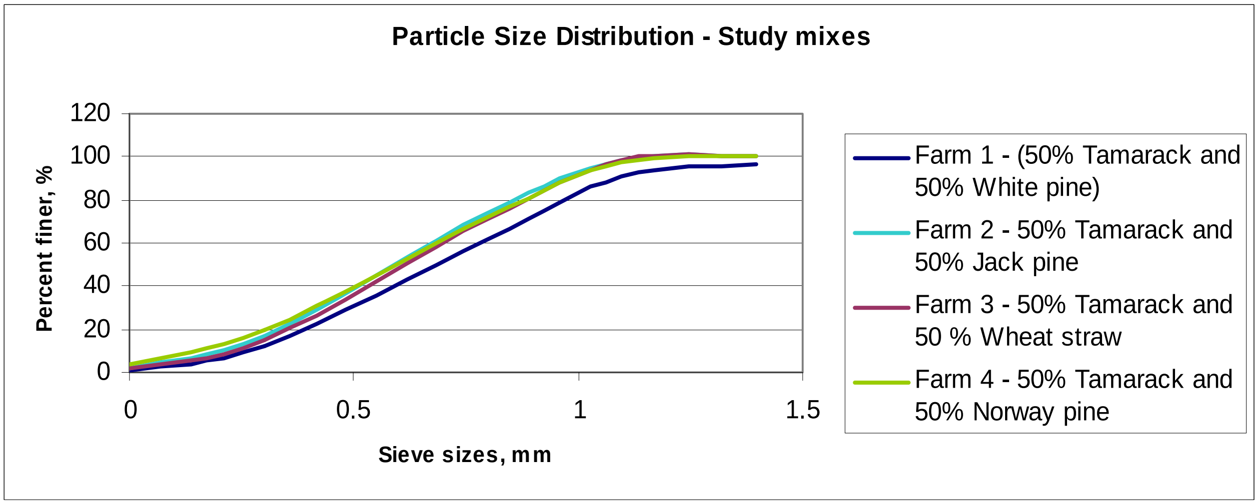

Figure 31: Particle size distribution for the lab media mixture

TEMPERATURE, OXYGEN AND MOISTURE CONTENT

Maintaining appropriate balance of oxygen, moisture, temperature, amount of organic matter, size and the activity of the microbial population is the key as to how well a compost bedded pack works.

Achieving high temperatures within the pack is important to kill pathogen and keep the surface dry. Temperature is directly proportional to the biological activity within the compost bedded pack. As the metabolic rate of the microbes accelerates; the temperature within the bedded pack increases. Maintaining a temperature of 55°C (131°F) or more for 3 to 4 days favors the destruction of weed seeds, fly larvae, and pathogens and coverts organic matter into compost that is odor and pathogen free (University of Minnesota – Dairy Extension). If the pack is not aerated, it will become anaerobic causing the decomposition rate to slow and temperatures to drop. The pack will lose some of its ability to kill pathogens due to the shift from aerobic to anaerobic and may also create unpleasant odors. Figure shows the temperatures recorded at depths 15 cm, 30 cm and 45 cm for the four farms at six different locations in the barn. As seen from the figures (Figure 32-37), there is a variation in the temperatures with respect to the location as well as depth. Temperature variation in different locations in the barn could be explained based on the intensity of the cows in those locations and how well the pack is aerated. Generally, higher temperatures are observed when the pack is fluffy and aerated as air promotes aerobic microbial activity. Pack areas with excessive moisture and compaction have reduced temperatures.

Table (12) reports the average temperatures at three different depths for the farms.

Oxygen is an essential element required by the composting microorganisms in order to generate adequate heat during the composting process. Aeration is the key to prevent anaerobic conditions in the bedded pack which slows the decomposition rate. Anaerobic decomposition does not reach the temperature necessary to kill pathogens as quickly and creates unpleasant odors. (Figure 38) shows the oxygen concentration at different locations and depths. It can be seen with the increase in depth the oxygen concentration also decreases. Below the tillage depths most of the farm packs were at 0% oxygen content.

Moisture, provided by manure, urine and microbial activity of the pack should be between 40% and 65 % for good composting condition. When the moisture is too low, the microbes won't have enough water, the compost will be too cool, and the rate of composting will slow down. If the moisture levels are too high, the pack becomes anaerobic; rate of microbial decomposition will be slow which again slows the composting process. The moisture content of the bedding material ranged from 50% to 60% across three depths in all the barns. The average moisture content across all the barns was 59.69% within the recommended range for composting of 50% to 60% moisture (NRAES-54, 1992). The moisture content can vary based upon the time since last addition of fresh bedding, weather, and cow density in the sampling area (Barberg A.E et.al 2007). Moisture content of other media was also tested. Anaerobic digested manure solids showed the highest moisture content of 72%, followed by ash (30%) and green tamarack (24%) - Figure 39. Lonza tamarack, pine shavings, poplar, corn cobs and soybean straw showed moisture content values 6% - 18%. Lab media mixtures showed moisture contents ranging 8% to 13% (Figure 40). Cows prefer lying on drier bedding. So the requirements for good composting must be balanced against cow comfort. Demonstration farms seemed to add new dry media when the surface had more than 61% moisture.

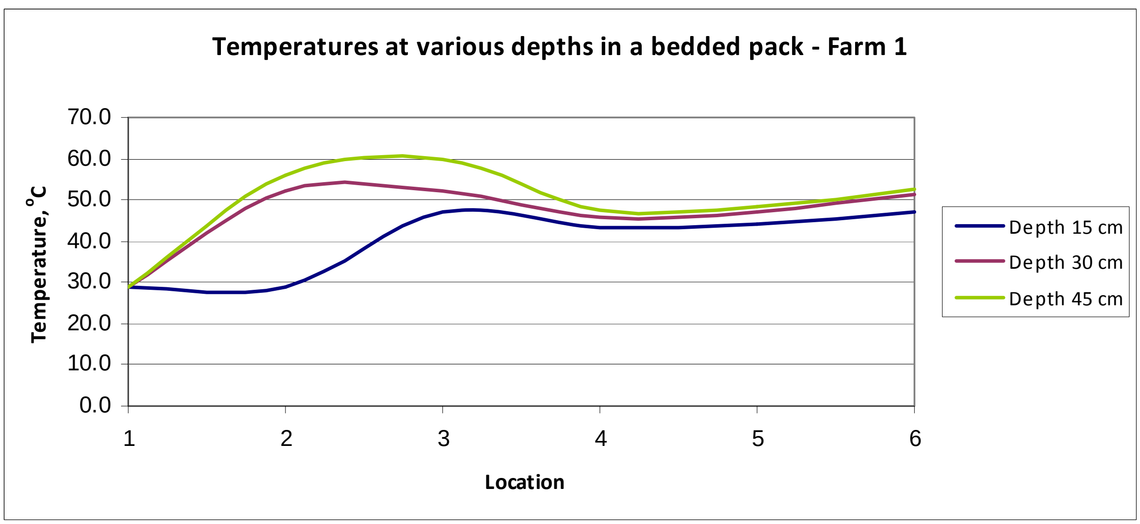

Figure 32: Temperature at various depths in a bedded pack

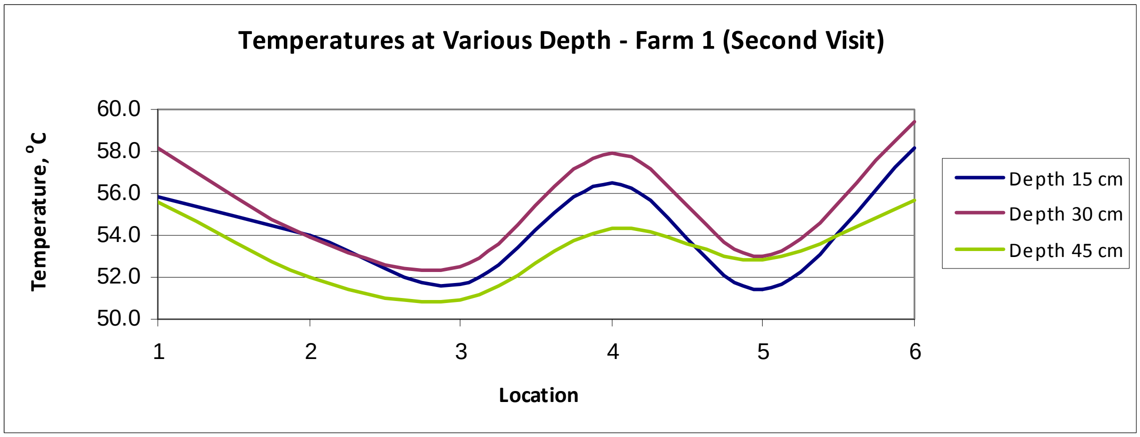

Figure 33: Temperature at various depths in a bedded pack

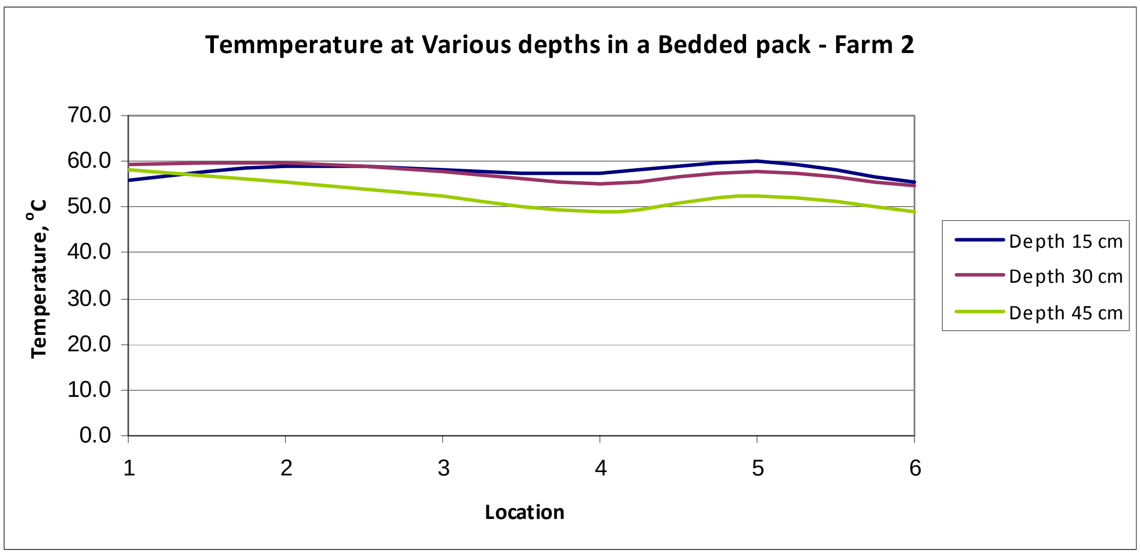

Figure 34: Temperature at various depths in a bedded pack

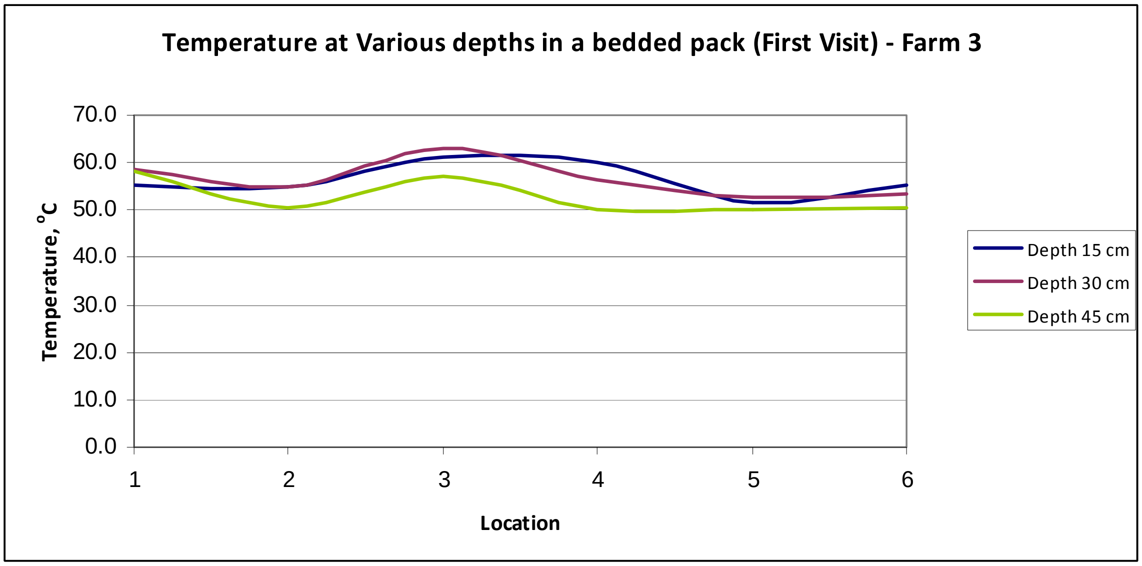

Figure 35: Temperature at various depths in a bedded pack

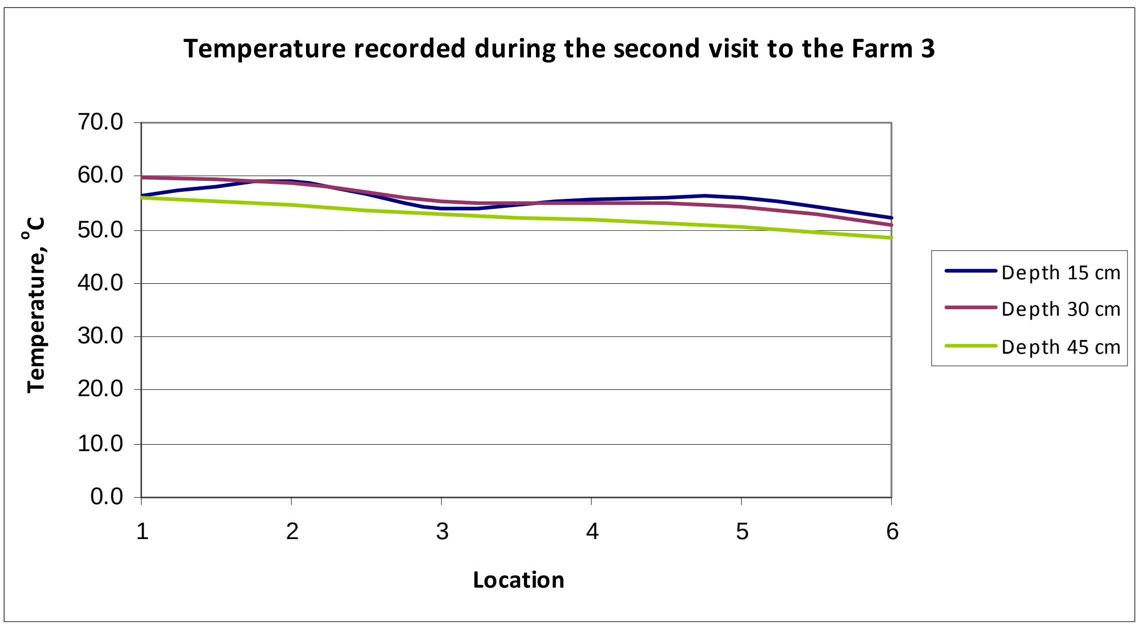

Figure 36: Temperature at various depths in a bedded pack

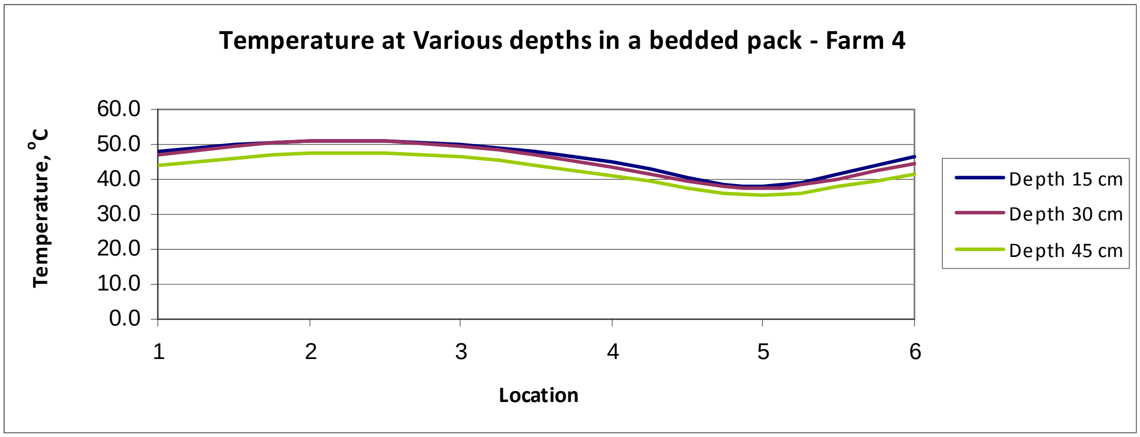

Figure 37: Temperature at various depths in a bedded pack

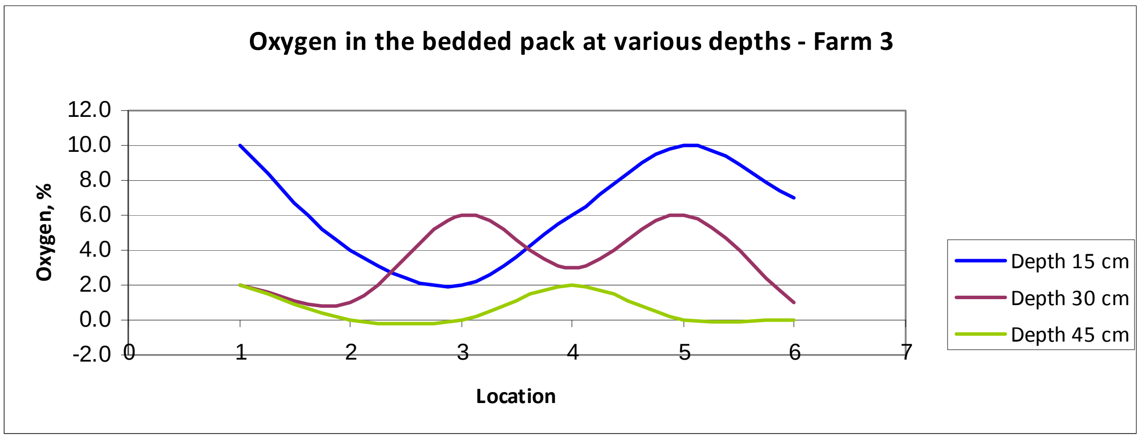

Figure 38: Oxygen at various depths in a bedded pack

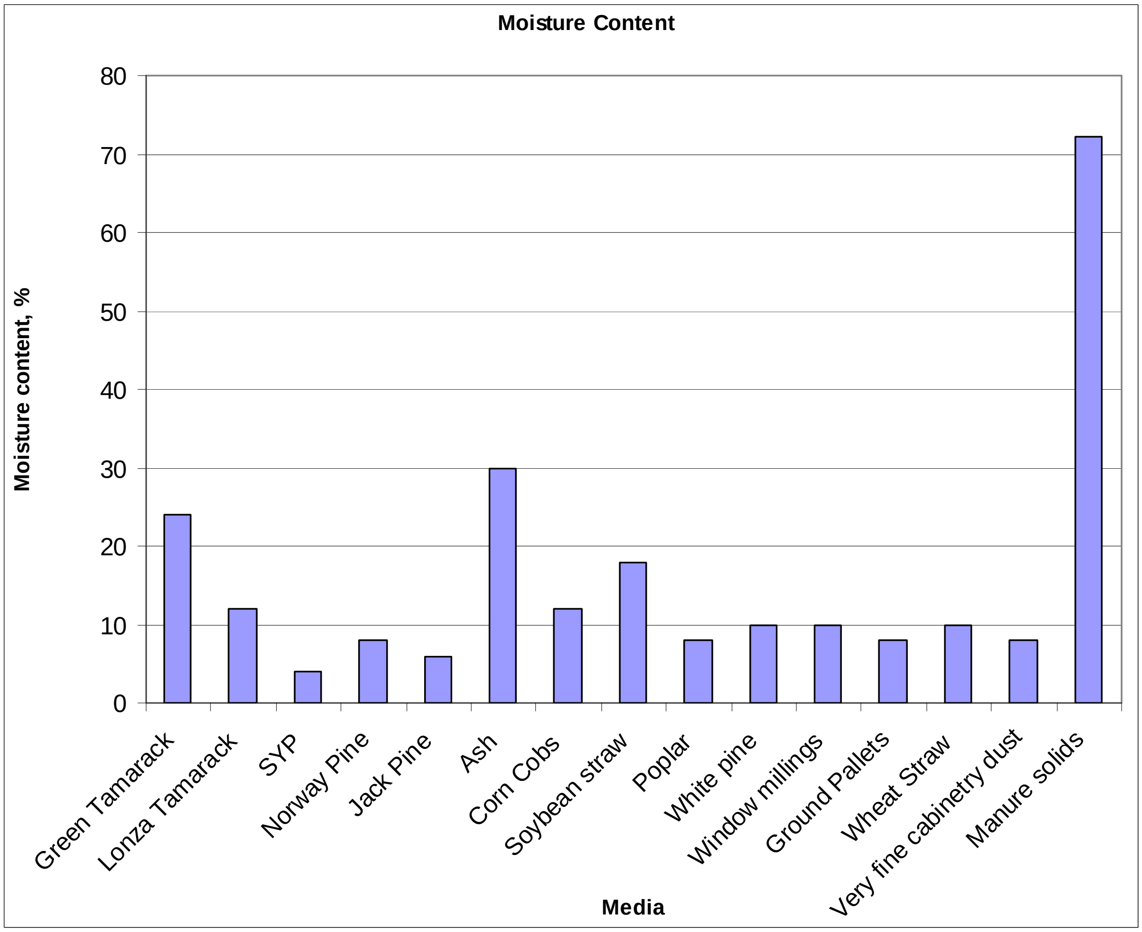

Figure 39: Moisture content of the lab media

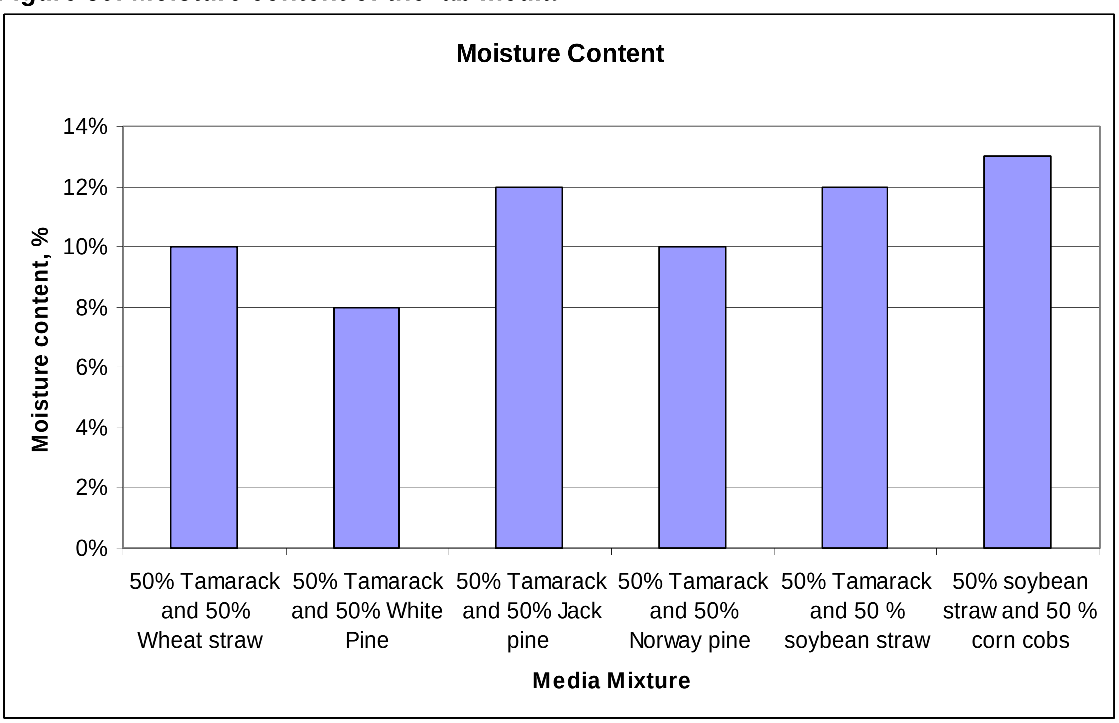

Figure 40: Moisture content of the lab media mixtures

CONCLUSIONS

Success of compost bedded pack depends upon proper pack management. Three important factors that have to be understood are the economics, availability of the media and the performance of the media. Various parameters such as moisture content, water holding capacity, physical structure and particle size distribution, oxygen content and pH of the media are important parameters that have to be taken into consideration.

Media/media mixtures with lower moisture content should be initially used in the pack. For good composting moisture content of the pack should be between 50%-60%. When the moisture is too low, the microbes won't have enough water, the compost will be too cool, and the rate of composting will slow down. If the moisture levels are too high, the pack becomes anaerobic; rate of microbial decomposition will be slow which again slows the composting process (Jeffrey Bewley 2009). Particle size of the media is an important parameter that influences the water holding capacity, rate of microbial activity and aeration within the pack. The fine particles improve handling, mixing, aeration and composting (Compost Barn Basic, Kevin A. Janni and Jeff Reneau, 2005), while larger particle sizes increase gas exchange and surface drying. Of all the parameters, compost dairy bedded pack is mostly about holding water in the media. Each kind of media will hold the most water when it starts out as dry as possible.

As a practical matter, media at 7%-10% moisture content works better than higher initial moisture contents. Our study showed the lab media that had the initial moisture content within the above mentioned range were Norway pine (8%), poplar (8%), Jack pine (6%), southern yellow pine (4%), white pine (10%),corn cobs and Lonza tamarack (both at 12%). Lab media mixtures (Mixtures of tamarack with pine shavings; mixtures of tamarack with soybean straw and mixtures of soybean straw and corn cobs) also showed moisture contents ranging from 8% to 13%. Some media up to 18% moisture content worked well. Media that has more than 18% moisture content costs will have more handling and transportation cost and does not last long in the pack. Most compost dairy bedded pack farms have to add additional media when the media gets more than 61% moisture content. Dry media holds more water than wetter media and is therefore worth more money to the dairy farmer.

Water holding capacity of the media within the pack is important. Water holding capacity increased with decreasing particle size. Our study also showed that the finest media; VFCD showed the highest water holding capacity. But even though it had higher water holding capacity, health issues for humans and animals due to dust as well as air quality issues in the barns should be taken into consideration. There has to be a balance between WHC and acceptable levels of dust. Mixing fine particles with wood shavings can be an option to reduce dust. Straws of all kinds showed moderately high water holding capacity, but since they have less physical structure to withstand compaction, it could be used in combination with wood products. Mixtures of 6mm tamarack with 6 mm soybean straw and 6mm tamarack with 6 mm wheat straw performed well. Although mixing media improves various parameters essential for composting in a bedded pack, it should be noted there is an additional mixing cost of $7-$10 per ton for each additional media to be thoroughly incorporated into the media mix before installing in the barn. The benefits of mixing two or more different media into a compost bedded pack system has to be balanced as to the additional costs involved in mixing and storing the media mixes.

Lignin content of the media also plays an important role as it provides resistance to microbial break down, which makes it last longer. Green tamarack, Lonza tamarack, pine products, and poplar showed higher lignin content when compared to corn cobs and straws. Mixing wood products with straw comparatively increased the lignin content. Media mixture of tamarack and wheat straw showed a comparatively higher lignin content value when compared to wheat straw alone and therefore lasts longer before media break down occurs.

A pH range of 5.5 to 7.8 is within acceptable parameters of bedding material for CDB. A slightly acidic pH helps limit the ammonia loss from the bedding thus conserving N (Misselbrook & Powell, 2005; Tiquia et al., 2002; Lory et al., 2002; Eiland, 2001). In general media with lower initial pH consume N better than the higher pH media.

The oxygen content of the entire pack should be between 12% and 16% to reduce odors and increase temperatures to above 55 degree centigrade (Widmer et.al, 2007). The pack should be tilled two to three times a day or at each milking to ensure aeration in the pack. Aeration is essential to incorporate oxygen for aerobic decomposition and provides a fresh surface for the cows to lie down. Aeration within the pack is dependent on the physical structure and particle size of the media. Fine coarse media provides a large surface area to volume ratio is easier to till and holds water well. Additionally, shavings, shredded wood pieces or coarse sawdust have enough structure to be easily stirred and remain fluffy enough for the oxygen transfer within the bedding material. Aerobic composting occurs almost entirely in the top tilled layer of the media in all of the demonstration farms studied. When oxygen is excluded the biological chemistry becomes anaerobic.

Our study showed that most of 11 lab samples – green tamarack, Lonza tamarack, norway pine, southern yellow pine (SYP), jack pine, ash, soybean straw, corn cobs, white pine, poplar, anaerobically digested manure solids (ADMS) and 6 media mixture samples - tamarack and white pine, tamarack and jack pine, tamarack and wheat straw, tamarack and norway pine, corn cobs and soybean straw, green tamarack and soybean straw performed well according to the various important parameters and could be potentially used in a compost bedded pack system. The factors that should be taken into consideration are the cost of the media, consistent availability and dryness of the media, water holding capacity, particle size distribution and the initial pH.

Layering different media in the barn and then trying to mix them together by tilling did not work in this study. To achieve thorough mixing, the mixing needed to be done before the media was laid in the barn. The additional mixing cost for two or three different media was $7 to $14 per ton in this limited study. Individual farm costs for mixing two or more media vary widely and need to be considered in calculating cost comparisons.

Tamarack was considered in this study is because it was identified by the Minnesota DNR in 2005 as an underutilized tree species that grows well in Minnesota and might be available at a lower cost than other tree species that are currently being used in CDB. Tamarack is a durable wood that can go through many wet dry cycles with minimal reduction in cell wall strength. This is an important parameter of media that could be used in a compost bedded pack system. Tamarack shavings have been recently been priced 5% to 15% lower than other conifer species of wood shavings (Woodline Sawmills, 2010). We found that tamarack is a viable media as compared to traditional media used in CDB. While its water holding capacity was slightly lower than some other tree species its cost was also lower. One of the limitations of using tamarack shavings is the very few number of forestry companies in Minnesota who currently harvest and process it. If the lower cost advantage of tamarack is to be captured by dairy farmers they will most likely have to be willing to negotiate a three to four years contract with media suppliers specifying tamarack as the species of wood to be used in manufacturing the finished media.

Corn cobs and soybean straw mixtures performed well in this study. They need to be dry and must compete on a cost basis with other alternative media. Currently they are cost competitive. Other mixtures of media containing two or more wood species also worked well and were higher in costs.

All farmers should consider the advantages of weighing all loads of media at certified scales. This will help assure accurate data and costs. In addition samples of each load should be taken to measure the moisture content of each media delivered to the farm. CDB is mostly about the available water holding capacity of the media that is used. The higher the initial moisture content the lower the value to the CDB farm.

Future research should focus on how the dryness of the media could be maintained in the bedded pack system including evaluation of forced aeration. It should also concentrate on the how the tilling equipment and compaction affects the CDB. Future study could also focus on how mixtures of three or more media work on the farm.

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APPENDIX A – DATA

Table 4: Chemical Characteristics of Lab media and media mixtures

Media	pH	EC (mmhols/cm)	Total Ash content (%)	Total Carbon content (%)	Total Nitrogen content (%)	C:N Ratio	Total Phosporous content (%)	Total Potassium content (%)	Lignin content (%)
Green Tamarack	5.3	0.2	0.51	50.91	0.12	443	0.004	0.070	28.7
Lonza Tamarack	5.6	0.1	0.28	51.56	0.07	737	0.002	0.032	30.9
Norway Pine	4.9	0.2	0.50	51.10	0.12	426	0.009	0.076	28.5
Southern Yellow Pine	4.3	0.5	0.26	53.33	0.08	667	0.001	0.033	32.9
Jack Pine	5.1	0.1	0.34	48.90	0.14	349	0.007	0.048	29.8
Ash	5.4	0.2	0.74	50.35	0.22	229	0.049	0.099	25.2
Soybean straw	8.7	2.4	5.66	43.97	0.58	76	0.116	0.908	17.9
Corn Cobs	5.8	0.5	1.38	46.68	0.38	123	0.024	0.514	17.6
White Pine	5.4	0.1	0.36	51.02	0.21	243	0.011	0.071	32.0
Poplar	4.4	0.5	2.50	50.85	0.23	221	0.028	0.174	22.3
ADMS	8.6	2.2	12.25	43.00	1.49	29	0.667	0.734	29.6
Window millings	4.9	0.4	0.44	49.39	0.10	494	0.005	0.095	22.8
Ground Pallets	5.1	0.6	0.48	49.53	0.16	310	0.010	0.088	23.7
Wheat Straw	7.4	1.3	8.05	44.59	0.50	89	0.063	0.685	21.6
Very fine cabinetry dust	5.2	1.5	0.96	49.43	2.38	21	0.014	0.095	30.7
Media Mixtures									
50% Tamarack and 50% White Pine	4.9	0.2	0.46	50.18	0.10	528	0.007	0.054	28.4
50% Tamarack and 50% Jack pine	4.9	0.3	1.74	49.68	0.12	414	0.010	0.051	27.1
50% Tamarack and 50% Wheat straw	5.1	0.4	0.47	49.77	0.11	452	0.005	0.061	27.7
50% Tamarack and 50% Norway pine	5.1	0.3	0.3	49.3	0.08	616	0.006	0.054	28.3
50% Corn cobs and 50 % Soybean straw	8.2	1.7	3.71	45.05	0.47	96	0.667	0.734	19.0
50% Green Tamarack and 50% Soybean straw	8.9	1.8	3.16	46.5	0.43	108	0.086	0.687	22

Table 5: Physical Characteristics of lab media and media mixtures

Media	Moisture Content (%)	Bulk Density (Kg/m^3)	Water Holding Capacity (%)
Green Tamarack	24	71	152.2
Lonza Tamarack	12	153	142.2
Norway Pine	8	55	192.3
Southern Yellow Pine	4	188	142.2
Jack Pine	6	52	212.4
Ash	30	258	72.2
Soybean straw	18	58	242.4
Corn Cobs	12	140	132.4
White Pine	10	27	282.2
Poplar	8	69	212.2
ADMS	72	65	572.4
Window millings	10	84	212.2
Ground Pallets	8	207	102.2
Wheat Straw	10	41	292.2
Very fine cabinetry dust	8	296	492.2
Media Mixtures			
50% Tamarack and 50% White Pine	8.0	53	242.2
50% Tamarack and 50% Jack pine	12.0	64	182.3
50% Tamarack and 50% Wheat straw	10.0	70	172.2
50% Tamarack and 50% Norway pine	10.0	212	212.2
50% Corn cobs and 50 % Soybean straw	13.0	142	242.3
50% Green Tamarack and 50% Soybean straw	12.0	44	102.4

Table 6: Water Holding Capacity of different media with different particle sizes

Particle Size, mm	WHC (%)		
	Ash	Tamarack	Corn cobs
25	70.53	0.00	192.33
12	81.43	133.93	202.33
6	87.18	142.58	234.83
2	105.68	161.48	242.33
1	154.28	223.13	372.33
0.425	194.88	286.23	492.33

Table 7: Water Holding Capacity of different media mixtures

Mixtures	WHC
Tamarack 6 mm & Wheat straw 6mm	162.35
Soybean straw 6mm & Tamarack 6 mm	102.35
Corn cobs 6 mm & Tamarack 6mm	211
Southern yellow pine 2 mm & Tamarack 6 mm	221.5
Ash 12 mm & Tamarack 6 mm	126.36
6mm Corn cobs and 6 mm soybean straw	242.325

Table 8: Extractable metals concentrations for Lab media, existing media used at the demonstration farms and lab study mixtures determined by inductively coupled plasma emission spectrometry (ICP) mg/kg (ppm) in the dry sample 485°C Dry Ash

Media	Al	B	Ca	Cd	Cr	Cu	Fe
L1	10.191	2.744	1210.800	<0.22	<0.28	0.886	19.873
L1 A	10.238	2.618	1204.600	<0.22	<0.28	1.069	19.607
L2	5.032	2.702	852.610	<0.22	<0.28	0.820	12.201
L3	18.089	3.712	1549.300	<0.22	<0.28	1.065	13.484
L4	5.925	2.038	857.900	<0.22	<0.28	0.661	3.440
L5	25.252	2.533	932.100	<0.22	0.669	1.472	311.550
L6	8.686	4.601	1636.900	<0.22	<0.28	22.396	49.757
L6 a	10.258	4.407	1444.500	<0.22	0.295	26.661	58.084
L7	160.490	18.834	8763.400	<0.22	2.438	14.492	170.950
L8	11.155	1.694	111.240	<0.22	1.524	2.004	22.296
L9	36.363	2.386	668.610	<0.22	<0.28	1.872	23.784
L10	9.062	8.434	8607.000	0.574	<0.28	2.523	15.421
L11	102.930	19.922	20584.000	<0.22	1.814	12.509	434.780
1E	17.664	4.249	831.610	<0.22	<0.28	1.398	8.784
1F	18.122	1.823	1002.100	<0.22	0.593	1.221	29.152
2E	12.693	5.665	1057.700	<0.22	0.504	2.245	79.062
2F	50.622	1.995	3279.800	<0.22	0.755	3.350	96.532
3E	187.840	1.109	2262.400	<0.22	1.072	2.131	193.800
3F	11.522	1.476	1191.500	<0.22	<0.28	0.815	20.408
3F Dup	11.675	1.557	1252.500	<0.22	0.344	1.038	23.523
4E	65.236	6.350	1346.300	<0.22	0.446	2.303	43.806
4F	21.853	2.001	1261.300	<0.22	<0.28	1.604	23.428
3F *	128.830	12.112	5088.200	<0.22	2.548	9.088	132.150
3F* Dup	129.670	11.531	4926.200	<0.22	2.794	9.056	131.880
G (soya bean and tamarack mixture)	67.572	14.246	6031.200	<0.22	<0.28	4.516	70.219

Table 8: Continued…

Media	Na	Ni	P	Pb	Zn	K	Mg	Mn

L1	23.613	<0.64	42.516	<3.52	7.355	697.120	330.590	57.320
L1 A	24.609	<0.64	42.194	<3.52	7.392	707.810	331.570	56.366
L2	81.218	<0.64	16.297	<3.52	7.116	315.940	201.370	244.940
L3	18.633	<0.64	89.386	<3.52	13.989	757.050	268.020	56.630
L4	15.730	<0.64	13.443	<3.52	12.252	324.950	189.880	151.350
L5	6.760					480.600	252.350	107.300
L6	24.811	<0.64	495.910	<3.52	4.810	1013.100	356.930	2.416
L6 a	28.148	<0.64	482.590	<3.52	4.855	965.300	358.830	2.503
L7	38.972	1.386	1157.500	<3.52	6.648	9083.900	3946.600	21.980
L8	10.369	1.229	240.140	<3.52	25.039	5143.400	342.090	5.690
L9	21.768	<0.64	104.630	<3.52	8.103	709.050	197.980	29.642
L10	46.115	<0.64	277.480	<3.52	99.224	1741.500	517.700	22.087
L11	2220.600	1.505	6666.300	<3.52	129.310	7335.400	4100.700	152.700
1E	255.220	0.839	52.619	<3.52	6.881	951.380	242.610	56.041
1F	23.356	<0.64	65.827	<3.52	9.011	536.680	238.560	50.678
2E	206.350	<0.64	104.220	<3.52	9.701	880.870	204.270	50.557
2F	33.364	<0.64	100.930	<3.52	12.748	505.100	1421.800	54.848
3E	15.903	<0.64	628.920	<3.52	8.928	6848.600	648.210	30.363
3F	23.263	<0.64	52.282	<3.52	9.904	607.830	300.210	58.749
3F Dup	23.078	<0.64	56.942	<3.52	9.173	604.140	303.420	62.209
4E	1402.300	<0.64	137.250	<3.52	14.530	953.420	337.220	53.695
4F	16.844	<0.64	62.811	<3.52	9.673	543.180	277.640	69.933
3F *	26.619	1.957	765.790	<3.52	18.108	8533.400	2595.300	16.938
3F* Dup	26.188	2.125	735.090	<3.52	18.049	8078.800	2462.700	19.936
G (soya bean and tamarack mixture)	43.166	<0.64	858.460	<3.52	5.522	6869.600	2320.200	32.964

Green tamarack= L1
Lonza tamarack= L2
Norway pine= L3
Southern yellow pine= L4
Jack pine= L5
Ash= L6
Soybean straw= L7
Corn Cobs= L8
White Pine = L9
Poplar = L10
Anaerobic digested manure solids = L11
E = Existing media on farm
F = mixture provided from study

Table 9: Chemical Characteristics of compost samples from four demonstration farms at various depths

Media	pH	EC (mmhols/cm)	Total Ash content (%)	Total Carbon content (%)	Total Nitrogen content (%)	C:N Ratio	Total Phosphorous content (%)	Total Potassium content (%)	Lignin content (%)
First Visit									
15 cm - 1A	9.2	14.4	14.84	44.39	1.77	25	0.328	1.815	30.2
15 cm - 2A	8.7	5.1	7.33	45.96	1.12	41	0.229	1.130	27.4
15 cm - 3A	8.1	2.1	21.60	38.32	1.94	20	0.366	2.589	21.8
15 cm - 4A	8.9	9.8	10.91	44.56	2.54	18	0.262	1.440	32.4
Second Visit									
15 cm - 1A	9.5	14.8	15.79	41.60	1.78	23	0.307	1.850	31.9
15 cm - 2A	9.2	3.9	6.64	46.35	0.90	52	0.222	0.870	29.4
15 cm - 3A	9.1	8.1	20.73	40.44	1.60	25	0.385	2.470	22.0
15 cm - 4A	9.2	9.0	5.68	44.55	2.14	21	0.292	1.810	32.0
First Visit									
30 cm - 1B	9.0	15.2	16.45	41.37	1.83	23	0.338	2.100	33.2
30 cm - 2B	*	*	*	*	*	*	*	*	*
30 cm - 3B	9.1	7.9	20.43	40.17	1.64	24	0.339	3.026	24.2
30 cm - 4B	8.8	9.1	10.88	44.10	2.60	17	0.266	1.500	*
Second Visit									
30 cm - 1B	9.6	16.7	15.52	41.55	1.75	24	0.306	1.810	31.9
30 cm - 2B	9.2	6.8	8.89	45.59	1.08	42	0.297	1.220	28.5
30 cm - 3B	9.1	10.0	20.55	39.08	1.63	24	0.355	2.370	24.8
30 cm - 4B	9.3	10.3	9.89	44.44	2.10	21	0.274	1.700	*
First Visit									
45 cm - 1C	8.9	9.0	15.96	41.83	1.81	23	0.332	1.900	32.4
45 cm - 2C									
45 cm - 3C	9.1	9.8	19.74	37.34	1.50	25	0.323	3.298	24.6
45 cm - 4C	8.5	9.9	10.26	44.76	2.63	17	0.226	1.320	32.3
Second Visit									
45 cm - 1C	9.3	12.1	14.23	42.10	1.53	28	0.259	1.74	30.7
45 cm - 2C	9.2	7.5	8.77	45.67	0.9	51	0.238	1.28	29.4
45 cm - 3C	9.0	10.4	24.14	38.95	1.45	27	0.379	2.3	25.8
45 cm - 4C	9.0	10.4	11.38	44.30	2.16	21	0.313	1.75	30.9
Bottom compost samples									
BCS – 2a	9.2	2.6	7.27	45.4	0.98	46	0.213	0.952	31.8
BCS – 2b	9.0	2.2	5.22	46.5	0.67	69	0.182	0.968	32.6
BCS - 3	8.9	9.8	28.15	35.4	1.68	21	0.323	2.641	33.3
BCS - 4	9.5	5.9	10.95	43.6	2.34	19	0.297	1.846	33.0

Columns with * indicates that there is no data
BCS – 2a = Bottom compost sample collected 6 inches from the bottom of the pack
BCS – 2b = Bottom compost sample collected 18 inches from the bottom
BCS – 3 = Bottom compost sample collected from Farm 3
BCS – 4 = Bottom compost sample collected from Farm 4

A = compost from a depth of 15 cm
B = compost from a depth of 30 cm
C = compost from a depth of 45 cm
D = compost from a depth of 60 cm
1A = Number denotes the Farm and the alphabet denotes the depth – Farm 1 at depth 15 cm

Table 10: Physical Characteristics of compost samples from four demonstration farms at various depths

Media	Moisture Content (%)	Water Holding Capacity (%)
First Visit		
15 cm (1A)	50	292.2
15 cm (2A)	58	152.2
15 cm (3A)	58	207.2
15 cm (4A)	64	282.2
30 cm (1B)	50	262.2
30 cm (3B)	63	212.2
30 cm (4B)	64	292.2
45 cm (1C)	54	292.2
45 cm (3C)	62	202.2
45 cm (4C)	66	282.2
Second Visit		
15 cm - 1A	54	232.2
15 cm - 2A	54	202.2
15 cm - 3A	60	222.2
15 cm - 4A	64	282.2
30 cm - 1B	52	232.2
30 cm - 2B	58	162.2
30 cm - 4B	64	242.2
30 cm- 3B	62	212.2
45 cm - 1C	58	242.2
45 cm - 2C	60	172.2
45 cm - 4C	66	252.2
45 cm -3C	62	202.2
60 cm - 3D	66	202.2

	Moisture Content (%)					
	Average	Min	Max	Std Dev	1st Quartile	3rd Quartile
All Farms	59.69	50.00	66.00	4.99	56.50	64.00
All Farms						
15 cm	57.78	50.00	64.00	4.41	54.00	60.00
30cm	59.50	50.00	66.00	5.83	56.50	64.00
45cm	61.25	54.00	66.00	3.99	59.50	63.00

Table 11: Extractable metals concentrations for compost samples from the demonstration farms at various depths determined by inductively coupled plasma emission spectrometry (ICP) mg/kg (ppm) in the dry sample 485°C Dry Ash

Media	Al	B	Ca	Cd	Cr	Cu	Fe	K
First Visit								
1A	499.580	34.162	14471.000	<0.22	2.200	31.344	707.050	18240.000
1A Dup	496.990	33.729	14439.000	<0.22	2.004	31.003	668.690	18121.000
1B	537.170	37.862	15338.000	<0.22	2.155	32.006	724.460	21023.000
1C	529.780	36.225	16055.000	<0.22	2.267	31.188	715.630	18971.000
2A	193.730	21.097	10848.000	<0.22	1.510	21.608	547.180	11331.000
3A	851.230	29.964	14350.000	<0.22	1.992	23.094	940.830	26784.000
3B	806.390	33.737	14335.000	<0.22	2.123	28.886	906.900	33394.000
3C	823.340	35.071	12937.000	<0.22	2.242	52.471	923.070	37300.000
3A - P2 -1	725.880	24.093	17161.000	<0.22	1.975	26.859	895.760	24972.000
3B - P2 -1	642.880	27.396	12454.000	<0.22	1.672	20.703	738.300	27125.000
3C-P2-1	1395.000	30.665	15616.000	<0.22	2.968	22.828	1490.200	28652.000
4A	270.370	28.547	12412.000	<0.22	1.370	24.312	332.490	14380.000
4B	275.200	29.476	12923.000	<0.22	1.429	25.454	337.220	14953.000
4C	265.340	26.240	10820.000	<0.22	1.238	22.297	318.990	13215.000
Second Visit								
1A	499.570	33.162	14090.000	<0.22	2.092	29.988	670.080	19225.000
1A Dup	485.370	31.487	13595.000	<0.22	1.977	28.195	645.180	17828.000
1B	511.020	33.989	14056.000	<0.22	2.114	29.364	657.970	18141.000
1C	558.000	32.556	12788.000	<0.22	2.002	26.028	657.260	17402.000
2A	139.260	14.843	10175.000	<0.22	1.226	17.337	273.750	8702.500
2B	187.160	20.259	13223.000	<0.22	1.899	25.667	410.880	12175.000
2C	182.460	21.129	11523.000	<0.22	2.039	22.067	397.900	12835.000
3A	687.560	22.355	14596.000	<0.22	1.741	17.799	838.740	24739.000
3B	823.110	23.689	13721.000	<0.22	2.032	19.727	941.300	23703.000
3C	928.090	23.033	14941.000	<0.22	2.391	17.968	1083.700	22967.000
4A	288.320	33.461	13900.000	<0.22	1.483	28.641	375.170	18141.000
4B	272.710	31.607	13152.000	<0.22	1.559	26.395	342.680	17056.000
4C	334.480	34.542	15588.000	<0.22	1.591	29.744	405.880	17473.000

Table 11: Continued…

Media	Mg	Mn	Na	Ni	P	Pb	Zn
First Visit							
1A	6420.700	175.470	11009.000	2.267	3294.700	<3.52	136.700
1A Dup	6289.800	172.860	10975.000	2.318	3264.800	<3.52	134.410
1B	6674.100	178.300	12976.000	2.388	3381.300	<3.52	142.380
1C	7007.800	178.430	11541.000	2.280	3315.600	<3.52	139.360
2A	3574.800	108.870	3657.200	2.033	2293.400	<3.52	83.512
3A	4909.900	161.290	4469.800	2.446	3479.900	<3.52	72.861
3B	4687.500	165.620	6628.000	2.216	3990.500	<3.52	89.229
3C	4992.800	161.080	7744.800	2.133	3360.600	<3.52	73.322
3A - P2 -1	4953.100	192.590	4835.200	2.483	3839.800	<3.52	111.250
3B - P2 -1	3658.200	159.450	5479.000	1.928	2797.900	<3.52	78.700
3C- P2 -1	5149.200	164.230	5435.200	2.804	3118.900	<3.52	71.392
4A	4235.000	119.380	5633.600	1.260	2621.900	<3.52	106.920
4B	4233.400	124.330	5953.500	1.333	2659.200	<3.52	113.450
4C	3704.200	115.990	5544.400	1.109	2259.900	<3.52	104.310
Second Visit							
1A	6071.700	166.510	11491.000	2.344	3157.300	<3.52	129.850
1A Dup	5861.800	160.220	10766.000	2.057	2984.100	<3.52	124.580
1B	5913.500	169.350	10932.000	2.100	3056.500	<3.52	132.120
1C	5217.800	163.150	9846.000	2.338	2594.900	<3.52	119.440
2A	3140.000	116.220	2986.800	1.075	2219.300	<3.52	78.762
2B	4054.900	136.430	4219.700	1.435	2971.100	<3.52	107.840
2C	3865.900	120.930	4405.700	1.303	2385.300	<3.52	91.610
3A	4244.600	162.400	4518.000	2.115	3853.600	<3.52	82.394
3B	4033.900	155.740	4478.600	2.280	3551.300	<3.52	78.145
3C	4424.300	161.260	4410.100	2.768	3790.900	<3.52	78.403
4A	4534.600	143.220	6973.900	1.646	2923.600	<3.52	121.610
4B	4214.700	133.810	6854.100	1.625	2738.800	<3.52	112.870
4C	4868.400	150.510	6995.700	1.324	3131.200	<3.52	152.960

Table 12: Temperatures (^{o}C) at various depths and locations in the four demonstration farms

Farm 1					
First Visit			Second Visit		
Location	**Depths**	**Temperature, ^{o}C**	**Location**	**Depths**	**Temperature, ^{o}C**
1	15 cm	28.9	1	15 cm	55.8
2	15 cm	29.0	2	15 cm	54.0
3	15 cm	47.0	3	15 cm	51.7
4	15 cm	43.1	4	15 cm	56.5
5	15 cm	44.2	5	15 cm	51.4
6	15 cm	47.3	6	15 cm	58.2
1	30 cm	28.9	1	30 cm	58.2
2	30 cm	52.0	2	30 cm	53.9
3	30 cm	52.0	3	30 cm	52.5
4	30 cm	45.7	4	30 cm	57.9
5	30 cm	47.0	5	30 cm	53.0
6	30 cm	51.4	6	30 cm	59.4
1	45 cm	28.9	1	45 cm	55.6
2	45 cm	55.9	2	45 cm	52.0
3	45 cm	59.8	3	45 cm	50.9
4	45 cm	47.5	4	45 cm	54.3
5	45 cm	48.2	5	45 cm	52.8
6	45 cm	52.7	6	45 cm	55.7

Farm 2		
Location	**Depths**	**Temperature, ^{o}C**
1	15 cm	55.7
2	15 cm	58.9
3	15 cm	58.1
4	15 cm	57.5
5	15 cm	60.0
6	15 cm	55.3
1	30 cm	59.4
2	30 cm	59.7
3	30 cm	57.8
4	30 cm	55.0
5	30 cm	57.9
6	30 cm	54.6
1	45 cm	58.0
2	45 cm	55.3
3	45 cm	52.5
4	45 cm	49.0
5	45 cm	52.3
6	45 cm	49.1

Farm 3					
First Visit			Second Visit		
Location	**Depths**	**Temperature, ^oC**	**Location**	**Depths**	**Temperature, ^oC**
1	15 cm	55.3	1	15 cm	56.2
2	15 cm	55.0	2	15 cm	59.1
3	15 cm	61.3	3	15 cm	54.1
4	15 cm	59.9	4	15 cm	55.7
5	15 cm	51.7	5	15 cm	56.0
6	15 cm	55.4	6	15 cm	52.4
1	30 cm	58.7	1	30 cm	59.6
2	30 cm	54.8	2	30 cm	58.6
3	30 cm	62.9	3	30 cm	55.3
4	30 cm	56.4	4	30 cm	55.1
5	30 cm	52.8	5	30 cm	54.2
6	30 cm	53.4	6	30 cm	50.9
1	45 cm	58.3	1	45 cm	55.9
2	45 cm	50.3	2	45 cm	54.7
3	45 cm	57.0	3	45 cm	52.8
4	45 cm	50.1	4	45 cm	51.8
5	45 cm	50.1	5	45 cm	50.6
6	45 cm	50.3	6	45 cm	48.6

Farm 4		
Location	**Depths**	**Temperature, ^oC**
1	15 cm	48.2
2	15 cm	51.0
3	15 cm	50.0
4	15 cm	45.1
5	15 cm	38.0
6	15 cm	46.3
1	30 cm	46.9
2	30 cm	51.0
3	30 cm	49.4
4	30 cm	43.7
5	30 cm	37.3
6	30 cm	44.7
1	45 cm	44.1
2	45 cm	47.5
3	45 cm	46.7
4	45 cm	41.2
5	45 cm	35.4
6	45 cm	41.7

Table 13: Oxygen (%) at various depths recorded at one of the demonstration farm

Location	Depths	Oxygen, %
1	15 cm	10.0
	30 cm	2.0
	45 cm	2.0
2	15 cm	4.0
	30 cm	1.0
	45 cm	0.0
3	15 cm	2.0
	30 cm	6.0
	45 cm	0.0
4	15 cm	6.0
	30 cm	3.0
	45 cm	2.0
5	15 cm	10.0
	30 cm	6.0
	45 cm	0.0
6	15 cm	7.0
	30 cm	1.0
	45 cm	0.0

Table 14: Chemical characteristics of compost samples at 3 depths from four demonstration farms in Minnesota

	pH					
	Average	Min	Max	Std Dev	1st Quartile	3rd Quartile
15 cm	8.98	8.10	9.50	0.43	8.55	9.20
30 cm	9.15	8.80	9.55	0.24	9.05	9.25
45 cm	9.00	8.50	9.30	0.26	8.95	9.15

	ELECTRICAL CONDUCTANCE (mmhols/cm)					
	Average	Min	Max	Std Dev	1st Quartile	3rd Quartile
15 cm	8.39	2.10	14.80	4.63	4.35	10.95
30 cm	10.85	6.82	16.65	3.69	8.50	12.75
45 cm	9.87	7.47	12.10	1.42	9.40	10.40

	TOTAL ASH CONTENT (%)					
	Average	Min	Max	Std Dev	1st Quartile	3rd Quartile
15 cm	12.94	5.68	22.52	6.27	10.02	17.02
30 cm	14.66	8.89	20.55	4.87	10.39	18.44
45 cm	14.93	8.77	24.14	5.50	10.82	17.85

	TOTAL PHOSPHOROUS CONTENT (%)					
	Average	Min	Max	Std Dev	1st Quartile	3rd Quartile
15 cm	0.30	0.22	0.39	0.06	0.25	0.34
30 cm	0.31	0.27	0.36	0.03	0.29	0.34
45 cm	0.30	0.23	0.38	0.06	0.25	0.33

TOTAL POTASSIUM CONTENT (%)						
	Average	**Min**	**Max**	**Std Dev**	**1st Quartile**	**3rd Quartile**
15 cm	1.75	0.87	2.59	0.60	1.36	2.01
30 cm	1.96	1.22	3.03	0.60	1.60	2.24
45 cm	1.94	1.28	3.30	0.69	1.53	2.10

LIGNIN CONTENT (%)						
	Average	**Min**	**Max**	**Std Dev**	**1st Quartile**	**3rd Quartile**
15 cm	28.39	21.80	32.40	4.33	26.00	31.93
30 cm	28.52	24.20	33.20	4.06	24.80	31.90
45 cm	29.44	24.55	32.40	3.10	27.60	31.60

TOTAL CARBON CONTENT (%)						
	Average	**Min**	**Max**	**Std Dev**	**1st Quartile**	**3rd Quartile**
15 cm	43.27	38.32	46.35	2.84	42.87	44.91
30 cm	42.33	39.08	45.59	2.41	40.77	44.27
45 cm	42.14	37.34	45.67	3.09	40.39	44.53

TOTAL NITROGEN CONTENT (%)						
	Average	**Min**	**Max**	**Std Dev**	**1st Quartile**	**3rd Quartile**
15 cm	1.72	0.90	2.54	0.53	1.60	1.99
30 cm	1.80	1.08	2.60	0.47	1.64	1.97
45 cm	1.71	0.90	2.63	0.56	1.48	1.99

CARBON TO NITROGEN RATIO CONTENT (%)						
	Average	**Min**	**Max**	**Std Dev**	**1st Quartile**	**3rd Quartile**
15 cm	28.06	17.54	51.50	11.88	19.20	29.22
30 cm	25.02	16.96	42.21	8.00	21.88	24.23
45 cm	27.24	17.02	50.74	10.99	21.81	27.19

Table 15: Summary statistics of chemical characteristics for four demonstration farms in Minnesota

Summary Statistics	pH	Electrical Conductance (mmhols/cm)	Total Ash (%)	Total P (%)	Total K (%)	Lignin (%)	Total Carbon (%)	Total Nitrogen (%)	C:N
Average	9.04	9.64	14.89	0.31	2.01	28.10	42.13	1.74	26.39
Min	8.10	2.10	5.68	0.22	0.87	21.30	35.09	0.90	16.96
Max	9.55	16.65	24.14	0.40	3.73	33.20	46.35	2.63	51.50
Standard Deviation	0.32	3.57	5.56	0.05	0.70	3.92	2.97	0.47	9.57
1st Quartile	8.90	7.69	10.89	0.26	1.46	24.50	39.69	1.49	22.61
3rd Quartile	9.20	10.40	20.55	0.34	2.47	31.90	44.55	2.08	26.69

APPENDIX B – COMPUTER MODEL

The optimization tool has been implemented using Excel Spreadsheets, and it was developed based on the results obtained in the "Media and Media mix Evaluation for Dairy Barn Compost Bedding Systems" report by the Research Group at the University of Minnesota, and the work from the Cornell Waste Management Institute (http://cwmi.css.cornell.edu/).

The objective of this optimization tool is to aid the user to determine the effect of different media and media mixtures in Composted Dairy Bedded-pack Barns (CDB) on composting properties such as: Moisture Content (%), Water holding capacity (%), C:N ratio, oven dried bulk density (Kg/m^3), oven dried free space (%) and oven dried volume (m^3)

The optimization tool is composed of two spreadsheets. The first spreadsheet allows the user to estimate manure production based on the number of animals (Heifer, Dry Cow or Lactating Cow) and their manure production (ft^3/animal-day). The second spreadsheet utilizes the mass of each media and the media characteristics such as: Initial moisture content of the media (%) and the mass of the remaining water holding capacity of the media (Mg) to calculate cost per ton of WHC for each media. This would help farmers to select a media based on the cost, initial moisture content and the mass of the remaining water holding capacity of the media. The spreadsheet automatically calculates cost per ton of WHC for each media and arranges the media in ascending order based on cost per ton of WHC. To use the optimization tool, the user can modify the values highlighted with the purple background.

Raw manure production rate for each category

Animal	Manure Production (ft^3/cow-day)	Typical Value (ft^3/cow-day)	Typical Value (m^3/cow-day)
501-1000 lb Heifer	1.0	1.0	0.02832
1001-1400 lb Dry Cow	1.3	1.3	0.03682
1001-1400 lb Lactating Cow	2.2	2.0 - 3.2*	0.05664 - 0.09063*

** Refer to table in the right*

Animal	# of Animals	Manure Prod. (ft^3/month)	Manure Prod. (m^3/month)
501-1000 lb Heifer	30	912	25.83
1001-1400 lb Dry Cow	30	1185.6	33.58
1001-1400 lb Lactating Cow	70	4681.6	132.59
		Total (volume in m^3):	**191.99**
		Total (mass in kg):	**190562.52**
		Total (mass in metric tonns):	**190.56**

Typical Manure Production for 1001-1400 lb Lactating Cows

Milk Production (lb/cow-day)	Manure Prod. (ft^3/cow-day)	Manure Prod. (m^3/cow-day)
40	2.0	0.05664
45	2.0	0.05664
50	2.0	0.05664
55	2.2	0.06231
60	2.3	0.06514
65	2.5	0.07080
70	2.6	0.07363
75	2.7	0.07647
80	2.8	0.07930
85	2.9	0.08213
90	3.0	0.08496
95	3.1	0.08779
100	3.2	0.09063

Screenshot of the "Manure production" spreadsheet

[redacted]

Screenshot of the "Model" spreadsheet

APPENDIX C - PHOTOS

Corncobs and Soybean straw mixture

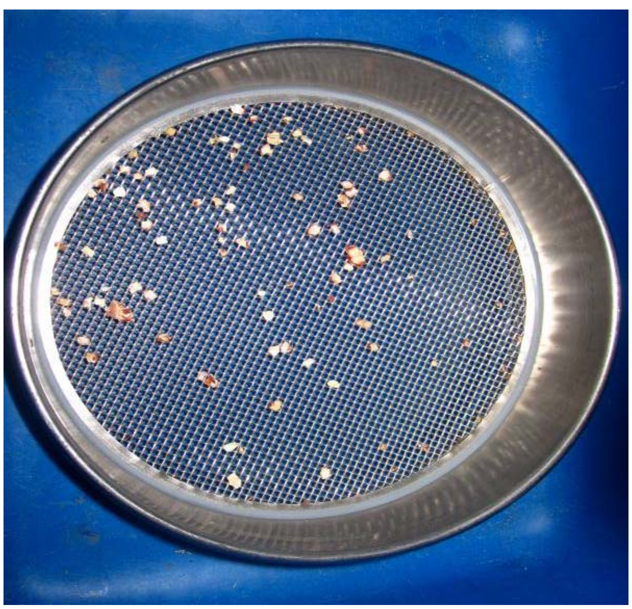
Jack Pine and Soybean straw mixture

Soybean straw and corn cob mixture retained on 12.5 mm sieve

Corncobs – Different particle sizes retained during sieve analysis

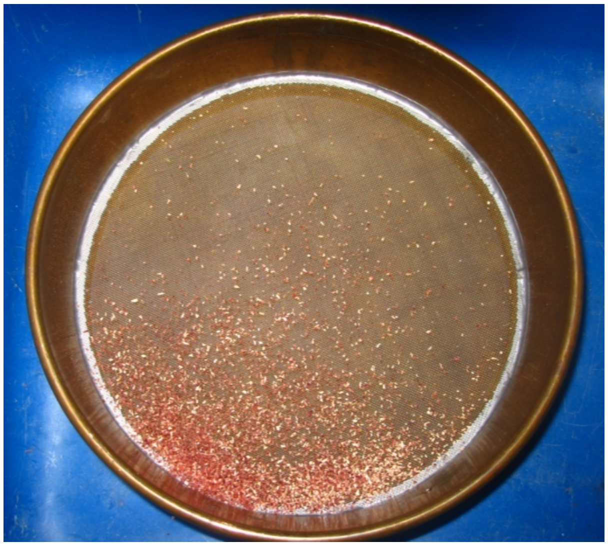
Corncobs retained on 12.5 mm sieve

Corncobs retained on 6.3 mm sieve

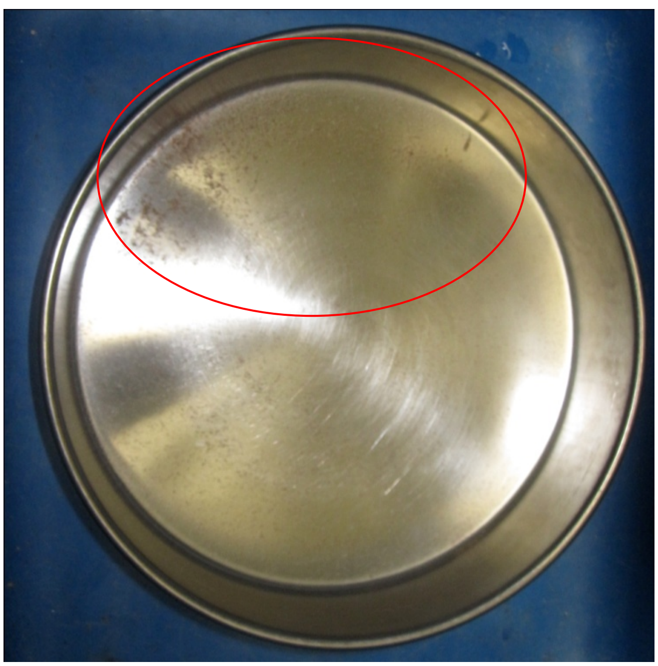


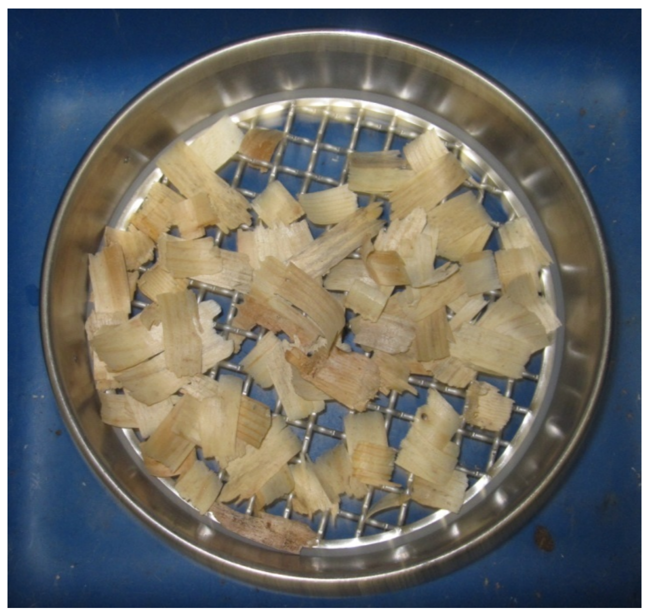
Corncobs retained on 2mm sieve

Corncobs retained on 1mm sieve

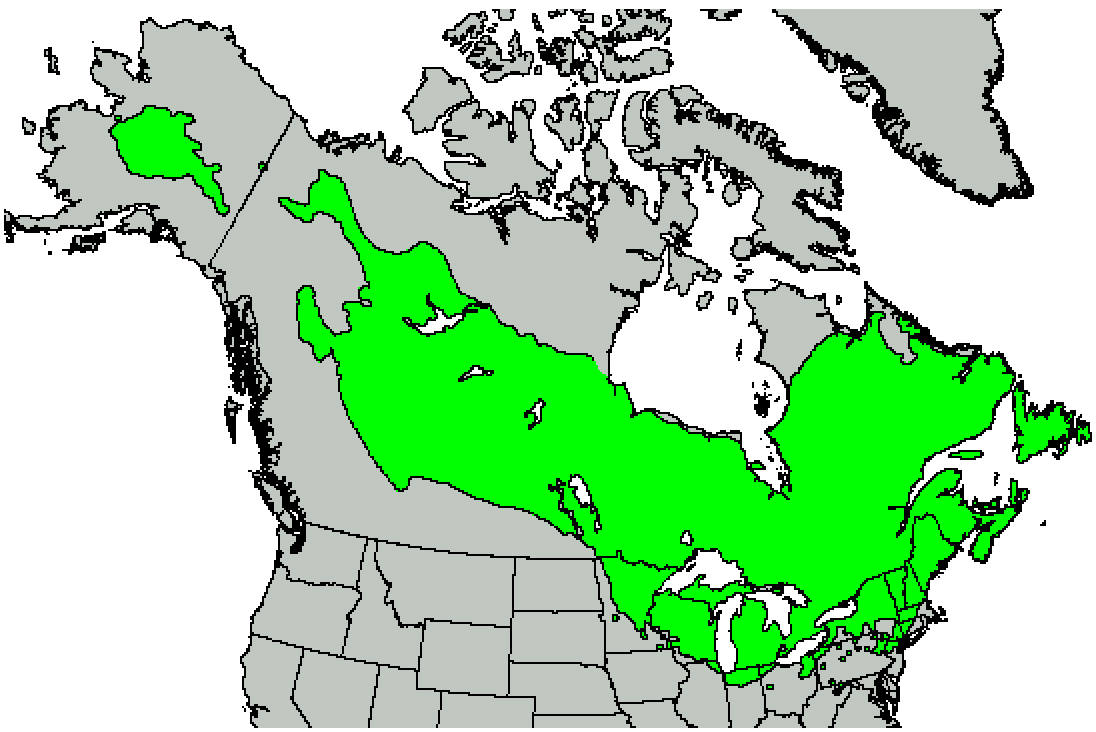

Corncobs retained on 0.425mm sieve


Corncobs retained on 0.250mm sieve


Fine corncob dust retained - Pan


Tamarack shavings retained on12.5 mm sieve


Corn cobs


The Native range of Tamarack

Tamarack in fall colors, with Black Spruce
Source: (Wikipedia)