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ABSTRACT

Keeping sows in the outdoor pasture conveys high risk on environmental pollution through nitrate leaching which might be tremendously high in autumn and winter. Integrating grassland based free-range pigs with selected energy crops has been proposed as one possible approach to reduce nutrient leaching; however the effect has never been quantified. The eco-efficient pig farming that takes care of pig's animal welfare and possible reduction of nitrate loss into environment may be achieved which will contribute to the Danish Green Growth Agreement of reducing up to 19,000 tons of NO_3-N between 2010 and 2015.

Apart from the main focus on NO_3-N leaching potential, this experiment also investigated N_{min} and phosphorus distributions at various soil depths and distances from willow plus estimating farm N balance from a commercial organic pig farm. In the experimental paddocks, two willow rows each from one side of the paddock are separated by 18.5 m distance covered by grass. In each of the four measurement rows established, the ceramic suction cups were installed at 1.45 m depth at 0.5, 2.5, 4.5, 6.5 and 9.5 m from willow while the two soil samples were taken at each cup at three soil layers, 0-25 cm, 25-50 cm and 50-100 cm. Through a 1 m soil column, the factorial ANOVA found significant highest ($p<0.001$) N_{min} close to sow's huts with 149 Kg N/ha followed by 101 and 100 Kg N/ha adjacent to feeders. The N_{min} content however differed with distance with NH_4-N of up to 90% near feeders while up to 84% of N_{min} was NO_3-N close the huts. The phosphorus near feeders had the highest level with 53 Kg P/ha when considering 1 m soil depth. In both N_{min} and P, the lowest levels were found closest to the willow (0.5 m) with 41 Kg N/ha and 39 Kg P/ha through 1 m soil depth. In addition, the N balance estimation of the farm where the total input was 404 Kg N/ha, about 104 Kg N/ha (26%) was converted into piglets while 39 Kg N/ha (10%) was estimated for willow N uptake.

Nitrate-N leaching as expected was the highest near the huts with an average of 37 mg NO_3-N/litre followed by 28 Mg NO_3-N/litre at 6.5 m. Of all the distance points, the leaching at only 4.5 and 6.5 were significantly to 0.5 m ($p<0.01$). Since excretory behaviour of pigs was not part of the experiment, the lower NO_3-N leaching closest to willow could be due to both lower excretion and also high water and nutrients uptake by trees. However, even though the NO_3-N from soil samples at 2.5 m was the second highest, the leaching wasn't as high as expected, which was attributed to high uptake by the trees whose significant uptake by roots may extend as far as 3.5 m away from willow. The 9.5 m close to feeders had the low leaching which could be due to low NO_3-N as NH_4-N dominated with about 90 % of the total N_{min} with 79% of this being in top soil. With their long growing season and deep root system, willow could substantially reduce N loss through nitrate leaching.

The results from this study suggest that, paddocks should be designed so as to maximize the potential nutrients uptake by willow as pigs are known to have high excretion activities near shelter zones such as trees. In addition to that, analysis of pig excretory behaviour will enable the findings to establish a clear-cut relationship of whether lower nitrate leaching close to willow is due to low excretion or high nutrients demand by trees. The hotspot areas on the other hand as observed in our experiment could still be carrying high N loss potential and therefore in addition to perennial crops, frequent reallocation of feeders & huts, rotation of pigs into new paddocks and regulate stocking density could be done together. These measures could both improve grass cover and reduce nutrient losses into the environment.

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DEDICATION

This Master's Thesis is dedicated to my parents, my father Joel B.B. Lao and my mother Paulina Lao for all the sacrifices they made for me to get better education. Your encouragement through prayers and best wishes kept reminding me how you would be proud of me for this achievement. I would also like to dedicate this thesis to my siblings, Samwel, Rachel, Rehema, Neema and Hosiana and my lovely daughter Karen.

DECLARATION

I hereby declare that this thesis ***"Combined free-range piglets and energy crop production – impact on nitrate leaching"*** is my own work and is submitted as a partial fulfilment for Master of Science in Agro-Environmental Management and delivered to Aarhus University. This work is the original material and all sources I have used or quoted have been indicated or acknowledged by means of completed references.

Name of student: Emanuel Joel Lao **Signature**: ___________________________

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LIST OF ABBREVIATIONS

ANOVA – Analysis Of Variance

EC – European Commission

EU – European Union

EUROSTAT – EC European Statistics

GMO – Genetically Modified Organisms

Ha – Hectare

Kg – Kilogram

LU – Livestock Unit

Mg – Milligram

Mm – Millimeter

N – Nitrogen

NH_4-N – Ammonium Nitrogen

NO_3-N – Nitrate Nitrogen

P – Phosphorus

UK – United Kingdom

USDA – United States Department of Agriculture

CHAPTER I: INTRODUCTION

1.1. Background Information

Free-range organic pig production is typically comprised of pregnant and lactating sows with piglets being grazing outside, roaming and resting around the pasture in the day and sleep in small huts during night time (Horsted *et al*,. 2012: Webb *et al*, 2014). The EU regulation requires organic free range pigs to have permanent access to pasture during summer for at least 150 days a year even though some farmers tend keep the pigs even longer. Weaning for piglets according to regulation is done at 40 days as (EC, 2008) even though there are country specific conditions which elongate the weaning age. With the indoors systems for weaners, which include a small outdoor running space, they will be fed until reaching the slaughter weight (Hermansen, 2005). In some farming systems, depending on national standards, farm specific objectives and local environment, different combinations of both outdoor and indoor settings can be practised (Vieuille *et al.*, 2003).

Like in other EU countries, the presence of grazing area in Danish free range pig production have raised concerns about possible environmental impacts including increased ammonia volatilization (Sommer *et al.*, 2001), denitrification (Petersen *et al.*, 2001) and high nitrate leaching (Eriksen et al., 2006). The high N and P surplus from the urine and defecations have environmental implication of increased leaching rate which may lead to contamination of ground water. This has negative health effects to human (Williams *et al.,* 2000) and also affects the aquatic ecosystems through eutrophication (Quintern & Sundrum, 2006: Honeyman, 2005). The N loss in free range system is not distributed equally over the grassland as high N loss rates are more pronounced in hotspot areas such as near the huts, shelters and feeders compared to the rest of the field (Andesen, 2000).

The study done by Eriksen and Kristensen (2001) in outdoor lactating sows reported uneven distribution of the mineral N concentration where relatively higher N concentration was found near feeding areas. The same results for outdoor pigs were found by Watson *et al.* (1998) where there was four times higher mineral N in hotspots close to feeding area compared to other parts less utilized by the pigs. Apart from excess N and P loading problem to the environment, the free range organic pigs have been associated with higher piglets mortality rate compared to indoors conventional pigs (Bilkei, 1995), management challenges due to seasonal weather fluctuations (Honeymoon, 2005) and maintenance of the grassland cover

(Vieuille et al, 2003). The combination of high nutrient loss plus higher piglet mortality rates in organic pig farming have let to lower N and P efficiencies (Nielsen and Kristensen, 2005)

Integrating free-range pig farming with some selected energy crops particularly willow, poplar and mischanthus has been one proposed approach to improve animal welfare by providing shelter and protection in adverse weather conditions (Horsted *et al,*. 2012: Sorensen, 2012). Also the trees with their high water and N uptake may reduce nutrients losses to the environment as well as improving agricultural diversity important for ecosystem services. With the average nitrate leaching in Danish agricultural land being about 70 kg N/ha, perennial energy crops such as willow and mischanthus have shown promising results of reducing between 40 - 65 kg N/ha (Jorgensen et al, 2005). There are several reasons for reduced leaching when perennial crops are established. Important is the deep and permanent root system, and the root zone for willow can be as deep as 1.3 m when well established even though the root depth could vary with soil type, willow clone type, nitrogen source and management (Mortensen et al,. 1998).

A recent related study by Horsted *et al.*, (2012) that investigated the influence of perennial crops on defecation behaviour, preferential sites for excretion and possible damage to the crops found that the defecation for pigs is significantly higher in areas with energy crops (willow & poplar and mischanthus) compared with the rest of the paddock. The pig excretory behaviour didn't seem to be significantly affected in big paddocks with 367 m^2 per sow as compared by three times higher stoking rate of 117 m^2 per pig. Willow trees close to the feeding and drinking troughs experienced higher excretion than the rest of the willows and this area accounted for 49% of total excretion even though the willow area was only 15% of total area (Horsted et al., 2012). With willow trees characterized by having tolerance to high plant density and water logging conditions (Volka et al., 2006), coppicing ability and deep rooting system that have been studied to reduce leaching to underground water (Mortensen et al,. 1998: Sevel et al., 2014). Hence in free range pigs these crops might as well be useful in reducing nitrate leaching which are associated with higher urination and defecations in areas close to the willow. The question is therefore how much benefit willow can contribute in highly N-loaded free range pig systems.

1.2. Research Objectives and Hypotheses

Developmental Objective

This master project will contribute towards eco-efficient organic pig farming that doesn't only aim at improving animal welfare but also reduce environmental impacts caused by nutrient leaching into environment. Also being a relatively new production approach with its knowledge and experience still sparse, the implementation of free-range pig farming with energy crops through research is important for key stakeholders particularly farmers and policy makers. With their high water and nutrient uptakes, willow trees in organic free-range pigs may contribute reducing NO_3-N leaching and this will be in line with Danish *Green Growth Agreement* which aimed for a reduction of about 19,000 tons of NO_3-N into aquatic environment from 2010 to 2015. In addition, this will also contribute to the National target of having 15,000 ha by 2015 and about 30,000 ha of energy crops by 2020 (EC, 2010).

Overall Scientific Objective

The overall scientific objective of this study was to investigate which benefits integration of willow trees into free-range farming system may have on animal welfare and environment. This involved sampling of both soil and soil water from the sow's paddocks plus critically reviewing the literature on free-range pig production systems, animal welfare and nutrients dynamics.

Specific Scientific Objectives

1. To quantify the mineral Nitrogen distribution (Nitrate-N and Ammonium-N) and Phosphorus at different soil depths (0-25, 25-50 and 50-100 cm) and distances from the willow trees (0.5, 2.5, 4.5, 6.5 and 9.5 m).

2. To quantify the Nitrate-N leaching at distances 0.5, 2.5, 4.5, 6.5 and 9.5 m from willow row using ceramic suction cups which were installed and replicated into four measurement rows. From the experimental paddocks, the distance from a willow row in one side of a paddock to the other was separated by 18.5 m grassland.

3. To estimate the nitrogen balance of a combined willow and pig system by data sampling and measurements in a commercial organic farm.

Research Hypothesis

The working hypotheses for this research project are as follows;

1. The N_{min} and phosphorus contents close to willow will be higher due to expected high urination and defecation activities by sows in this shelter zone.
2. With their deep root structure and high water and nutrients demand, the nitrate leaching close to the willow trees will be lower compared to leaching at increasing distance away from trees.
3. Unlike NO_3-N that is soluble to water and can easily be leached, NH_4-N can bound with soil particles before it is nitrified. It is therefore expected relatively largest proportion of NH_4-N concentrations in top soils (0 -25 cm) than in subsoil.

CHAPTER II: LITERATURE REVIEW

2.1. Outdoor organic pig farming system

In recent decades, there has been an increased number of pigs raised in outdoor settings in Europe and parts of Northern America (USDA, 2007). In UK for instance, the frequency of outdoor pigs was 20% in 1995 compared to only 6% in 1975 (Edwards, 1995). In the case of US, 15% of farms with gestating sows, the sows are kept outdoor while in addition 45% of US farms with sows, the sows are being kept indoor but with a permanent outdoor running access (USDA, 2007). Free range pig farming is characterized by pregnant and lactating sows being roaming and grazing in the pasture while they spend night time in the small huts within the paddock (Webb et al, 2014). The sows are supposed to be kept in outdoor groups except in their late stages of pregnancy and during suckling (EC, 1999).

Weaning age for outdoor piglets according to EU legislation should not be less than 40 days even though there are country specific regulations that are stricter. For Danish organic pig production, the Friland A/S which is the biggest meat exporting company has cooperated with Danish Animal Welfare Society to set what is so called Code of Practise. The Code of Practise are a set of rules and regulations that a farmer has to meet in order for their pork to be sold at Friland A/S. These practises include weaning age of piglets, housing requirements in outdoor settings, disease and health control, water and animal feed, transport of animals and overall farm management. For instance the weaning age of piglets in Danish free-range organic pigs is more strictly with 7 weeks since farrowing compared to only 40 days under EU (Kongsted and Hermansen, 2005). The area required per pig for finishers in the indoor facilities should be 1.0 and 1.3 m^2 for outdoor running access and indoor space respectively (EC, 1999). A typical outdoor pig farming is composed of the optimum number of 20 to 30 pigs per hectare with the pigs being moved into other paddocks in autumn or spring after 1 to 2 years (Williams at al., 2000).

Organic pig farming in Denmark is being done in free range system but the difference with a conventional free range system is that organic pig production has to fulfil EU organic standards and regulations plus some country specific production regulations and standards. Such regulations according to 2007 EC regulation on organic production and labelling of organic products and repealing is prohibition of mineral N fertilizers, pesticides, GMO and hormones for breeding purposes. Others related to livestock production include disease prevention that should be based on proper choice of breeds, husbandry practises and adequate nutrition that meets animal demands. In addition, the stocking density and housing conditions of the livestock should give pigs the opportunity to express their natural behaviour that enable them to fulfil their developmental, physiological and ethological needs (EC, 2007). For instance, pigs raised organically need access to outdoor pasture not less than 150 days in the summer even though some farmers tend to keep the pigs on the pasture all year around (Kongsted and Hermansen, 2005).

In some countries, the combinations of both indoor and outdoor housing are being practised in which the pig farming settings take advantages of both housing systems. In some outdoor systems, weaners and finishers, regardless of having access to outdoor run in their indoor housing, they are being taken out for couple of weeks in summer (FiBL, 2011). In other combinations, the sows are being penned in indoor facilities prior and up to four weeks after parturition in individual farrowing pens. In this system, piglets can be able to move between pens while also high chance for supervision prior and after parturition can be achieved. Therefore the practicability and combination of both outdoor and indoor settings in pig production system will depend on local environment, national standards and farm specific facilities and standards (Vieuille et al., 2003). For example, with regards to the local conditions, some countries along the Gulf Stream experience wide range of weather variation compared to East European countries (i.e. more cold winter and hot summer seasons) and this may pose some challenges in outdoor sows (Akos and Bilkei, 2004). Among other advantages the free-range pig rearing offers, animal welfare has been considered as a major benefit (Eriksen and Kristensen 2001; Kongsted and Hermansen, 2005).

2.2. Animal welfare and other benefits offered by free-range pig farming

The animal welfare, which is probably the most important basis for free-range pig farming, has been regarded as a complex concept that with its attributes being differently perceived (Kling-Eveillard et al., 2007). In most cases the "welfare" has been related to effective state of the animal that depends on both physical well-being as well as satisfaction of their behavioural needs (Lindgren et al., 2014). In the study done by (Spooner et al,. 2014) to find out attitudes of farmers towards their understanding of "animal welfare", in most cases the farmers have related the animal welfare with alternative terms such as "comfort ", "care", "husbandry" and "contentment". Pigs in free-range organic farming are required by EU regulation to be kept on pasture where there are diverse social and environmental settings for expressing their natural behaviour. Also, this article number 14 of EC organic farming regulation recommend minimization of suffering to animals, reduced duration of transportation, upgraded housing conditions that will improve the demands of animals. In addition to that, the personnel responsible for taking care of animals should possess the basic required knowledge on husbandry, health and welfare needs for animals (EC, 2007).

The naturalness has also been mentioned in a third IFOAM principle for organic farming (principle of fairness) which states "animals should be provided with the conditions and opportunities of life that accord with their physiology, natural behaviour and well-being" (IFOAM, 2005). Therefore coupled with continual care given by a farmer, according to production conditions, the animal welfare is attained by provision to an animal with conditions to express their natural behaviour (Edwards et al., 2014). In EU regulation, high animal welfare standards that meet animals' specific behavioural needs is a result of housing conditions, husbandry practises and stocking density (EC, 2007). In addition to that, the use of antibiotics is restricted and natural immunity and disease prevention should be based on selection animal breeds that suit the local conditions.

With the outdoor pig system, studies have come with consistent findings on higher activity rates of outdoor pigs compared to confided pigs (Cronin and Amerongen, 1991; Jarvis et al., 2002). With more ability to carry out locomotion, the outdoor lactating sows and piglets have shown extensive behavioural inventory by exploring the environment and spent more time standing and feeding (Jarvis et al., 2001, 2002: Hötzel et al,. 2004). With exploration of complex environments offered by outdoor system, studies have shown relatively low aggression rates of piglets (Beattie et al., 1995; Hötzel et al,. 2004). Also significant reduction of undesirable social behaviour including belly nosing and agonistic interactions (Webster and Dawkins, 2000), nibbling and tail biting (Lindgren et al., 2014), before and after weaning were observed. The best explanation for this is the reduced piglet oral activities towards each other (Lindgren et al., 2014) which was associated by presence of diverse physical/environmental and social environment provided by outdoor settings (Cox and Cooper, 2001; Beattie et al., 2001; de Jong et al., 1998). In addition to that, outdoor reared pigs have shown less aggression behaviour during pre-slaughter mixing (Terlouw et al., 2009).

With provision of more space that encourage curiosity, the outdoor pig system seems to offer more adaptive skills to stress for piglets and this can be explained through increased solid feed consumption, exploration and social interaction (Cox and Cooper, 2001). The outdoor system also prepares the piglets for weaning as through the outdoor active life which reduces their contact with the sows, there has been higher solid food consumption rates before and after weaning for piglets (Cox and Cooper, 2001; Horrell and Ortega, 2001). In relation to improved food consumption, Spooner et al., (2014) acknowledged that when animals are "happy", it might possibly have positive implication to productivity of the farm. Therefore, in order to make sure that animal welfare is being considered in free-range system, the farmer needs to have strong commitment.

2.3. Concerns and possible production challenges in outdoor pigs

With a wide range of weather conditions throughout the year, there might be lower control of outdoor environment compared to pigs in confined settings (Honeyman, 2005). In Denmark, heat stress has been proposed to increase the risk for high piglet mortality (Pedersen, 2015) and sudden death of lactating sows related to the disease complex called ‘summer-sows’ is also expected to be related to heat stress (Jakobsen & Kongsted, 2015). All pigs of over 20 kg are required to have access a wallow or sprinkling facilities when environmental temperature is above 15℃ according to Danish regulations (Kongsted and Hermansen, 2005). This is in particular important for sows in late pregnancy and lactation due to a high production of body heat. However, this is very time-consuming in large herds with individual paddocks for lactating sows.

With regards to production, the pre-weaning piglet survival in outdoor settings has been among main welfare and economic challenges (Bilkei, 1995; Baxter et al,. 2009). The pre-weaning mortality rates has been recorded to be between 15 - 20% (Leenhouwers et al., 2002). The birth weight which is associated with size and shape as well as thermoregulation have been studied to be among key survival indicators (Arango et al., 2005). The survival rate also depend on extent of weather fluctuations (Bilkei, 1995), frequency of changes in sows posture, infrequent nursing, diseases and longevity of farrowing (Baxter et al., 2009). Studies done by Edwards et al. (1994) reported that mortality rate in the first 72 hours since farrowing accounts for 75% of total mortality before weaning. Therefore the severity of morbidity and mortality of piglets in outdoor is highly depending on management and hence poor management increase chances of financial losses to a farmer (Akos and Bilkei, 2004).

With wet conditions in the grazing area, the sows might bring the mud into the hut´s bedding that increases the chances for higher piglet mortality. Also muddy conditions make it difficult for sows to feed properly which results into reduced colostrum’s and milk production thus diminishing piglet survival (Akos and Bilkei, 2004). With the main cause of piglet's mortality being sows lying down on piglets, the extent of stockman supervision will highly determine mortality rate on the herd (Bilkei, 1995). Lastly, another concern in free range pigs is the maintenance of pasture stand throughout the year, and this has a lot to do with stocking densities and rotational of animals between paddocks. Keeping high the level of grass helps to reduce piglet's mortality and this can be explained by having dry and clean, mud free pig hut (Kongsted and Hermansen, 2005). In addition, having enough pasture will increase roughage availability for pigs as their daily feed requirement (Kongsted and Hermansen, 2005).

The presence of grazing area in outdoor settings increase the risk of environmental pollution particularly through excess nutrient loading, mainly Nitrogen and Phosphorus (Staufferet et al., 1999; Petersen et al., 2001; Sommer et al., 2001). However, the extent of environmental impacts will depend on intensity of outdoor production particularly stocking rate (Baxter et al., 2009), management and suitability of location for production (Quintern and Sundrum, 2006). Nitrate leaching and ammonia volatilization potential in outdoor systems is higher due to impossibilities of controlling excretes and urine in outdoor pasture and larger area required (Kumm, 2002; Salomon et al. 2007, 2012). Also, uneven excretion and urination in grazing area creates hotspots which results into heterogeneity in soil nutrient distribution (Watson et al., 2003). Stauffer et al., (1999) reported 20 times higher leaching potential in front of the huts compared to the rest of the pasture area. Similar results were found by other studies done by Stolba & Wood-Gush (1989) and Andresen (2000) where there were higher excretion frequency close to dwelling areas compared to other parts of the paddocks. The nitrate leaching potential is increased with higher stocking density due to increased net nutrients surplus in the system (Eriksen and Kristensen 2001).

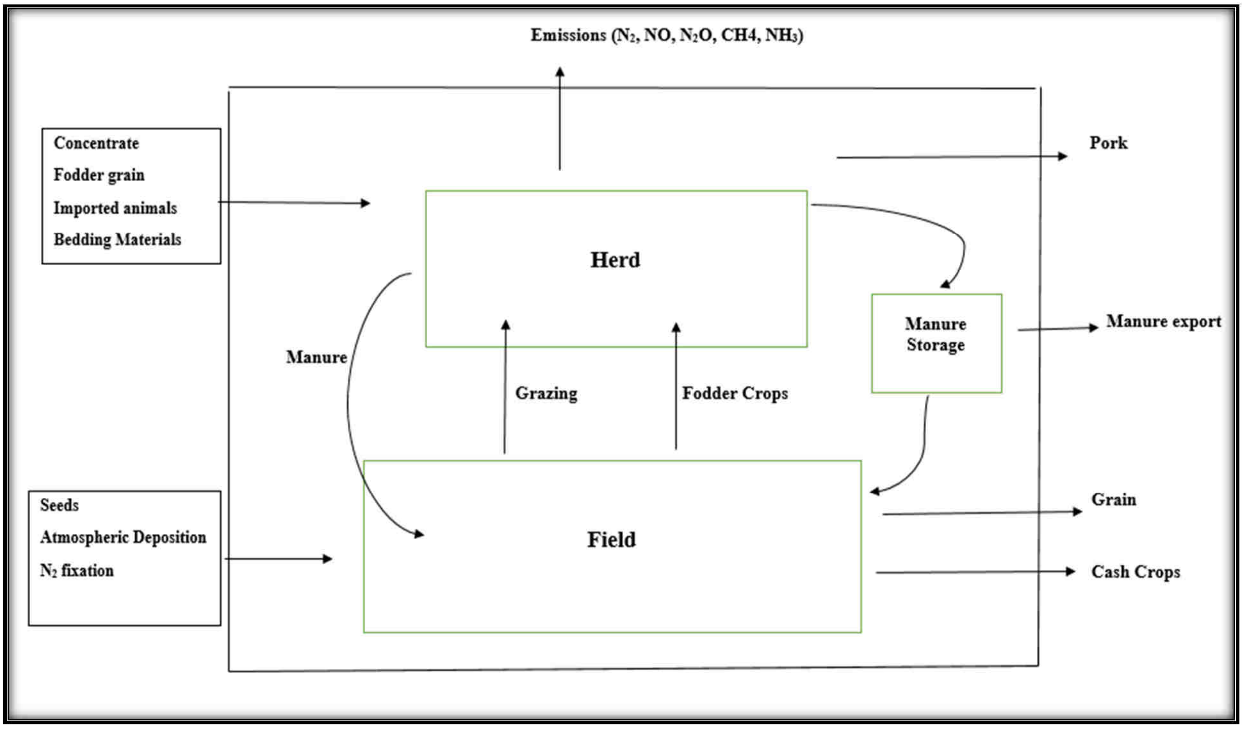
2.4. Nutrient flow and dynamics in organic pig farming

2.4.1. Nitrogen balance

The excess nutrient surpluses into the environment is prone to be lost out of the farm through different pathways including nitrate leaching (Staufferet et al., 1999), and gaseous N emission to atmosphere occurs via denitrification (Petersen et al., 2001) and volatilization (Sommer et al., 2001). The major sources of N are urine which is in mainly in form of urea together with excrements that constitute organically bound N and mineral nitrogen. Urine and solid excretes create hotspot areas where potential nutrient loss is relatively higher compared to the rest of the paddock (Andresen, 2000; Eriksen and Kristensen, 2001). NH_4^+ and NO_3-N from urine are plant readily available forms of nitrogen with the latter being of highly ecological and environmental relevance through leaching (Quintern and Sundrum, 2006). NH_4^+ could also be produced after mineralization of excretes and fodder even though these two sources possess relatively moderate to lower leaching potential.

In determining nitrogen efficiency and potential losses in a farming system, nutrient surplus has been widely used as an indicator (Watson et al., 2003; Nielsen and Kristensen, 2005). The efficiency is expressed as how much of the input is converted into desired products (and co-products) with the remaining being excreted and deposited on the soil. The N deposited as ammonium-N (as ammonia and nitrous oxide compounds) will be lost to the atmosphere while organically bound N will be mineralized into ammonium-N and then nitrate-N that will be added into soil mineral N pool (Watson et al., 2003). The nitrate-N can be available for plant uptake, leached and some of it anaerobically denitrified into atmospheric as nitrogen gas (N_2) in which potent greenhouse gas nitrous oxide (N_2O) and NO are produced in the process (Williams et al., 2000). However, the accuracy of nutrient balance will depend on complexity of a farming system as well as associated errors and uncertainties in quantifying the actual inputs and outputs with the heterogeneity of nutrient distribution in outdoor settings being the main reason (Eriksen and Kristensen, 2001; Nielsen and Kristensen, 2005). N efficiency under Danish organic outdoor farming has been reported to be relatively lower than indoor conventional pigs i.e. about 28 +/- 4.6% for organic versus 35 +/- 2.5 % for indoor pigs. Below is a sketch of typical Danish outdoor organic pig farming that includes inputs, outputs and emissions as simulated from Nielsen and Kristensen (2005).

Figure 1: Flows accounted in nutrients balance calculation balance at farm level in organic pig settings



Farm balance accounts inputs and outputs (including emissions) from both herd and field balances. For field balance, where feed crops are grown, the main nutrient input is manure, atmospheric deposition, N fixation (in case there are nitrogen fixing plants e.g. clover), imported feed. Manure stored from the indoor weaners and finishing pigs are in most cases used in as major N and P sources for crops while also importation of manure from other farms could also be involved. The amount of manure to be applied per hectare per crop differs and this is guided by harmony rule that aims at controlling excess nutrient loading to the environment (Kongsted and Hermansen, 2005). With organic yield for crops being lower, with reported being 67% compared to the ones grown conventionally (Badgley and Perfecto, 2007), importation of both grain and concentrate is inevitable so as to meet pigs daily feed demand. This will however depend mainly with land size used as well as the size of herd. For the grazing area, the deposited is used as the main nutrient source for the grass due to practical possibilities of being able to collect manures from the outdoor or using synthetic fertilizers in organic pig farming (Nielsen and Kristensen et al., 2005). The importation of concentrates is crucial because additional of synthetic essential amino acids is as well restricted in organic pig farming together with lower feed efficiency that might not fulfil pig nutritional demand (Nielsen and Kristensen, 2005).

Apart from manure, atmospheric deposition is another input source which in Denmark is between 10 and 15 kg N/ha/year with the main source being combustion and agriculture from outside Denmark that accounts for 41 and 20% respectively (Hertel et al,. 2013). Danish agricultural activities contribute 36% while combustion that comes within Denmark accounts for only 2% of the total N deposition (Hertel et al., 2013). The N_2 fixation for leguminous crops also contribute to N input and it depends on the composition of the forage for example in grass/clover pasture where clover covers over 25% the N fixation can be as high as 150 kg N/ha/year while around 20 kg N/ha/year can be obtained with low clover content (Daalgard et al,. 2012). The seed for growing pastures and crops as well as straws for bedding materials add another N in the system also. The grown crops as a source of feed for pigs, are the output in the field component of the farm so mostly they are utilized by the pigs in the herd component. It might happen that a farmer may sell some of the crop yield in order to buy some concentrate or other cheaper and available animal feed, even though this is not that common (Nielsen and Kristensen, 2005).

The main farm output is meat (pork) which is calculated as how much N is present in one kilogram of pork to obtain how much N is being exported out of the farm. The estimated amount of N and P in one kilogram of pork is 26 g N/kg and 5.5 g P/kg respectively (Olsson et al, 2014). Also for the case of a new farm, one of the input as seen in figure 1 above is imported live animals. Therefore with inputs and output, the surplus can be computed and the difference is the N that is left in the soil through urine and faeces which can either be taken by plants, retained in soil mineral pool or being lost. All the emissions, either through NO_{3}-N leaching, denitrification, nitrous oxide emissions or ammonia volatilization can be estimated from the N surplus using the emission standards from the literature. However the comparison between farms with regards to N and P surpluses differs due to livestock density in the farm, how much of N and P is imported in feed or exported in manure, management and imposed environmental regulations (Nielsen and Kristensen, 2005). For instance with harmony rule that requires any excess from 1.4 LU of pig manure to be exported to other farms, the environmental effects might appear on the other farms. To summarize the N surplus, the positive N balance (N input - N output) value means there is excess input and/or less utilization which brings environmental concerns while negative balance impacts the agronomic status of a system as much N is being taken of the farming system.

In estimating the N balance at field level, the difference between N input and N output which is expressed into percentage (i.e. Field N balance (%) = Field N input/ Field N output* 100%) where the same expression is also used for herd balance (i.e. Herd N balance (%) = Herd N input/ Herd N balance * 100%). The farm N efficiency expresses the percentage of how much of the incurred input have been converted into desired output, pork. N from urine and faeces from the grassland isn't accounted in the estimating since it remains in the system. The same is true for the home grown feed since is being used by pigs within the farm system. A lot of studies have quantified a relatively lower N efficiency in organic pig farming and the explanation could be due to two reasons. Firstly, the high piglet mortality rate which could be as high as 20 % from birth to weaning and this affect the efficiency since it lowers the N output percentage. Also lower feed efficiency in outdoor settings is another reason as there is high risk of feed waste and also difficulties in controlling excretes on the pasture (Eriksen et al., 2002; Sommer et al., 2001). Lastly the lower yield of home-grown organic feeds as compared to conventional feed means the increased need for importing the more feed which could increase the risk of both feed waste and surpluses.

2.4.2. Nitrate leaching potential

The excess surplus of nutrients in the outdoor pig farming is prone to be lost through leaching which enters underground water that could lead into increased eutrophication and reduced drinking water quality (Watson et al., 2003; Akos and Bilkei, 2004; Quinter and Sundrum, 2006; Edwards et al., 2014). The loss of NO_3^-, which is highly mobile in water is also associated with indirect emissions of nitrous oxide (N_2O) when NO_3^- is being anaerobically reduced into diatomic nitrogen (H_2) which is an inert gas (Bolan et al,. 2004). Apart from NO_3^-, ammonium (NH_4^+) and dissolved organic N (DON) may also be lost through leaching even though NH_4^+ is less prone for leaching due to its ability to bound with soil particles (Webb et al., 2014). The NO_3^- leaching potential in outdoor pig farming depends on soil type and condition, subsequent soil management, the vegetation cover and climate (Webb et al. 2014). High nitrate leaching potential is expected in hotspot areas in the grazing pasture where there is point deposition of urine and excretes, (Sommer et al., 2001; Eriksen & Kristensen, 2001) and also where is a combination of sandy soil with high moisture content (Ivanova-Peneva et al,. 2006). The extent of leaching is more pronounced with higher stocking density which has implication of increasing urine and excretes deposition together with soil disturbances through overgrazing and reduced grass cover (Webb et al,. 2014).

Under Danish outdoor pig farming conditions, the N surplus per hectare as reported by Eriksen et al., (2002) could be as high as between 300 to 600 kg N/ha with NO_3^-N leaching potential was estimated to be around 150 kg N/ha. However the distribution of mineral N within the paddock is not always uniform due to hotspot areas as well as excretory behaviour of pigs. Eriksen and Kristensen (2001) found higher inorganic N concentration close to the feeding troughs which was 454 kg N/ha and only 10 metres away from the troughs the mineral N decreased to the half. The same findings were reported by Eriksen (2001) where mineral N were quite higher (500 kg N/ha) around 10 metres from feeding troughs and the concentration were decreasing to 330 and 200 kg N/ha at 22 and 28 metres away from the feeding troughs respectively. A similar two years study done by Webb et al., (2014) in a sandy soil with 12 sows per hectare quantified the lower first-year nitrate-N concentration that was even below EC limit for water quality which is 11.3 mg NO_3-N /L. However in two years' time, the mineral N levels from a system was estimated to be between 184 to 316 kg N/ha which was in three fold levels compared to the arable controlling measurements. With such high surplus the nitrate leaching potential was between 126 to 192 kg N/ha compared to only 52 kg N/ha in control measurements. The increased N surplus in these two years according to Webb et al (2014) was be explained by lower feed efficiency, increased urine and excretes in the pasture as well as ongoing mineralization.

Williams et al., (2000) also support the argument that the first winter leaching could occur from N residues which were present in the soil from the previous crop. Also there are some contrast findings on higher NO_3^- close to the feeding area as (Quintern and Sundrum, 2006) reported lower concentration compared to the average nitrate leaching i.e. 9 kg N/ha compared to 59 kg N/ha. The possible explanation for such difference was due to higher denitrification rate. Therefore with an outdoor pig system (without integrated with energy crops), most of studies have quantified that the N surplus that is lost through leaching is higher in areas close to the huts and feeders.

2.4.3. Ammonia volatilization

According to FAO, (2006), ammonia emission from agriculture accounts for 94% of global anthropogenic NH_3 emission with livestock sector having the biggest share of 68% of the emissions. There is however well research documentation that most of these emissions are being produced from the buildings rather than in outdoor systems (Galloway et al., 2004; Philippe et al., 2011). NH_3 is of environmental importance as it contributes directly to acidification and eutrophication of sensitive ecosystems and indirectly have impact on ozone pollution (Webb et al., 2014). With controlling the N emission (and other pollution sources apart from agriculture) in Europe, EC National Emissions Ceilings Directive and The Gothenburg Protocol which is under UNECE (United Nations Economic Commission for Europe) are among the specific measures that have been taken to regulate emissions among member states (Bolan et al,. 2004, Ivanova-Peneva et al,. 2006). For example, compared to 1980 NH_3 emissions, with the reference being Dutch ammonia legislation, there have been a significant reduction of ammonia emission of 40% in Netherlands (Ivanova-Peneva et al., 2006). With reference to pig production, ammonia is produced primarily from urea (and little also faeces) which is the main form of urine through hydrolysis process under the influence of an enzyme urease (Ivanova-Peneva et al., 2008; Olsson et al., 2014).

There is an established equilibrium between ammonium (in aqueous form) and ammonia (in gaseous form) in the deposited urine and excretes, and the partial pressure difference between the soil surface and atmosphere will influence the extent of NH_3 volatilization from the aqueous form (Philippe et al., 2011). The NH_3 production is affected by the temperature, pH, moisture content, ammonical N concentration, air velocity and time (Sommer et al, 2006: Philippe et al., 2011).

The relationship between solar radiation and increasing ammonia emission has been explained by several studies. Sommer and Hutchings (2001) explained increased atmospheric turbulence due to solar radiation could transport NH_3 away from the atmosphere-ammonical N phase. Also with the radiation, there is an increase of water evaporation which increases the ammonical N concentration that triggers the emission. With turbulence transport due to solar radiation being mainly responsible for NH_3 upwardly, the horizontal NH_3 loss will highly depend on wind velocity (Sommer and Hutchings, 2001). Unlike in indoor pig farming, the temperature effect in free-range pigs can be difficult to control and therefore emissions might be relatively higher especially in summer periods compared to cold months (Philippe et al,. 2011). Apart from solar radiation, the ammonical N infiltration rate is another important factor that may affect NH_3 loss. High rainfall may dilute the ammonical N concentration which reduces the NH_3 emission even through the emission might increase as the water evaporates (Sommer and Hutchings, 2001). Also increased infiltration rate means some of NH_4^- will be adsorbed with soil particles, which technically reduces ammonical N concentration and hence low NH_3 emission. The NH_4^- sorption capacity will however strongly depend on soil type, soil moisture and pH. With the pH, where by the optimum level for urease is slightly alkaline (7.5- 9), the activity rate is high while decreasing as the pH becoming more acidic (Bolan et al., 2004).

The dissociation of ammonia from ammonium is highly favoured under alkaline conditions and this is the reason that slurry acidification have been used as a means to inhibit ammonia emission in agricultural production. The contact area as well can be another influence on volatilization rate as the bigger the area exposed, the higher the chance of NH_3 subjected to emission factors including wind and temperature (Bolan et al,. 2004). As the pasture-covered area being 80% or more of the total land area in most of outdoor settings (Williams et al., 2000), urine and faeces usually spread in most of the soil within the paddock and this might favour temperature and wind as emitting factors. This is true in organic settings as synthetic amino acids are not allowed which requires an additional supply of dietary protein that ends up with lower N efficiency (Daalgard et al., 1998). The lower N efficiency makes excess N excretion in which about 50% is given out through urine and approximately 20% in the faeces which may increase the loss via ammonia volatilization (Ivanova-Peneva et al,. 2008; Olsson et al,. 2014).

2.4.4. The fate of dissolved Phosphorus in outdoor pig systems

Apart from Nitrogen, Phosphorus is also an essential nutrient in pig's diet and as well it is of environmental concern (Matula, 2011; Olsson et al., 2014). There has been a significant P reduction from point sources including households and industries which leaves higher contribution of diffuse sources in P loss (Heathwaite and Dils, 2000). In North Western Europe for instance, 50 to 80% reduction from point sources has been achieved and this was contributed by improved wastewater treatment plants as well as detergents free from phosphate (Smit et al,. 2009). Reports have shown that agriculture is the main contributor of P loss in countries of Baltic Sea as well as North Sea Basins where P loss can account for more than 50% in countries with high agricultural activities (Smit et al,. 2009). Other P loss sources apart from agriculture include aquaculture, sewage treatment, industries, natural background losses and atmospheric deposition (Bomans et al., 2005).

With pigs being non-ruminant mean they lack the ability of extracting P in the cereals which is in form of phytate (Nielsen and Kristensen, 2005). In non-organic farming there is addition of synthetic phytase, an enzyme responsible for digesting the phytate and make the P being available in pig's diet (Poulsen et al. 2000). However with EU regulation, where feed additives are not allowed in organic farming, hence there is an increase of dietary P which result into higher P excretion. For instance, in a survey from 63 Danish farms between 1997 and 2003, the P in concentrate for outdoor sows was higher (73 +/- 21 kg P/ha) as compared to indoor pigs (52 +/- 47 Kg P/ha) (Nielsen and Kristensen, 2005). However, even with higher total input in outdoor sows, the P herd efficiency has been as low as 28.3+/-4.6 % which is according to a survey under Danish pig farming (Nielsen and Kristensen, 2005). The low P efficiency in organic sows have also been pointed out by Olsson et al., (2014) where P body retention in pigs range from only 37 to 40 % of the total P input while about 50 % is being passed out through faeces. Also with low P extraction from the feed, about 9% of P in the diet is being excreted via urine (Poulsen et al. 2000). There is high variation for a number of factors including farm specific conditions, seasonality and dietary P used.

In analysis of P dynamics in the soil, water extractable P is important to provide information on P availability for grass stand uptake as well as possible environmental impacts (Svanback et al., 2013). In soil water analysis, water samples are used to analyse the total P and dissolved P and the difference between the two makes the particulate P (Matula, 2011). In general, a typical total P in the soil varies from 0.2 to 2.0 g P/kg of soil even though most of this P is not in a form readily for grass uptake (Bomans et al,. 2005). With particulate P being a dominant form, the dissolved P is in very small quantities (usually less than 0.1% of total P) even though when reaching water it supports rapid algae growth as it is in readily available form (Svanback et al., 2013).

Surface run-off and erosion are important pathways for P loss even though these pathways are highly limited to high rainfall events where mostly particulate P bound with soil particles but also dissolved P are lost (Heathwaite and Dils, 2000). The extent of P loss through soil surface will firstly depend on biochemical processes that determines P form that will be lost, but also the hill slope hydrology which have implication on infiltration mechanisms and loss pathways. The preferential P loss pathway through macropore is important to areas such as grasslands where there is little effect of surface runoff and soil erosion (Heathwaite and Dils, 2000), and the same is true to where the landscape terrain is flat (Svanback et al, 2013). In the outdoor grassland, depending on various factors such as management, stocking density, soil characteristics and precipitation, the dissolved P leaching for example can vary from very low levels that are not detected to several mg per litre (Svanback et al., 2013). With the influence of landscape flatness, countries like Sweden and Finland with flat landscapes and where the soil is well drained, the major P loss pathway is usually the subsurface transport through channels created by worms and roots (Svanback et al, 2013). The preferential P loss differs with soil characteristics particularly the soil texture. The soils with high clay content are in most cases dominated by preferential P pathway due to lack of connectivity of flow path and (absence of hydraulic conductivity) (Nimmo, 2012).The risk for dissolved P loss is however high in sandy soil due to its lower adsorption capacity as due to early saturation with soil particles. In addition, some farming practises such as no till and permanent forage stand might help in preserving the soil structure and maintaining the macropore channels responsible for preferential P loss

With an outdoor grassland in free-range pigs, excess nutrient can be associated with increased P loss through both matrix and preferential pathways as the surface run-off and soil erosion are minimal. In a comparative study by Nielsen and Kristensen (2005), P surpluses per hectare in four different farm types were being examined. Compared to conventional dairy, organic dairy and indoor pigs, the outdoor raised pigs produced significantly higher P surpluses 42+/-7.7 kg P/ha and this was three times more compared to indoor pigs (table 1). However, the possible reasons for highest P surpluses for outdoor sows in the above study might be differences in farming systems e.g. stocking rates, ability to control manure and among others these two factors may question the relevancy of comparisons. With harmony rules, manure exported differs with farming system, for example, little or no can be exported from outdoor sows while any excess from 1.4 and 1.7 LU should be exported in indoor pigs and dairy cows respectively (Nielsen and Kristensen, 2005).

With the P uptake in the grassland according to EUROSTAT (2013) estimated to be 31% of the P output, the increasing P surpluses through lower feed efficiency with excrete deposition in the pasture might pose significant ecological impacts to the environment.

Table 1. The average surplus levels for N and P in four different types of farms with 95% confidence interval (Nielsen and Kristensen (2005).

Farm type (no. farms)	Livestock rate LU ha^{-1}	Manure kg N ha^{-1}	kg P ha^{-1}	Nitrogen surplus[a] kg N ha^{-1}	Phosphorus surplus kg P ha^{-1}
Conventional dairy (25)	1.54	175	33	175 ± 16.2^{a}	16 ± 3.6^{a}
Organic dairy (13)	1.14	148	26	113 ± 24.6^{b}	7 ± 5.5^{b}
Pigs indoors (19)	1.54	108	29	123 ± 21.6^{b}	13 ± 4.8^{a}
Pigs/sows outdoors (6)	1.69	182	53	251 ± 34.6^{c}	42 ± 7.7^{c}

[a] Results followed by the same letter were not significantly different at $P<0.05$.

2.5. Willow trees in free-range pig production

Even though free range pig farming performs better in relation to animal welfare (Salomon et al., 2007), various improvement possibilities to cope with weather variations and managing nutrient loss have been carried out. Introduction of perennial energy trees into this farming system seems to be a promising and sustainable way of producing renewable energy while improving animal welfare, agricultural diversity and environmental benefits (Horsted et al,. 2012). In Danish free-range organic pig farms, only few farmers have already established willows and poplar trees even though limited studies have been done to come out with concrete findings on prospects and challenges on integrating these crops in the paddocks.

Integrating trees into the pasture, also known as silvopasture or silvopastoral farming, has been done since 1600s with diversification of agricultural income through wood production and improving shelter and fodder for livestock being the focal objectives (Garrett et al,. 2004). Most of the approaches used in these agro-ecosystems are less intensive approaches and with less potential for undesirable consequences to the environment (USDA, 2012). By increasing agricultural diversity, these systems offer a number of ecosystem services including wind control, soil erosion management, improved pollination, source of food materials, decorative floral and biofuel. The presence of woody perennials in the system also offers opportunity to mitigate the impacts of global warming through sequestration of atmospheric carbon dioxide (Montagnini and Nair 2004).

A willow tree (Salix spp.), is a perennial energy crop that is characterised by having quick juvenile growth, coppicing ability even after multiple harvests, tolerance with high planting density (Volka et al,. 2006) and deep rooting system (Mortensen et al,. 1998). The high transpiration as well as extensive and diffuse root system of willows enables the trees to have wide range of tolerance to water logging conditions (Volka et al,. 2006) as well as being potential for other applications including reduction of nutrient loss to environment (Mortensen et al,. 1998). In a free range pig system combined with willow crops, the pigs should be introduced in paddocks with willow when the trees are well established so as to avoid the aggressive rooting behaviour the pigs may execute on the willows (Horsted et al., 2012). This is because with the rooting and manipulating behaviour of pigs, the young willow trees might be destroyed. Garrett et al., (2004) reported browsing of terminal shoots by the animals might result into deformity or disrupt tree growth and this might threat sustainability of integrating trees in grazing areas. However, whenever there was a constant supply of nutritional fodder in grazing area, Garrett et al., (2004) reported that animals were less keen to browse the tree shoots.

In relation to animal welfare, the well-established trees provide shelter against wind, and the microclimate created by trees is important for pigs particularly for temperature regulation during hot days (Horsted et al., 2012). A study by Sallvik and Walberg (1984) to investigate effect of wind velocity and temperature on outdoor pigs found pigs prefer areas with lower velocity regardless of the temperature. The same study reported frequent cases of shelter seeking when the temperature was 5^{o} C which was below their lower critical temperature. Shade has been reported by Garrett et al. (2004) to improve animal performance, with primary emphasis placed upon heat stress amelioration. In addition to the behavioural shelter seeking, previous related study by Horsted et al. (2012) showed that in presence of willow trees in the paddocks, pigs excrete most of the time close to the willows compared to other areas. Also willow trees away from the feed and water troughs were found to experience lower excretory behaviour compared to willows close to the troughs. In free range pigs without energy crops, studies reported areas close to huts and feedes having higher leaching potential compared to the rest of the paddock. Stauffer et al., (1999) found 20 times higher leaching potential close to feeding and pigs hut. The higher leaching potential close to feeding troughs and huts have also been reported by Eriksen and Kristensen, (2001) and Salomon et al., (2007).

With regard to reducing underground water pollution, studies in US have reported the potential of willow shrubs (with no combination with pigs) to uptake heavy metals and organics from the soil as well as enhance the breakdown of organic to non-toxic compounds in a process so called phytoremediation (Ebbs et al,. 2003). Also willows have shown some preliminary prospect on regulating ground water and this could be explained by its perenniality, fast above and below biomass growth, high transpiration rate and tolerance in wet conditions (Volka et al., 2006). Nair and Graetz, (2004) reported higher nutrient uptake by the soil and vegetation in the woody perennials ecosystem with grazing animals whereby the loss of nutrients into streams channels were minimised. The potential nitrate leaching will however depend on one or combinations of factors which include soil texture, water percolation and moisture content of the soil.

Lastly, as the willows are part of pig production system, there might be some concerns and challenges brought by either presence of trees or their interaction with pigs and other system´s components. In the preliminary stakeholder meeting of AGFORWARD research project (co-funded by the European Commission, Directorate General for Research & Innovation) with Danish organic farmers, among other issues the farmers identified some possible consequences of integrating energy crops into free range farming. Compared to indoor settings, the free-range pig's settings are less automated which means more time will be spent by a farmer with machinery like daily transporting feed and water as well as during restraining and inspecting the pigs. Also the harvesting of willows may pose challenges to a farmer especially when the tree heights are too higher. In addition from economic point of view, a farmer has to foregone a certain piece of land to plant willow instead of being been included in feed production or grazing area for pigs. Therefore a farmer might need to trade-off between the benefit they lose for not growing crops if will be compensated by the repayment from energy crops. From Danish legislation however, the energy crops have to be harvested before 10 years old and then the subsidies can be ongoing similar to conventional crops. Regardless of the mentioned challenges which might directly or indirectly affect a farmer, this integrated farming system seems to offer a lot opportunity both for good animal welfare and environmental sustainability.

Conclusions on Literature review

- With EU regulation and country specific production standards, free-range organic pig farming have been operated on a basis that conform with animal welfare, product quality and environmental protection. Outdoor pigs are able to express their natural behaviour and the restricted use of antibiotics, hormones and pesticides have been among major reasons for the growth of organic pig farming globally. A good example of country specific standards is by Danish Friland A/S that works together with Danish Animal Welfare Society where a farmer is required to oblige the Code of Practise in order for them to sell their pork to this largest exporting meat company in Denmark. While EU regulations apply for all European States, the country-specific standards might be different due to some factors including production conditions and climate variability.
- Being faced with some production challenges particularly for high piglet mortality rate, some practises in outdoor organic farming could put into emphasis and/or introduced. Farrowing hut, being the primary structure in reducing crushing, protecting piglets and principal modifier of the environment, it has to be provided with sufficient amount of straws without forgetting sufficient grass on the paddock. With regard to higher mortality rates in outdoor settings, close supervision prior and after farrowing should be improved. The above proposed improvement strategies should put consideration on improvement of farm breeding goals i.e. careful genetic selection of pigs in order to improve piglet survival rates. The maternal genetic traits including maternal behaviour and lactation output might have positive influence in survival rate of piglets. However in most cases pigs are being bred for increasing growth rates and not improving maternal traits for piglet survival.
- Usually, with free range pigs there is an inevitable risk of excess nutrient loading from excretions in outdoor grassland. The relatively larger land resources need for home-grown feed, lower yield and poor feed conversion by pigs compared to conventional farms may question the sustainability of organic pig production. Therefore some practises including frequent rotation of pigs into new paddocks, having proper paddock design, improved measures on pig's diet and integration of the perennial energy crops into paddocks are likely to reduce the excess nutrients losses.
- With the energy crops, the presence of willow in the paddocks increase farm structural diversity that enhance the extensive behavioural inventory of pigs which enable pigs to express their natural behaviour. Environmentally, willow trees with their long growing season, coppicing

ability, deep rooting system and high nutrient demand, studies have reported the potential of these trees to act as buffers for ground water pollution while at the same time produce bioenergy. With the leaching especially with sandy soil which in Denmark being as high as 70 Kg N/ha, these trees have been reported to have a potential to reduce NO_3- leaching between 45 - 65 Kg N/ha. However, the significance of willow in reducing nitrate leaching might be influenced by number of factors such as stocking density, spatial allocation of features in the paddock, pig rotational regimes, farm history, appropriate willow age to integrate with pigs and general farm management practices.

CHAPTER III: MATERIALS AND METHODS

3.1. Site description and experiment layout

The experimental part of this master project was carried out in a free-range organic pig farm at Hovborgvej Brorup, Region of Southern Denmark (Ulvehøjvej 1, 6650 Brørup) located at 55° 34' 35" N, 8° 59' 30" E. This farm is among the two biggest organic pig farms in Denmark with established energy crops in the pig paddocks (AGFORWARD, 2014). The lactating sows in this particular farm which are approximately 180 are kept in individual paddocks for all year long. The weaning age is 8 weeks where the piglets are moved in the indoor stables with access to outdoor run until they reach slaughter weight. All the weaned piglets are finished on the farm (AGFOWARD, 2014). The willow together with poplar trees have been established back in 2009 in a 1 hectare area of grassland that is used for lactating sows with the willow not have been harvested at least by the time this study was carried out. In order to investigate the nitrate leaching which in Denmark normally occurs between September and March (Blicher-Mathiesen et al., 2014), ceramic suction cups were installed in autumn of 2014 (late October) in the paddocks where the pigs had been removed 4 weeks before installation started.

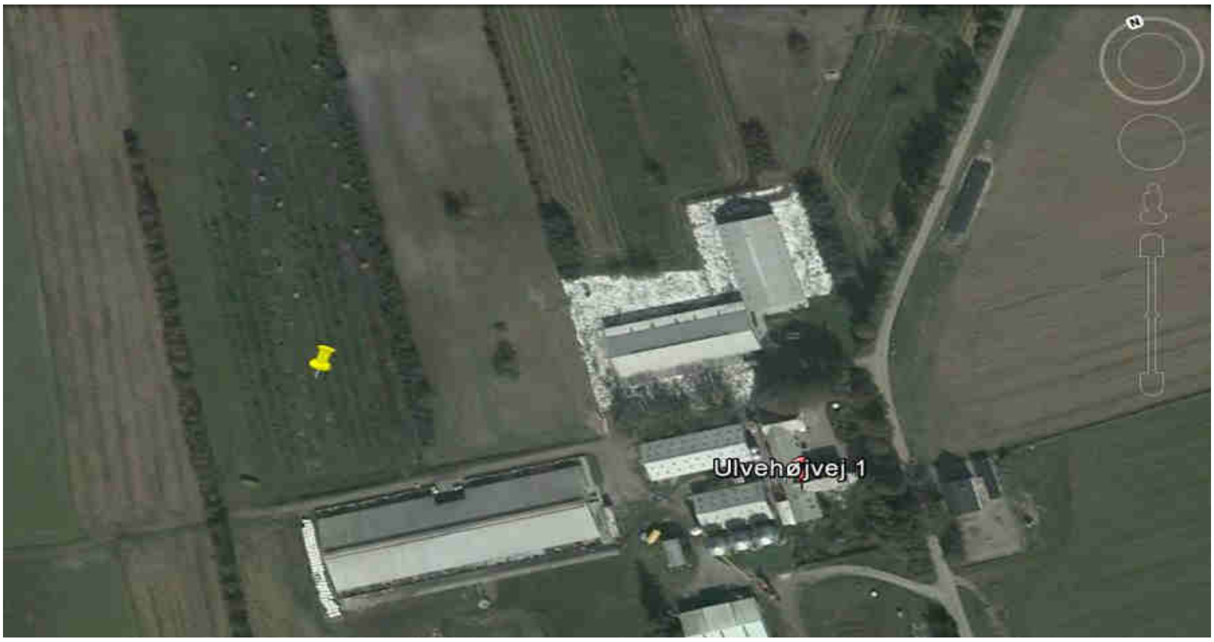
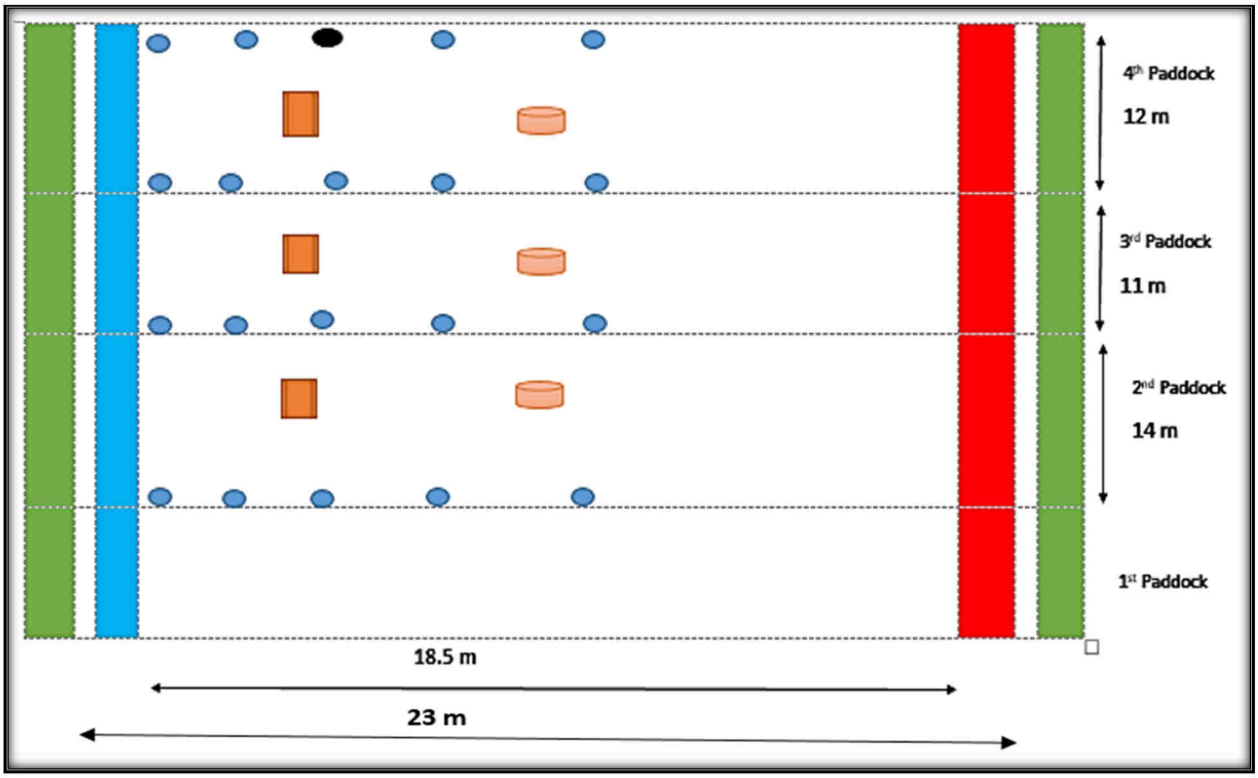


***Figure 2**: The Google Earth map showing the Holm Brian's farm where experiment have been conducted. The yellow pin on the left shows the two years old willow as when this Google Map was produced in 2011. At the bottom left of the picture is the concrete stable with an outdoor run for weaners and finishers.*

The individual paddock's length dimension with only grazing area is 18.5 m while with willow inclusion at both ends of the paddock makes it 23 m length and one paddock from another was demarcated by an electric fence. Unlike the constant length of the paddock, there is however small variation in paddock width as seen in figure 3 where the average width value for the paddocks used in this experiment was 12.3 m. Therefore the paddock size for an individual sow is 282, 9 m^2 (12.3 m x 23 m) which makes the stoking density for the lactating sows to be 35 sows per hectare. There were three willow clone types that were included in the paddocks used in this experiment. Tordis clone in particular was included in both sides of the paddock while there was also Inger and Tora clones as seen in figure 3. The electric fence that marks the end of the paddock was between the two willows rows located on each side of the paddock. However, the suction cups were installed in the paddock side with a row of willow clone which was Inger.

Four measurement rows of 10 metres long from the willow were established with five suction cups in each established measurement row at increasing distances of 0.5, 2.5, 4.5, 6.5 and 9.5 metres from the willow. The starting point of the measurement row was chosen to have a live standing tree and this made the distances between the measurement rows to be different. The distance between first and second row being 4 m, second and third 9 m and lastly third and fourth rows 14 m as shown in figure 3 below. Before installing the suction cup, a small ditch of 0.7 m and 0.15 m depth and width, respectively were dug along the measurement rows to facilitate required depth of the cups from the surface and also to avoid the existed mud to run down the measurement tracks. Due to nature of willow roots which can go as deep as 1.3 m from the surface, the points where cups were installed, and the drilling machine made a hole of 1.5 m depth from the surface (this includes 0.7 m of the ditch). Also in order to make sure there is a good contact between the suction cup and soil and avoiding spaces around the cup, 30 ml solution of Silica Flour Millisil M 6.1 was applied at the bottom before inserting the cup. With the soil being sandy and having some small stones, it was not easy to have a uniform depth for all the suction cups as shown in appendix 1 and an average depth for all cups was 1.45 metres. For the same reason, one pipe of the cup got broken and this made the total cups installed at once being 19 instead of expected 20 cups. The sampling and vacuum control tubes from the five suction cups in each row were connected in one vacuum control chamber/sampling chamber (see appendix 3).



Legend:

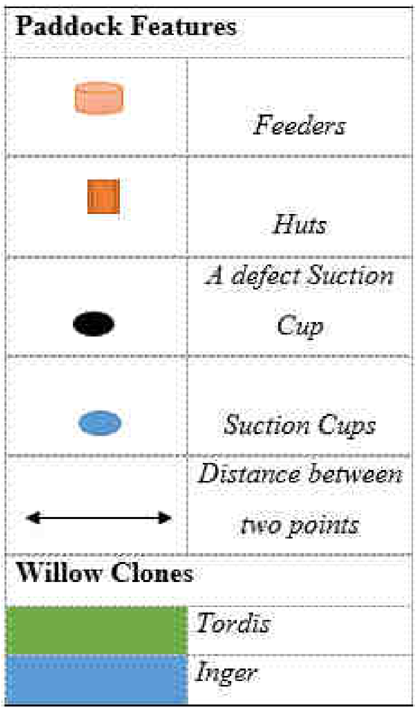


Figure 3*: The experimental layout for lactating sow paddocks showing four measurement rows, each with five suction cups (except in row 1 which had a defect suction cup) established against the two rows of willow trees in each side. The grazing area in the paddock was having insignificant grass cover during autumn and winter. The hut is located at nearly 4.5 m while the feeders are between 6.5 and 9.5 m as seen also in figure 12. The first paddock was not used in the experiment while paddock 2 to 4 are where suctions cups were installed and soil samples were taken. Note that 18.5 m is the distance covered by grazing area while with willow the length becomes 23 m. Also a paddock ends in the middle of the two willow rows in each side of the paddock. The sketch above is not in scale.*

3.2. Soil Sampling

At 1.5 m on each side of suction cup installed, the soil drill was used to take soil samples at three depth levels of 0-25 cm, 25 - 50 cm and 50 - 100 cm from the soil surface. The samples were used to characterize both physical and chemical soil properties including soil texture, total Carbon, Olsen P test for Phosphorus, mineral-N distribution (NO_3^- and NH_4^+) and soil pH. Therefore for all the soil sampling units and at all depth levels there were a total of 60 samples which were deep frozen until the analyses were made. The first analysis with soil was done to quantify the Nitrate-N, ammonium-N and Olsen P at each distance and soil depths with the remained soil samples being kept for further analysis on texture and pH.

With the deficiency of enough soil to carry out soil texture and pH analysis at each soil depth and distance, the decision was made to pool the soils of similar distances from the willow (a total from 0 to 100 cm). By doing so it was therefore not possible to investigate the variation of soil texture and pH with depth, and the analysis was only focused on a distance variation perspective. The soil texture analysis alone needed 100 g, while for total Carbon about 10 to 15 g of soil was required. As shown in table 2 below, the new sample A for instance, was a result of pooled original samples which were sample 1, 2 and 3 together with samples 16, 17 and 18. All of the pooled samples came from the same distance of 0.5 m from willow and the same was true for the other distances. As a result of pooling similar distances, the number of replication for new samples became two unlike the original samples which had four replications.

Table 2: The pooled new soil samples at similar distances from the willow for soil texture and soil content analysis

New Sample	**Distance (metres)**	**Soil Sample numbers from where New Sample was pooled from**	**Total weight of New Sample (grams)**
A	0.5	1,2,3 + 16, 17 18	146
B	2.5	4,5,6 + 19,20,21	156
C	4.5	7,8,9 + 22,23,24	161
D	6.5	10,11,12 + 25,26,27	192
E	9.5	13,14,15 + 28,29,30	214
F	0.5	31,32,33 + 46,47,48	111
G	2.5	34,35,36 + 49,50,51	279
H	4.5	37,38,39 + 52,53,54	272
I	6.5	40,41,42 + 55,56,57	162
J	9.5	43,44,45 + 58,59,60	172

3.3. Laboratory mineral N (Nitrate-N and Ammonium-N) analysis

For mineral N analysis (NO_3^- and NH_4^+), samples collected from the field were being kept in plastic bottles at the freezer with temperature -20^0 C in order to avoid volatilization of ammonium which is triggered as the temperature increases. One day before the analysis started, the samples were taken off the freezer into a room temperature in order to defreeze them. The next process was weighing them and then mix with Potassium Chloride (1 M KCl) before being taken to a shaker in order for the solution and soil particles to thoroughly mix. When shake well, the soil samples were filled in test tubes ready for centrifugation that took place for approximately 5 minutes at 3000 rpm (rounds per minute). With the test tubes, the samples were taken for analysing the quantities of Ammonium-N and Nitrate-N using Spectrophotometry method as used by Best (1976), whereby autoanalyser was connected to the sampler and spectrophotometer by using the tubes (*see appendix 4*). In Autoanalyser machine there were separate tubes for both nitrate and ammonium that pass through the pre-mounted analyser membrane. Hydrazin was used to convert nitrate into nitrite under Copper catalyst ($CuSO_4^{2-}$). The nitrite was then reacted with sulphur amide and ethylenediamine ($C_2H_4(NH_2)_2$) to an azo dye (which can be range from brown-orange-pink colour depending on the NO_3^- concentration) while the actual concentration was determined using spectrophotometer at 520 nm. For analysis of ammonium-N concentration, the ammonium reacts with salicylate ($C_7H_6O_3$) and sodium dichloroisocyanurate under the catalyst Sodium nitroprusside $Na_2[Fe(CN)_5NO]$, to form a pale green or emerald solution before being determined by the spectrophotometer at 660 nm. The separate concentration readings for nitrate and ammonium from the spectrophotometer were eventually being displayed in the connected computer.

3.4. Soil water sampling

The soil water has been sampled every 2 weeks since installation of cups with the first measurement being on 7th November 2014 until 5th March 2015. A suction of 70 kPa was applied 2 days before taking samples which made soil water slowly penetrate into the suction cup. After collection of 9 times, water samples were sent to a private and independent environmental laboratory called “AnalyTech Miljølaboratorium A/S” for analysis of NO3-N concentrations. This laboratory also investigated the Olsen P concentration in the soil water in only one sampling period from the last water samples collected on 5th March 2015. The method used for analysing the nitrate-N was UV Spectrophotometry as used by Navone, (1964) using the spectrophotometer with glass cuvette. The cuvette has two opposite sides which are opaque and transparent with the later sides being able to transmit Ultra Violet light (UV). The soil water samples were kept in the refrigerator at 4 ^{o}C before the analysis began. In laboratory analysis, the wavelength of 220 nm was applied to obtain the nitrate levels in the sample. However with presence of dissolved organic matter in the sample which could also be absorbed at 220 nm, the UV of 275 nm was used where only nitrate cannot be absorbed and the difference between the two wavelengths gives the approximate nitrate levels in the soil water. In order to avoid or minimize the interference effect of some suspended materials such as hydroxide and carbonates, simple filtration together with additional of hydrochloric acid was used

3.5. Laboratory Olsen P test

The method used for Olsen P determination was the standard method developed by Olsen *et al.,* (1954). The 10 g of dry soil was weighed into 50 ml test tubes and filled with 20 ml $NaHCO_3$ aqueous solution of pH 8.5. The temperature of the solution was recorded and adjusted to the range of 20 ^{o} C. The $NaHCO_3$ stock solution was prepared by dissolving eighty four grams (84 g) of $NaHCO_3$ crystals in deionized water in a 2L volumetric flask. 10 ml of polyacrylamide was added to the solution ad stirred thoroughly. The pH was adjusted to 8.5 with 2M NaOH and the solution filled with deionized water to 2 litre on the volumetric flask. Each dry soil in test tube was then filled with 20 ml aqueous NaHCO3 solution. After samples were shaken in a rotator for 30 minutes and centrifuged at 3000 rpm for 5 minutes. One (1 ml) millilitre of supernatant was taken with vacuum pipette and diluted in 9 ml deionized water for staining.

3.6. Statistical Analysis

Before sorting the data and conducted statistical analysis, both soil mineral N (NH_4-N and NO_3-N) and P concentrations were converted from mg/Kg TS into Kg/ha as seen in *appendix 6*.

3.6.1. Mineral Nitrogen and Olsen P distributions

A two way ANOVA factorial design with the main effects of distance and depths was used. The distance consisted of five levels (0.5, 2.5, 4.5, 6.5 and 9.5 meters) while the depth had three levels (0-25, 25-50 and 50-100 cm) i.e. 3x5 factorial design. With this design there were four replications which were represented as four measurement rows. The study was therefore carried out to investigate whether the two independent variables had interactive effects on mineral nitrogen (NO_3-N and NH_4-N) and Olsen P concentrations in the paddocks where lactating sows were kept. Whenever there was significant difference (when the *F*-test ($P \leq 0.05$) was significant) the Tukey test was used to point out which pair of concentration means differed significantly. The model for this two-way ANOVA factorial design is as elaborated below.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$$ whereby;

- Y_{ijk} - the observed concentration at depth *i* and distance *j*
- μ mean of the concentrations
- α_i - effect of depth *i*
- β_j - effect due to distance *j*
- $(\alpha\beta)_{ij}$ - interaction of depth i and distance j
- e_{ijk} - error term. Also *i* =1, 2,3 while *j*,1,2,3,4,5

The (3x5) factorial design can be presented in a simple matrix table 3 below where by A, B and C are concentrations that might or might not have interactive effects of both depth and distance e.g. A3 is the concentration that is determined by the interactive effect of distance 4.5 m and depth 0-25 cm.

Table 3: The 3 x 5 factorial matrix to investigate the distribution of Mineral-N and Olsen P at different soil depths and distance from the willow

	Depths		
Distances (m)	**0-25 cm**	**25-50 cm**	**50-100 cm**
0.5	A1	B1	C1
2.5	A2	B2	C2
4.5	A3	B3	C3
6.5	A4	B4	C4
9.5	A5	B5	C5

3.6.2. The analysis of Nitrate-N in soil water

A factorial design with two way Analysis of Variance (ANOVA) was used with the main effect with this analysis being distance from willow and time of sampling. The effect of time is due to the fact that the soil water sampling has been carried out from autumn (early November) to late winter (early March). The soil water was collected 9 times after every two weeks between the whole sampling periods mentioned. This pattern was replicated with four measurement rows. Unlike nutrient distribution where soil were taken at different depths, the effect of depth in nitrate leaching is not considered since all the suction cups were installed at an average depth of 1.45 m from the soil surface. The ANOVA was used to test whether there was an interaction of time of sampling and distance from willow on the nitrate leaching potential or whether the nitrate concentrations were affected by time of sampling or the distance from willow trees. Tukey test was conducted when the F-test ($P \leq 0.05$) was significant. The statistical model for this analysis is as follows;

$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$ where by

- Y_{ijk} - the observed Nitrate concentration at sampling time i and distance j
- μ mean of the concentrations
- α_i - effect of sampling time i
- β_j - effect due to distance j
- $(\alpha\beta)_{ij}$ - interaction of sampling time i and distance j
- e_{ijk} - error term Also i =1, 2, 3 while j,1,2,3,4,5

The (5x9) factorial design can be presented in a simple matrix table as follows where by letter A - I represent the first to the last soil water sampling period at various distances.

Table 4: The 5 x 9 factorial matrix for investigating the NO3-N concentration in soil water at different distances from the willow from November from 2014 to March 2015

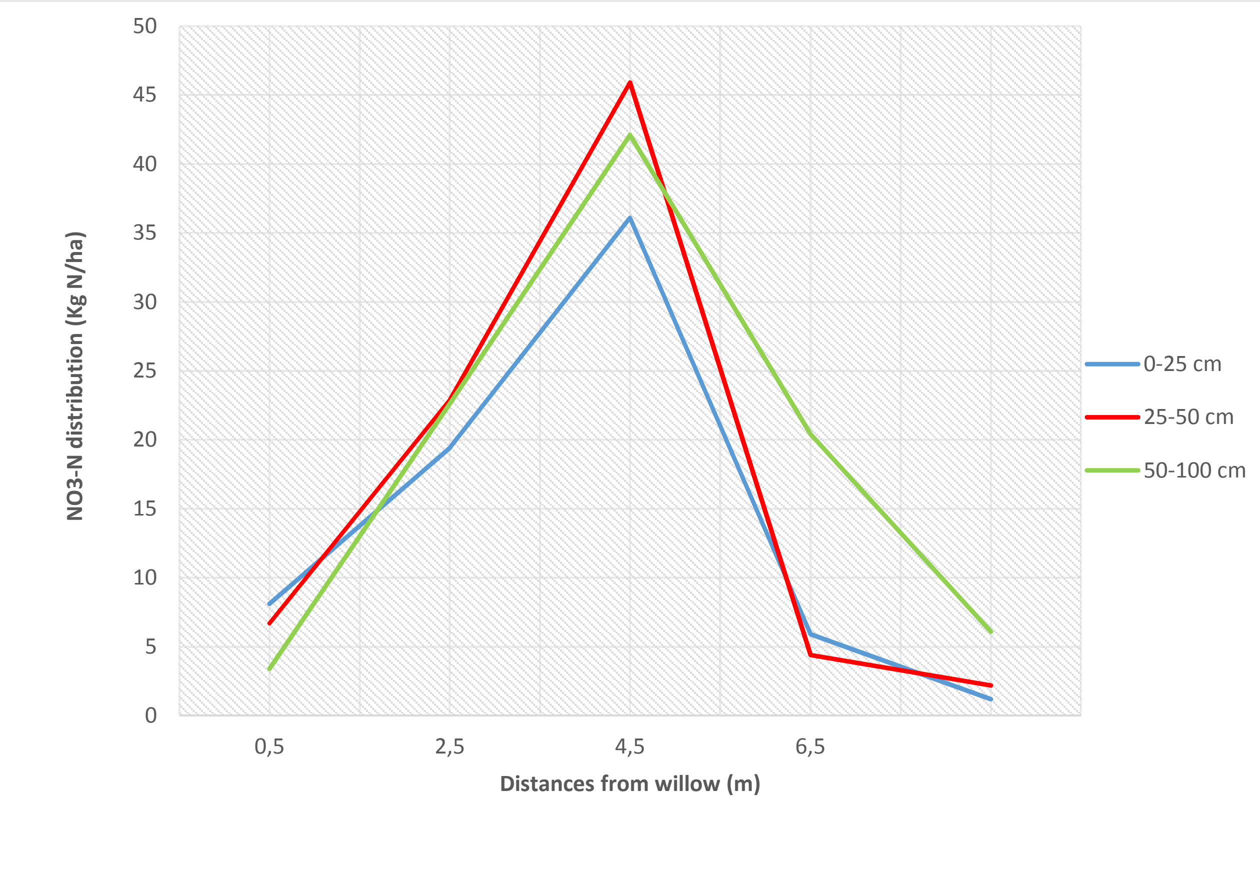
Distance from Willow (m)	Sampling time (November 2014 to March 2015)								
	A	B	C	D	E	F	G	H	I
0.5	0.5A	0.5B	0.5C	0.5D	0.5E	0.5F	0.5G	0.5H	0.5I
2.5	2.5A	2.5B	2.5C	2.5D	2.5E	2.5F	2.5G	2.5H	2.5I
4.5	4.5A	4.5B	4.5C	4.5D	4.5E	4.5F	4.5G	4.5H	4.5I
6.5	6.5A	6.5B	6.5C	6.5D	6.5E	6.5F	6.5G	6.5H	6.5I
9.5	9.5A	9.5B	9.5C	9.5D	9.5E	9.5F	9.5G	9.5H	9.5I

CHAPTER IV: RESULTS

4.1. Nitrate-N distribution at various soils depths and distances from willow

In relation to NO_3-N distribution in the lactating sow paddocks, statistical analysis found a significant interaction effect of the depth and distance (DF=8, $p<0.05$). There was also a strong significant difference in NO_3-N distribution due to distance at various points away from the willow trees (DF = 4, $p<0.001$) while analysis found no main effect due depth variations (DF=2, $p>0.05$) as seen in *Figure 4* below.

Figure 4. Nitrate-N distribution at different soil depths and distance from the willow



The NO_3-N distribution tended to increase from 0.5 m before reached peak levels at 4.5 m and then sharply decreased to the last distance point. At distance 4.5 m from the willow, NO_3-N concentration was significantly higher at all the soil depths compared to other distance points (*Figure 4*). When considering the total average NO_3-N through the whole soil column (0 - 100 cm), the NO_3-N at 4.5 m was 124 Kg N/ha which was about 2, 4, 6 and 11 times more of the total average at 2.5, 6.5, 0.5 and 9.5 m distances respectively. In the lower soil profile (50 - 100 cm) that is susceptible for leaching, the NO_3-N at 4.5 m was as high as 42 Kg/ha with the closest levels came from 2.5 and 6.5 meters with 23 and 20 Kg N/ha respectively (*table 5* below). With NO_3-N variation with depths, the major significant difference in depth levels was at 6.5 m distance where the lower soil level (50-100 cm) had 20 Kg N/ha which was more than three times compared to topsoil.

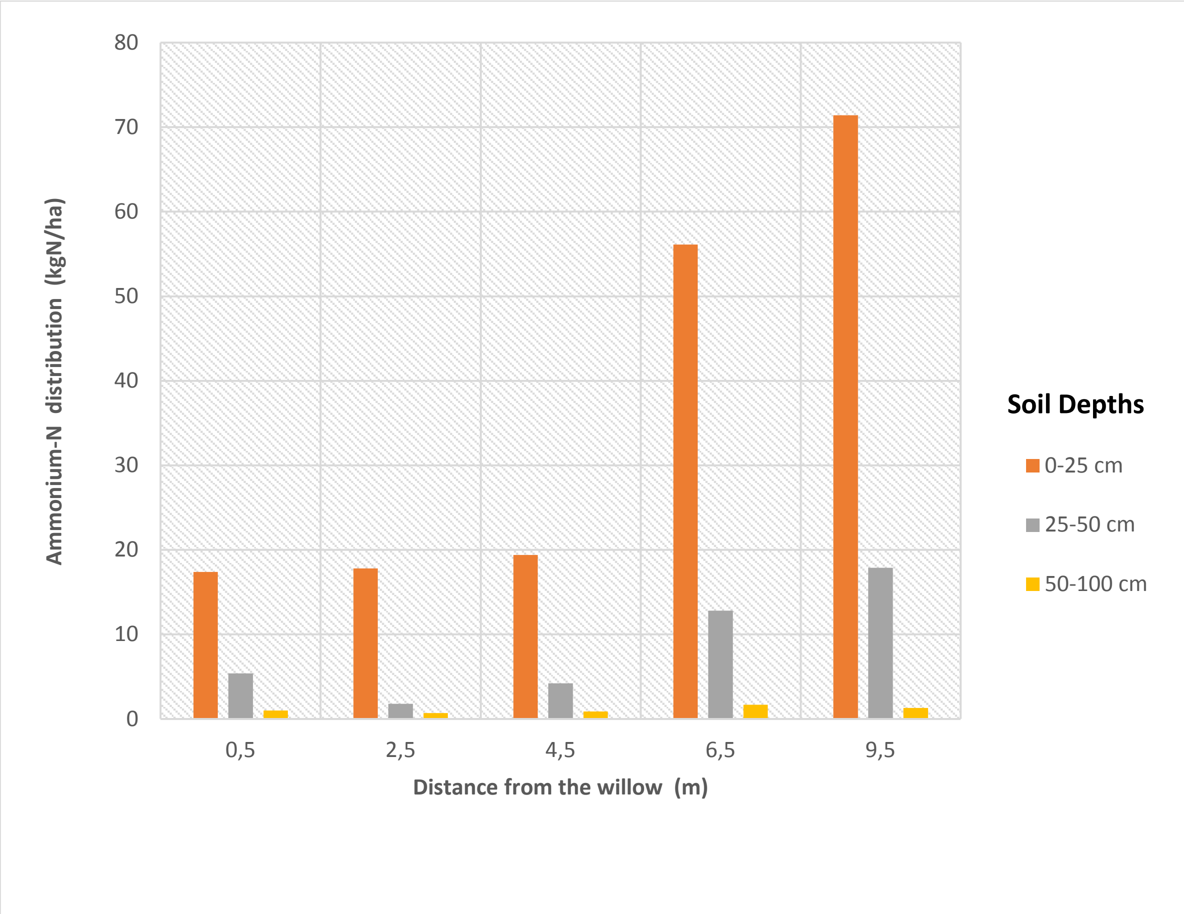
Table 5. The average and total Mineral Nitrogen and Phosphorus (Kg/ha) at each soil depth and distance from the willow trees

Distance (m)	depths (cm)	NO3-N (Kg/ha)	Total NO3-N at each distance (Kg/ha)	NH4-N (Kg/ha)	Total NH4-N in each distance	Mineral N	Total Mineral N in each distance (Kg/ha)	Phosphorus (Kg/ha)	Total P in each distance (Kg P/ha)
0.5	0-25	8	18	17	24	25	42	25	39
	25-50	7		5		12		11	
	50-100	3		1		4		2	
2.5	0-25	19	65	18	20	37	85	31	39
	25-50	23		2		25		7	
	50-100	23		1		23		1	
4.5	0-25	36	124	19	24	56	149	30	43
	25-50	46		4		50		11	
	50-100	42		1		43		2	
6.5	0-25	6	31	56	71	62	101	31	53
	25-50	4		13		17		17	
	50-100	20		2		22		5	
9.5	0-25	1	10	71	91	73	100	28	50
	25-50	2		18		20		19	
	50-100	6		1		8		2	

4.2. Ammonium-N distribution with soil depths and distances variations

The statistical analysis also showed the interaction effect of depth and distance on distribution of NH_4-N in the lactating sow paddocks ($DF= 8$, $p< 0.05$). There were also a strong significant influence of both distance ($DF=4$, $p<0.001$) and depth ($DF=2$, $p<0.001$) on the distribution of NH_4-N. The NH_4-N from willow to 4.5 m was similar at all the three soil depths even though large proportion of NH_4-N was found in top soil. NH_4-N was however significantly higher at 6.5 and 9.5 m distance with 70. 5 and 90.6 Kg N/ha respectively which were 3 times higher compared to the NH_4-N in the first 4.5 m from the willow trees (*Figure 5*). In all the distance points from willow, the top soil (0 - 25 cm) contributed between 73 to 87% of the total NH_4-N in the whole soil profile. The distances 6.5 and 9.5 m are where the feeders were located in the summer and early autumn before the experiment commence.

Figure 5. Ammonium-N distribution at different soil depths and distance from the willow



4.3. Total mineral-N distribution at different soil depths and distance from the willow

When considering the total average of the four measurement rows for mineral N, the statistical analysis did not find the interactive effect of the two main factors (depth and distance) on N_{min} distribution ($df=8$, $p>0.05$). There was however strong significance due to the main factors depth variations ($DF=2$, $p<0.001$) and distance ($DF=4$, $p<0.001$), see *figure 6* below.

Figure 6: Mineral -N distribution at different soil depths and distances from willow

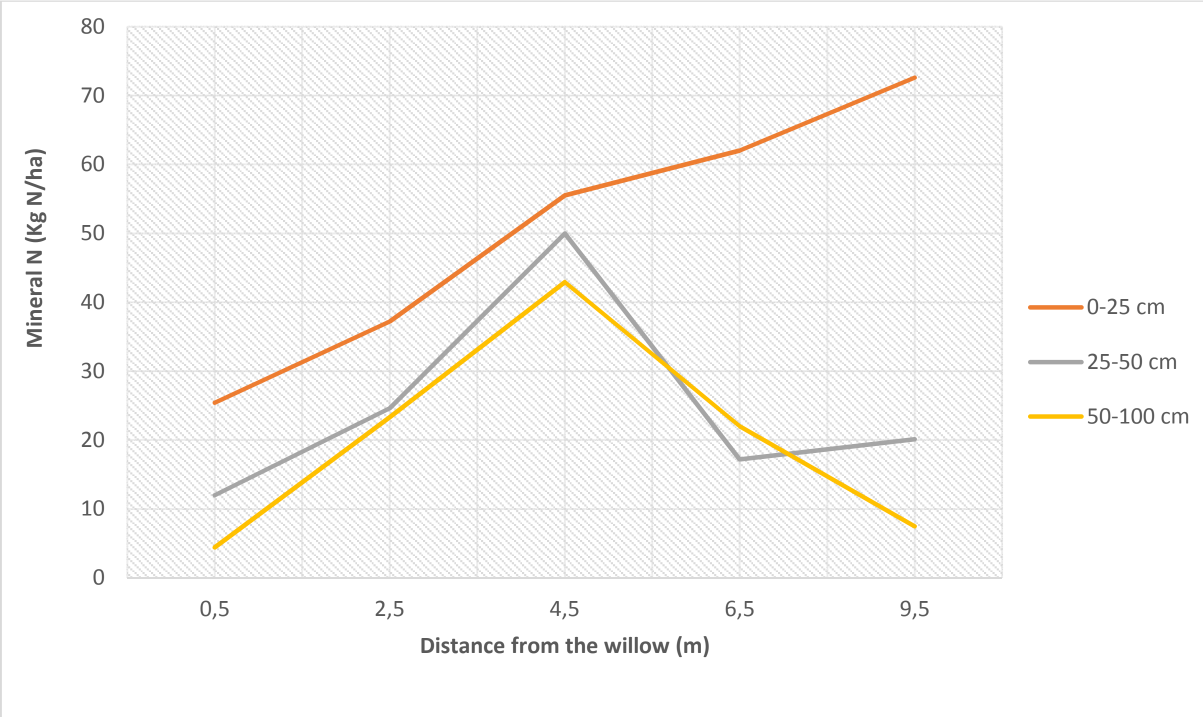
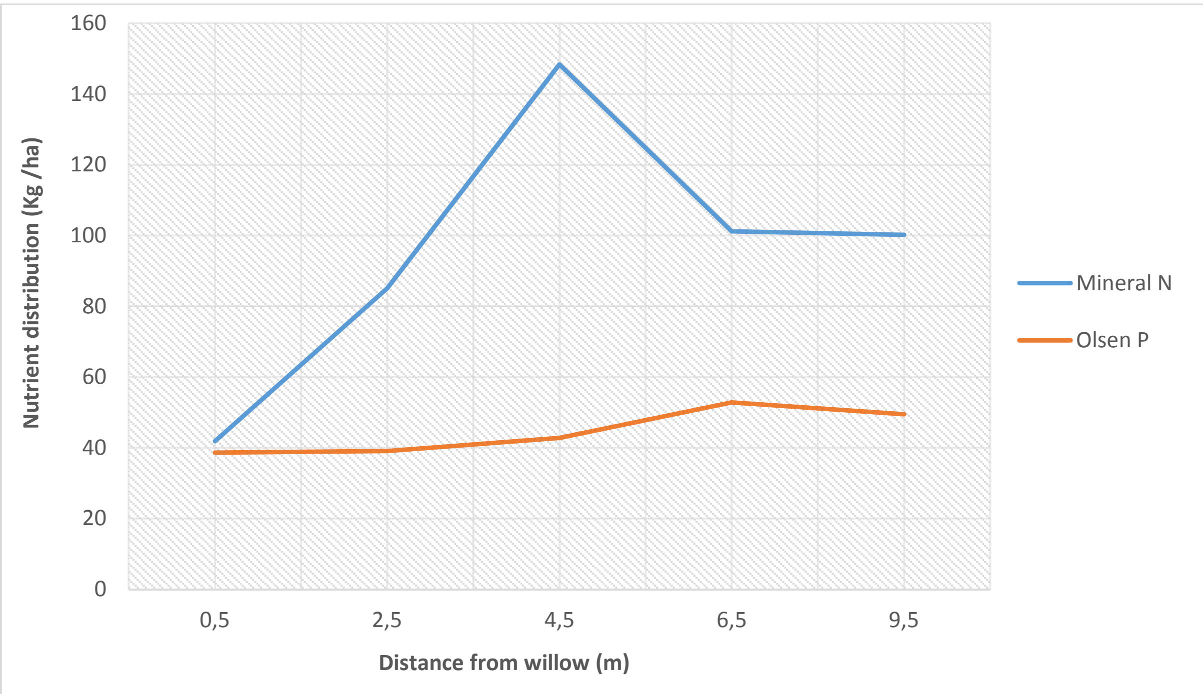


Figure 7. The total mineral N and Olsen P concentrations in a 1 m soil column with various distances from willow



From the willow up to 9.5 m distance, the mineral N showed a significant increasing trend for the top soil (0- 25 cm) with the lowest levels of 25.4 Kg N/ha at 0.5 m and the highest of 72.6 Kg N/ha at 9.5m (*figure 6*). The constituents of this Mineral N differed with distance. For instance the highest contribution of NO_3-N in the top soil (0-25 cm) was found at 4.5 m with about 64% of mineral N while 90 and 98% of NH_4-N accounted for total mineral N at 6.5 and 9.5 m respectively (*table 5*). For the other lower soil profiles, there was an increasing trend for mineral N up to 4.5 m while at 6.5 and 9.5 m the mineral N seemed to decrease.

When taking into account the total mineral N at the whole soil column (0 - 100 cm), the distribution levels at 4.5 m distance with 149 Kg N/ha were significantly higher compared to other distance points (*figure 7*). The NO_3-N at 4.5 m contributed 83% of the total mineral N for the whole soil column and this is the highest proportion of NO_3-N followed by 76% (64.5 Kg N/ha) at 2.5 m distance. In the other way round, the NH_4-N accounted for about 70 and 90% of total mineral N at 6.5 and 9.5 m distances respectively.

Therefore in summary, NH_4-N seemed to concentrate more close to 6.5 and 9.5 m distances which were the location for feed and water troughs as seen in *figure 12*. The mineral N at 6.5 and 9.5 m distances had nearly a similar mineral N content of 101 and 100 Kg N/ha respectively (as seen in *table 5* and *figure 7*) even though they had different proportions of NH_4-N and NO_3-N which will be explained in the discussion part. In addition, the NO_3-N was found in higher levels at 4.5 m distance which was the closest point to the lactating sow huts. This was followed by the 2.5 m distance which was also close to the sow's huts.

Table 6: ANOVA output summarizing the significance levels existed on the Mineral N, Olsen P and NO_3-N in the soil water

Variables	Main Factors & Interaction	Degrees of Freedom	P-value	Significance
NO3-N concentration in soil	Distance: Depth	8	0.0206	*
	Distance	4	8.952e-09	***
	Depth	2	0.1709	NS
NH4-N concentration in soil	Distance: Depth	8	0.01832	*
	Distance	4	1.798e-08	***
	Depth	2	< 2.2e-16	***
Mineral N concentration in soil	Distance: Depth	8	0.06761	NS
	Distance	4	0.0002116	***
	Depth	2	6.348e-07	***
Olsen P concentration in soil	Distance: Depth	8	0.2182	NS
	Distance	4	0.01147	*
	Depth	2	< 2e-16	***
NO3-N in Soil water	Distance: Sampling Time	32	0.9012	NS
	Distance	4	0.001523	**
	Sampling Time	8	0.939754	NS

Legend: NS - Not significant, * - Significance level

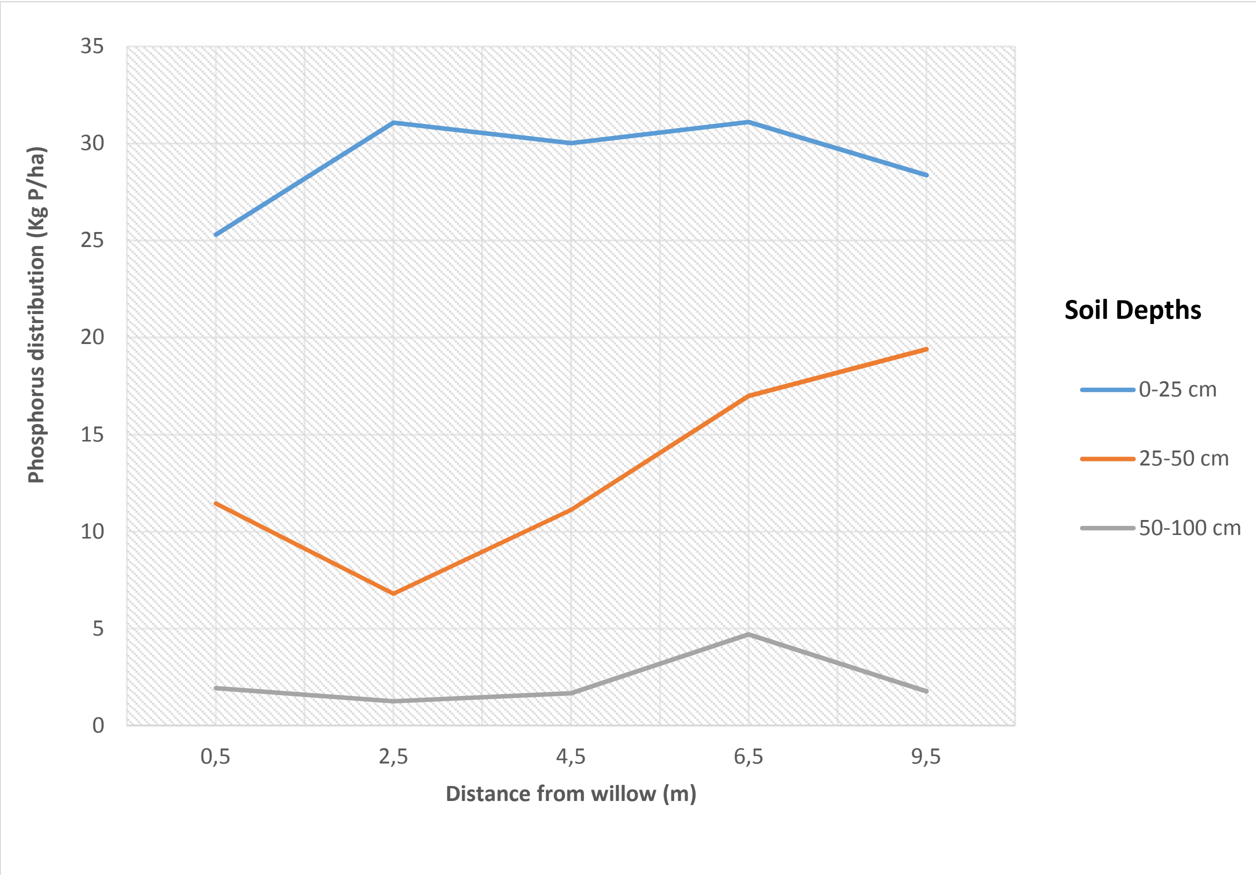
Significance codes:

NS	P > 0.05
*	P < 0.05
**	P < 0.01
***	P <0.001

4.4. Olsen P variations in the paddock

The ANOVA analysis found no interaction effect of depth and distance on the distribution of Phosphorus. The effect due to depth variations was strongly significant ($DF=2$, $p<0.001$). There was also an influence of distance on P distribution even though the effect was not as strong as due to depth variation (DF 4, $p< 0.05$). The Phosphorus in the top soil (0 - 25 cm) was nearly the same from 2.5 to 6.5 m distances with 30 - 31 Kg P/ha with the lowest value came from the closest point to the willow with 25 Kg P/ha. These variations in top soil were not significant. For the subsoil (25 - 50 cm) however, there was an increasing of P levels from the 2.5 to 9.5 m as shown in *figure 8* below. On the total P through the soil column (0-100 cm), the 6.5 m distance had the highest P with the total of 53 kg P/ha followed by 50 Kg P/ha at 9.5 m while the lowest value was found in the closest point to the willow with 39 Kg P/ha (*table 5*). Therefore, most of the Phosphorus in topsoil were found close to feeders than near the trees when considering the distribution in a 1 m soil column.

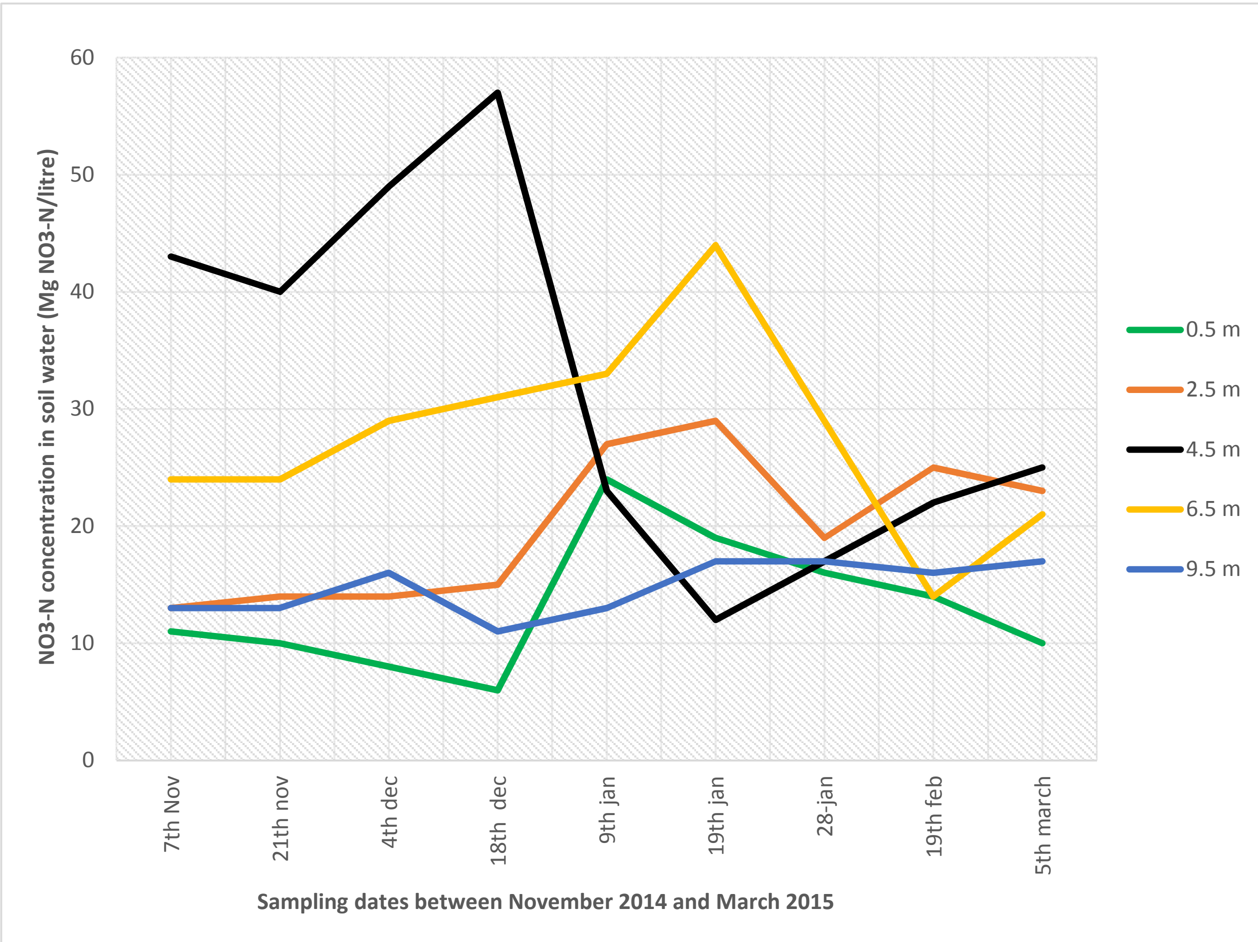
Figure 8: Distribution of Olsen P at various soil depths and distance from the willow



4.5. Nitrate-N concentration in the soil water

Even though there was an interaction effect of distance from the willow and sampling time on the NO_3-N concentration in the soil water, the statistical analysis didn't find them significant (DF=32, $p>0.05$). The concentration level was only found to be significantly affected by the distance variations (DF=4, $p<0.01$) while NO_3-N variation at each distance due to time measurement were not statistically significant (DF=4, $p>0.05$).

Figure 9: The average NO_3-N concentrations in the soil water at different sampling periods and different distance points



With variations due to distances, the Tukey test found only significant difference of NO_3-N concentration at 4.5 and 6.5 distances when they were compared to the closest measurement point to the willow (0.5 m) and at 9.5 m. The other variations with distances were not statistically different. There was an increasing trend for 4.5 and 6.5 m distances with the two having the average peak levels of 57 and 44 mg NO_3-N/litre respectively, with the former recorded the highest concentration compared to other distances. The sampling time for peak concentration at 4.5 m was 18th December 2014 (the fourth sampling) while for 6.5 m distance was 19th January 2015 (sixth sampling).

The average NO_3-N in soil water didn't show high variations with sampling dates throughout the experiment where highest and lowest average levels were 24 and 18 mg NO_3-N/litre, respectively. Unlike sampling dates, distance variations revealed high NO_3-N differences during sampling period. For example 4.5 m recorded the highest average level of 37 NO_3-N/litre for all sampling times even through the highest concentration was 57 NO_3-N/litre in 18th Dec 2014 (fourth sampling). Unlike other distances, the NO_3-N at 9.5 had the lowest average difference between the highest and lowest levels with 6 NO_3-N/litre while 4.5 m had the biggest average difference with 45 NO_3-N/litre.

It was important to make a comparison between NO_3-N concentration in soil water and the NO_3-N levels from the soil samples. Figure *10 a* and *b* below display an average NO_3-N for 20 suction cups (x-axis) for all sampling period with the trend of soil NO_3-N. Note the missing value for a defective suction cup number 3. Suction cups 8 and 13 (4.5 m) found at measurement rows 2 and 3 from the experimental site had the highest NO_3-N from both soil water and soil samples. The pattern for measurement row number 4 was not consistent as previous two rows since highest NO_3-N in soil water was at 6.5 m (suction cup 19). The much better trend could however be observed in figure 10 b where 4.5 m recorded highest NO_3-N levels in both soil water and soil samples. Even though the 2.5 m had high NO_3-N in the soil, this didn't corresponded into NO_3-N in soil water as compared to 6.5 m which had high concentration in soil water. It can also be observed the more or less similar soil water NO_3-N at 0.5 and 9.5 m even though their soil nitrate levels differed. The explanations for these can be seen in the next chapter of discussion.

Figure 10 a: The relationship showing the trend of NO_3-N concentration in soil water with the levels in soil samples

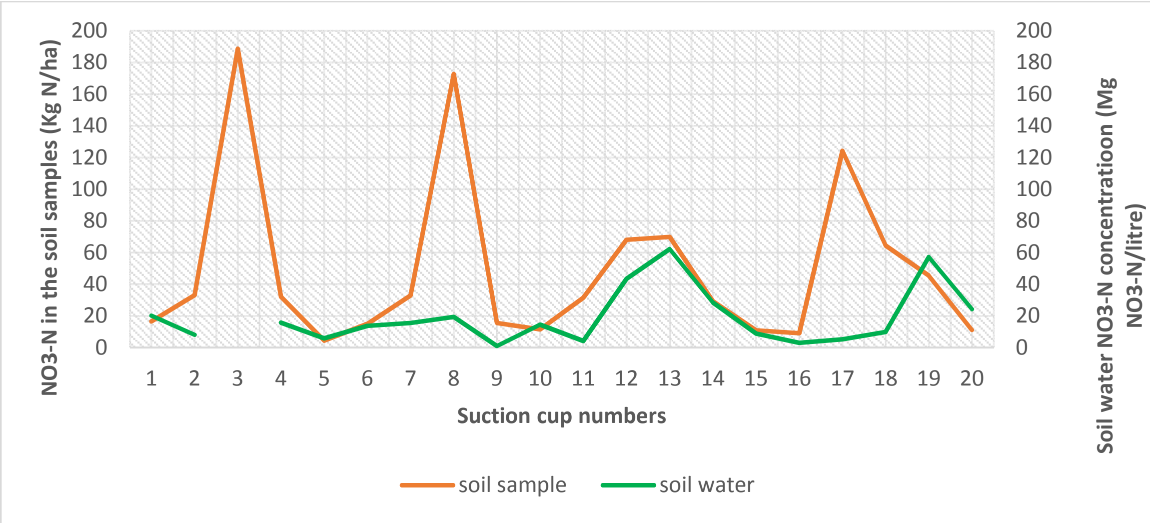
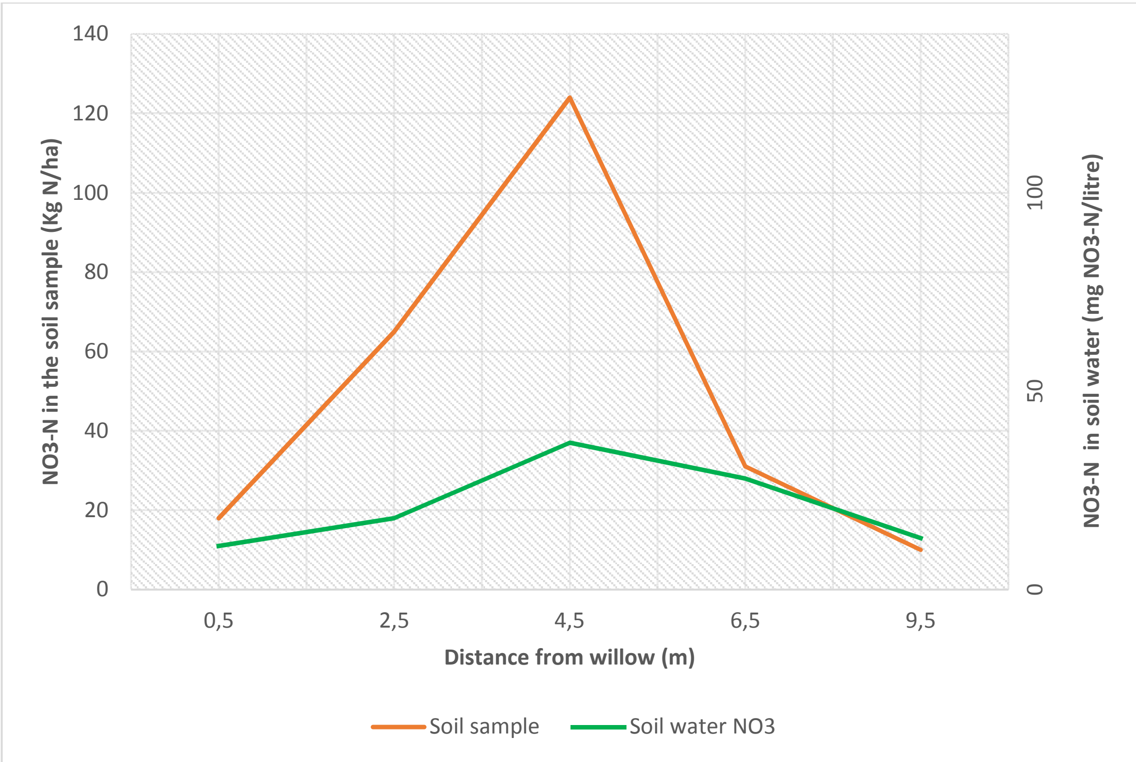


Figure 10 b: The relationship showing average soil water NO_3-N for all suction cups and the soil NO_3-N



4.6. The result for soil properties

From the soil texture classification using the Danish soil classification system (JB-system), all of the soil samples were Coarse sand (JB 1) with exception of 6.5 m distance where by the classification was Coarse Loamy Sand (JB 3) with clay content 5.4 %. The clay content at 6.5 m distance was twice as much as that of 0.5 m distance (*table 7*). For total Carbon in 100 g of soil, the C tended to increase from as you move away from the willow (0.5 m up to 9.5 m) with 9.5 m distance having nearly twice of C found at 0.5 m distance and the same was true for amount of humus. The only measured parameter that showed consistency with different distances was soil pH which was moderately acidic with an average of 5.8 as shown in table 7 below. The soil pH just like the other parameters including soil carbon and soil structure was from an average of 0-100 cm soil column depth.

Table 7: The output for laboratory analysis for soil texture and other soil contents

Distance (m)	**Clay (< 2 µm)**	**Silt (2-20 µm)**	**Course silt (20-63 µm)**	**Fine sand (63-200 µm) + Course sand (200-2000 µm**	**Humus**	**JB Number**	**Total C**	**pH**
m	g/100 g	g/100 g	g/100 g	g/100 g	g/100 g		g/100 g	N/A
0.5	2.35	2.65	4.79	89.03	1.2	1	0.70	5.8
2.5	3.36	2.89	3.74	88.41	1.6	1	0.94	5.8
4.5	3.36	2.89	3.24	88.35	2.2	1	1.27	5.8
6.5	5.23	5.02	4.94	82.64	2.2	3	1.27	5.8
9.5	4.11	2.89	3.95	86.73	2.3	1	1.36	5.8

4.7. Climate conditions

The climate data for rainfall, daily temperature and soil temperature were obtained from the Danish Metereolical Institute database using a grid of 10 x 10 km for Ulvehøjvej. This investigation was done when the daily temperatures ranged from 14 ^{o}C in mid-October to below 5 ^{o}C in March which was more or less similar to that of soil temperature. The rainfall received from the area showed consistent high precipitation from early August to mid-October while also there were some high rainfall spells in both mid-December and mid-January.

Figure 11a: The daily temperature and daily soil temperature at the study area (Ulvehøjvej 1, 6650 Brørup) from May 2014 to March 2015

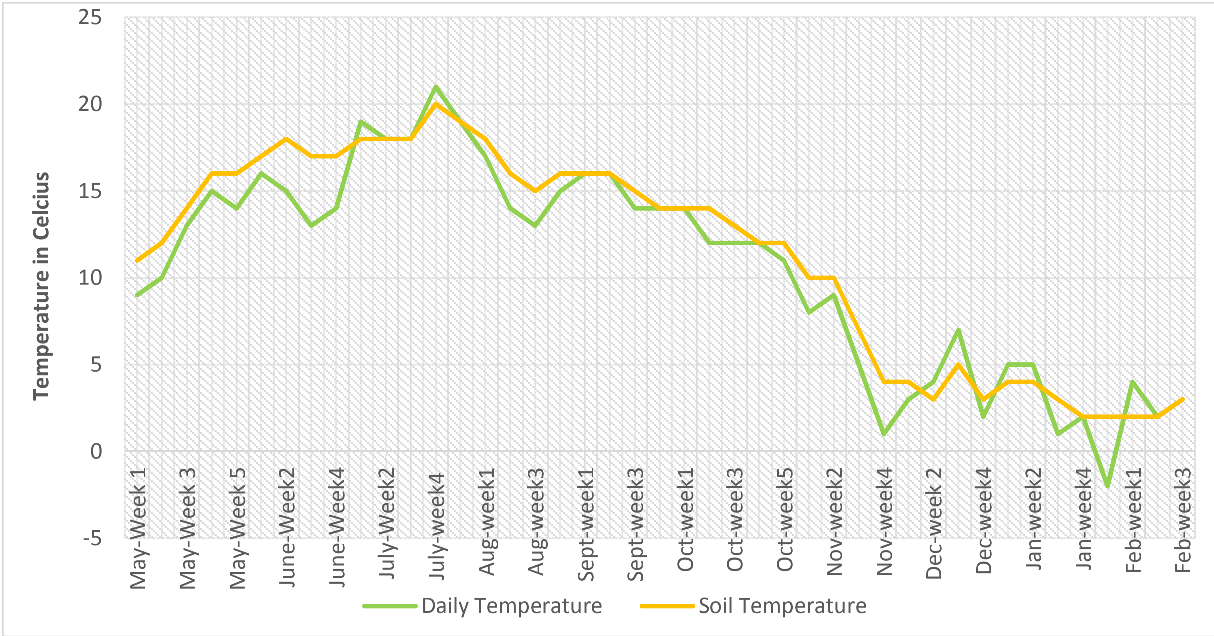
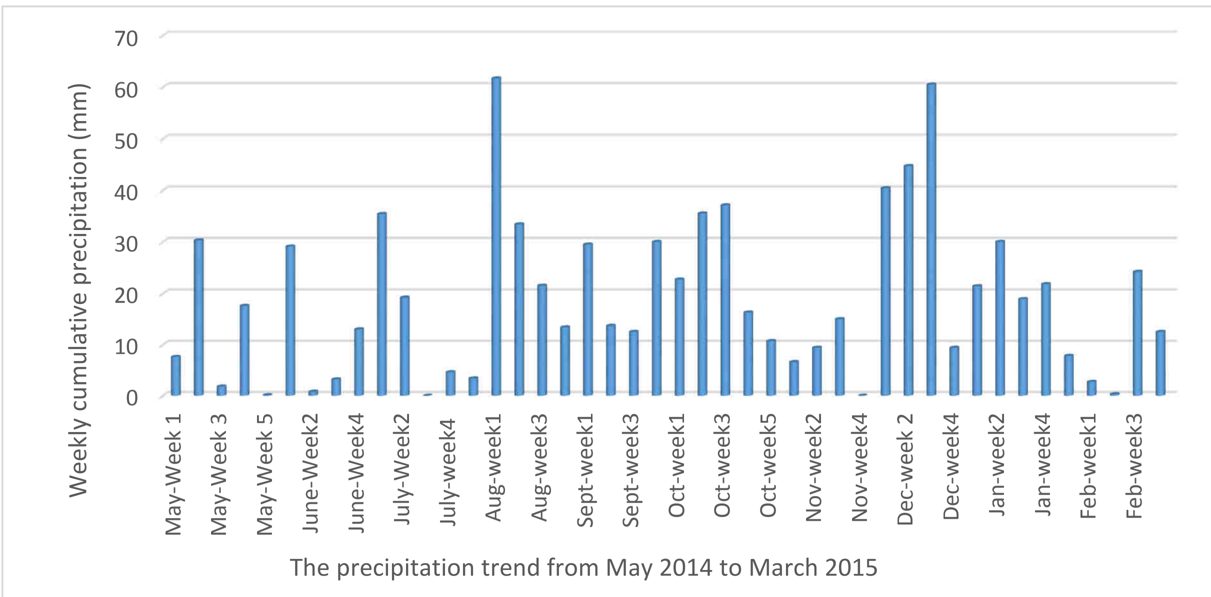


Figure 11b: The weekly cummulative precipitation at the study area from May 2014 to March 2015



4.7. Estimation of Nitrogen balance for organic free-range pig paddocks

In order to estimate the Nitrogen balance at the farm level, several input and output data were required, both from a particular farm and others from standard values obtained from literature. For the input data, the daily intake of sows with piglets was 10.8 kg of feed per sow per day where by 15.8% of it was crude protein. The number of piglets per sow at Brian's farm was 11.2 where they are being weaned after 8 weeks when they have 12 kg (Brian Holm, personal comment). Other input data including grass yield per hectare, atmospheric deposition and N fixation were taken from literature and available standard emission factors that are valid in Danish organic pig farming as according to Nielsen and Kristensen (2005). To estimate the N balance in Kg N/ha the number of sows per paddock were converted into 1 ha which is equal to 10,000 m^2. With the paddock dimension being 23 m by 12.3 m therefore the paddock size which means an area required by sow was 283 m^2 /sow or a total of 36 sows per hectare.

For the output, we had two major N output which were the piglets and as N uptake into willow biomass. Piglets have been weaned after 8 weeks and being taken to be finished in indoor settings with an outdoor run. The total weight of a single pig was multiplied for all number of weaned piglets per hectare which for this experiment were 322 (after deducting 20.2% mortality rate from farrowing until weaning) with obtained total value also being multiplied by N in 1 kg of piglet meat which is 27 grams as used by Eriksen et al,. (2002). The difference between the above total input and exported out of paddock piglets is what is being deposited on the paddock. Some of the N deposited will be taken by willow and grass (even though there was almost bare land in the paddock), atmospherically lost, incorporated in soil organic matter or be leached below the root zone.

The N uptake by willow was estimated from the N application rate of 120 Kg N/ha by Pugesgaard *et al.*, (2014) and Cavanagh et al., (2011). The later study where pig slurry was applied to the willow gives about 110 Kg N/ha uptake by willow when the recommended N of 120 Kg N/ha would be applied. The willow samples analysed by Cavanagh et al., (2011) were from the stem and the total uptake value was used for N balance estimation. However, since not all the paddock in this experiment was covered by willow, the N uptake considered was only willow area which was 2 metres covered by a paddock between the willow rows plus 2 metres on each side of the paddock into a grazing area. With such implication, the area technically covered by willow per paddock was 98.4 m^2 (8 m x 12.3 m) which makes the potential N uptake by willow to be 39 Kg N/ha. The herd calculation and N balances at the farm level are as shown in tables below.

Table 8. Herd calculations per hectare for free range sows integrated with willow trees

Herd Calculations			**Paddock size**		**Units**
Number of sows	36		lenght	23	m
Number of piglets /sow	11,2		width	12,3	m
Number of piglets	403		Paddock area	282,9	m^2
Mortality before weaning	20,20%		1 hectare	10000	m^2
Dead piglets	81		Number of sows /ha	36	
			Area covered by willow		
Total weaned piglets	322		length	8	m
			width	12,3	m^2
			Willow area/paddock	98,4	m^2
			Willow area/ha	3542,4	m^2
			N uptake by willow	38,9	Kg N/ha
			% willow area/paddock area	35%	

In computing the N balance of the farm per hectare several important assumptions were made. Even though according to Danish harmony rules, the N quota estimates the grass yield with no clover (which was the case for our study) to be 210 Kg N/ha, the grass-covered area within the paddock was nearly insignificant both as feed for pigs as well as its significance for N uptake. This was therefore ignored during the estimation. With such assumption, the N surplus after deducting the N uptake by willow and piglets became 260, 8 Kg N/ha as seen in *table 9*. With the associated N emissions both directly and indirectly remained N in the soil which has a potential to be leached as NO_3-N (plus soil pool changes) became 201 Kg N/ha. Since this study didn't analyse some of the parameters from the calculations such as N uptake by willow and other N losses apart from leaching (e.g. denitrification, ammonia volatilization and N_2O emission), we therefore used the standard values from literature even though we understand there might exists variations due to a number of factors including farm-specific conditions and tree-grass biochemical processes. The last thing for N balance calculation was to compute the

N efficiency which express how much of the N input have been converted into desired products. The overall N efficiency for this investigation was 36% of the N input whereby out this 26% was converted into piglets and the other 10% from the estimated N uptake by willow into biomass which is responsible for bioenergy production.

Table 9: Input, output and balance for Nitrogen in a free-range pig farm integrated with willow trees

N Balance				
Input			**Kg N/ha**	**References**
Grass yield			0,0	
Imported feed			383,9	(Brian farm document)
N fixation			0,0	
Atmospheric Deposition			15,0	
Straws			5,0	Nielsen and Kristensen, (2005)
Seeds			0,0	Nielsen and Kristensen, (2005)
Total N input			403,9	
Output				
Weaned piglets = 322			104,2	Eriksen et al., 2002
Uptake by Willow			38,9	Cavanagh et al., (2011)
N surplus			260,8	
Emissions	Emission Factor			
NH_3 during grazing	0,13		33,9	Eriksen et al., 2002
Denitrification	0,1		26,1	Eriksen et al., 2002
Potential NO_3 leaching + Soil pool changes			200,8	
N Efficiency (%) = 36%				
N willow uptake (%) = **10 %** (38,9/403,9 Kg N/ha)				
N to piglets (%) = **26 %** (104,2/403,9 Kg N/ha)				

CHAPTER V: DISCUSSION

5.1. Spatial Mineral N distribution in sow's paddocks

Several studies have documented the heterogeneity in spatial distribution of mineral N in the outdoor pig paddocks. The defecation behaviour and hence nutrients distribution have been most influenced with the spatial allocation of features such as feeding and drinking troughs, huts (Webb *et al.*, 2014) and perennial trees within paddocks (Horsted *et al.*, 2012). In semi-natural environment, where there are diverse environmental and social stimuli, Stolba and Wood-Gush, (1989) studied that pigs use mostly wooded and bushes areas for their shelter compared to other areas in the paddock. If available, pigs tend to find the shelter especially for temperature amelioration and where there is less stress from wind velocity. This would however results into increased excretory behaviour and hence nutrients loading close to these shelter zones.

The current study observed an increasing trend for mineral N from willow up to 4.5 m. Compared to the closest measurement to the willow with 42 Kg N/ha, the mineral N at 4.5 m was three fold with 149 Kg N/ha (with about 84% being NO_3-N). At further distances of 6.5 and 9.5 m, even though the mineral N wasn't as higher as at 4.5 distance, there were about two fold N_{min} as compared to willow zone (0.5 m).When soil sampling was carried out in autumn of 2014, pigs had been removed four weeks earlier but the sow huts had been located at nearly the same distance as 4.5 in the summer just few months earlier. This was however against our experimental hypothesis in which we expected higher mineral N near trees due to usage of shelter zones as preferential sites for excretion in semi-natural environment. The study by Horsted *et al.,* (2012) in free-range pigs with willow and mischanthus reported high excretory behaviour near the willow zones. From this study (Horsted *et al*,. 2012) where pigs spent 54% of their activities for resting near the trees and about 49% of the excretion behaviour close to willow zone, we expected these results to be reflected on mineral N concentration on the current study. Also, another similar experiment with free-range pigs and energy crops done by Sorensen, (2012) found the N_{min} the 0-75 cm soil profile in willow zone was higher than the distribution close feeders, mischanthus and combination of willow and mischanthus.

These contrast findings on mineral N distribution as observed in our study could be explained by two main reasons: firstly being high N uptake by willow and secondly the spatial allocation of features in the paddock particularly by considering the trees, huts and troughs. Firstly, the low mineral N near willow could be due to higher N demand by the willow as mineral N was increasing as moving away from the trees from 42 Kg N/ha at 0.5 m and reached peak levels of 149 Kg N/ha at 4.5 m before having a nearly uniform mineral N at 6.5 and 9.5 m with 100 Kg N/ha. Willow with their fast biomass growth, long growing season and deep root system carries potential for a significant mineral N uptake (Ali, 2014). The N balance estimated the uptake by willow which covers nearly 35% of the experimental paddock area could be as high as 39 Kg N/ha (see table 9). The high N uptake for energy crops have also been reported by Jorgensen *et al.,* (2005) to have potential of reducing up 40 - 65 Kg N/ha of NO_3-N that could be easily lost by leaching in sandy soil. With the willow in a study area being about 6 years old (AGFORWARD, 2014), the root system would be expected to be well established up to few metres horizontally away from the trees and this could possibly reduce the N_{min} concentration close to the trees.

The higher mineral N at 4.5 m throughout the soil profile could mainly be due to excretions deposited by sows close to their hut since the contribution of N_{min} from bedding materials is normally low. The N_{min} distribution results from the current study has also reported by Eriksen and Kristensen, (2001) for an outdoor pigs with no trees where there was an increase of mineral N as moving closer to the huts. High concentration in hotspot areas have also been reported by Salmon *et al.,* (2007) whereby about 95% of nutrients excreted were deposited to a small area in a mobile system that covers only 24% of the total paddock area. The distribution close to the hut alone covered about 39% which was the highest, followed by 37 and 19% on feeding and drinking areas respectively.

Also, the second possible explanation for low N_{min} close to the willow than what we expected was due to spatial allocation of trees, huts and feeding & water troughs. The distance between huts and feeders was only about 4 metres apart and which was nearly the same distance from the huts to the trees. The experiment by Horsted et al., (2012) reported high excretion activities close to the willow, with the willow zone located between the huts and feeders while in our current study the hut was located between the willow trees and feed & water troughs. Unlike our experimental paddocks, the study by Horsted et al., (2012) was in particular complex with different zones within a single paddock which include zones of grass, willow, mischanthus plus willow + poplar for both small and large paddocks. The grazing area for pigs in our study area had little grass cover for the sows and this have made pigs to depend most of their daily diet from the imported feed. This might be the reason of higher levels of N_{min} between the hut and feeding troughs where pigs could spend most of their time. High NH_4-N concentration at 6.5 and 9.5 which were about 71 and 91 % of total N_{min} respectively, reflect the high urination hotspots as the two distance being close to the feed & water troughs.

The pig's urine that's mainly in form of urea could rapidly change into NH_4-N before being oxidised over time when favourable conditions of nitrifications are available (Salmon et al. 2007). This has hence resulted into higher NH_4-N levels that were about 3 and 4 times more at 6.5 and 9.5 m respectively as compared to NH_4-N close to the willow. Eriksen et al., (2002) in the outdoor pig farming found highest N_{min} in the feeding area particularly at the 0-40 cm soil depth which was similar to our experiment. From this reported study, ammonia volatilization in the feeding area as well in shelter vicinity were the highest with ammonia emission ranging between 0 – 28 Kg NH_3-N/ha. The main source of NH_4-N was presence of urine patches near the feed & water troughs which was the same case as in our experiment. Eriksen and Kristensen (2001) with the detailed mapping of spatial N distribution showed highest N_{min} in the topsoil close to the feeders of up to 454 Kg N/ha which with the decreasing levels of up to 50% as moving just 10 m away from the feeders. In addition to the feed and water troughs in the current study, there has been some muddy pools in the middle of the paddock (between 6.5 and 9.5m) as seen in *figure 11* below which could be another reason for higher NH_4-N in this zone. Quintern and Sundrum, (2006) explained that even though the mineral N available in feeding zones and muddy pools are readily plant available form, they can be in a high risk of being lost through ammonia volatilization and denitrification.

Figure 12*:The experimental site showing the lactating sow huts close to the willow trees on the left side while feed and water troughs are nearly in the mid of the paddock that is covered with little grass cover. The truck tire marks between the troughs and huts are for farm management including feed and water supply. The picture was taken during reconnaissance survey on 8th October 2014 nearly three weeks before both suction cups were installed and soil samples were taken.*

5.2. Phosphorus distribution and transport potential in the sows paddock

With pigs being non-ruminant which means they lack the ability to extract phosphorus in cereals that is in form of phytate, there is always an additional of an enzyme phytase for non-organic pigs responsible for phytate digestion (Poulsen, 2000). However for organic pig production, feed additives including phytase are prohibited which makes a farmer to provide excess feed so as to meet pig's daily feed requirements. The exclusion of feed additives especially under Danish free-range pigs has resulted into less P feed efficiency which could be as low as below 30 % (Nielsen and Kristensen, 2005). The major source of P loss in outdoor pigs is through excretion of faeces that accounts about 55% (Olsson *et al.*, 2014) while other sources are urine that is about 9% of P input (Poulsen et al, 2000) and the rest is from feed spillage coming from the feed troughs. For these reasons, pig excretion close to feeding and drinking troughs is expected to create higher P levels as when compared to the rest of the paddock.

In our study where through 1 m soil profile there was an increasing P levels at increasing distance where the highest concentration was close to the feeders. With the P characteristic of being able to attach with soil particles (adsorption), most of P excreted and spilled from feed in the paddock tend to concentrate mostly in the top soils even though soil pH and texture could have major influence on its transfer through the soil profile. The same theory was true as the current study expected where on average 65% of total P was at the top 25 cm soil surface. Watson et al., (2003) with outdoor pigs also found the similar trend in loamy sand paddock in which a top soil (0-30 cm) had 59% and 62% as total P and inorganic P, respectively. Also, in the current study total P in the whole soil column (0 -100 cm), the 6.5 m distance which was close to the feeders had the highest P levels with 53 Kg P/ha with the lowest levels found close to the willow (0. 5 m) with 39 Kg P/ha.

Salomon et al., (2007) with a mobile outdoor pig fattening system reported highest P concentrations near the hut with 40 g/m2 (equivalent to 400 Kg P/ha) followed by the levels close to feeding and drinking troughs which was 36 g/m2 (equivalent to 360 Kg P/ha). In this study (Salomon et al., 2007), the P loading from the feeders and huts accounted for 95% of total P load while the other 5% came from the grazing area even through the latter was responsible for 76% of the total paddock area. However unlike the current study, the study by Salmon et al (2007) had clay soil but the magnitude of P distribution were more or less similar with our experiment. The fact that the total P in soil column (0-100 cm) was increasing from the willow up to the troughs (0.5 to 6.5 m), even though there was a slight low levels at 9.5 m, this shows the importance of feeders in P distribution in our study.

Just like relatively lower mineral N in the closest distance to the willow, the P distribution was also the lowest at 0.5 m and this could partly be explained by both higher uptake N and P by the trees and possibly low excretion activities in this zone. Unlike the topsoil which showed slight significant difference with distance variations, the subsoil (25 – 50 cm) indicated quite significant variation. There has been an increasing P levels from 2.5 to 9.5 m with the later having 19 Kg P/ha which was nearly two and three times more than what was at 0.5 and 2.5 m respectively. The highest P levels in subsoil at 6.5 and 9.5 m (17 and 19 Kg P/ha) were close to feeders where there is expected to have high feed fouling and excretion. The P distribution in the soil column and amount of extractable P (Olsen P and P-AL) that could be transported down the soil profile depends on how P can be adsorbed and desorbed with soil particles. The P adsorption depends on a number of factors including soil pH, soil texture and amount of rainfall received by soil (Andersson et al., 2013).

The adsorption capacity to soil particles decreases as pH increases (and vice versa) and the same is true when the soil is too sandy which decrease the sorption as a result of early saturation of soil particles. For instance Sato and Comerford, (2005) reported a 13% increase in P desorption as the pH increased from 5.9 to more neutral at 7 and this might have an implication of more P being available for plants uptake or being prone for leaching. There are however some variability in P adsorption and desorption rates with the mentioned determining factors above. With 5.8 pH level in our experiment which is regarded as moderate acidic soil, the Aluminium is the dominant ion that reacts with phosphate and most of the formed complex compounds are amorphous Al, Si and Fe phosphates (Liang et al. 2010). These complex compounds will then result into very insoluble phosphate compounds with high adsorption which makes them not available for grass uptake as well as being leached below the root zone. This has been partially justified with the Olsen P concentration in the soil water where by on average it was less than 0.01 mg /litre. The low Olsen P in soil water with the highest being 0.02 mg/litre could be due either the soil haven't been reached saturation and also the P in the soil being not in extractable form (Eriksen et al., 2006).

Some P leaching studies have reported that lower P concentration in the soil water could be do absorption of some of P by the porous ceramic cups, hence might not reflect the actual P leaching potential (Magid *et al*. 1992). In this study where lysimeters and porous suction cups were installed at 90 cm depth, the inorganic P in lysimeter was more than 2 times than the one from suction cups. Unlike suction cups which measure only the immobile pore water, the lysimeter could also measure the preferential flow. The fact that suction cups sample a small portion of the soil pore network, the preferential flow especially in soils with more clay would be underestimated in the analysis. This may therefore question the technique effectiveness in determining the actual P leaching potential down the soil. Increasing replications could enable having representative samples even though this may also come with an additional operation cost with the suction cup technique normally involve easy to installation, little disturbance to the soil as well as low capital cost (Carrick et al., 2013).

Also, the soil pH analysed from the soil samples in this study was however the sum of soil in the whole soil profile (0-100 cm) even though pH might possibly differs with different levels of soil depth due to pigs activities such as urination, defecation and feed fouling which results into varied concentrations within the paddock. The importance of pH in relation of P transport have been studied by Andersson et al., (2013) in Swedish in sandy soil with an average pH of 5.9 in a 1 m soil depth. The study found the P loss with this soil was lower compared to the other site with clay soil with average other site with pH of 7.5. The explanation for this was due to high adsorption capacity of sandy soil in topsoil which makes low P leaching compared clay soil that the high pH has resulted into increasing desorption. Therefore the high P sorption index and low P saturation from this study found lower P leaching in sandy soil even though there was high P concentrations in topsoil. There are however other studies that reported the importance of subsoil characteristics in extractable P (Olsen P and P-AL) leaching. A study by Peltovuori, (2007) in Finland found the highest P adsorption capacity at soil depths from 30 to 70 cm which significantly affected the P transport below the root zone even though topsoil didn't have very high adsorption capacity.

With free-range sows being kept in outdoor pasture for the whole year, maintenance of pasture stand is particular important in order to increase N and P grass uptake from the soil before they are lost. The research site for the current study did however have little portion of the grass-covered land which makes little grass uptake from excreted nutrients by pigs. According to EUROSTAT (2013), when well established the grass can take as much as 31% of the P output. The presence of bare soil could therefore increase the risk of P loss into ground water. This is because unlike Phosphorus, the excreted nitrogen from the paddock can be lost through a number mechanism such as via ammonia volatilization (NH_3), denitrification (where NO_3^- is being reduced to N_2 with N_2O also being emitted) and nitrate leaching. Also compared to nitrate leaching, the extractable P leaching is however in relatively small quantities which subject the rest of the P surplus to accumulate in the soil.

5.3. Estimated Nitrogen balance

The high N surplus in the outdoor sow paddocks possess a high risk of NO_3-N being transported into ground water which might result into eutrophication. The fact that these excreted manure and urine cannot be exported out of the farm, has subjected the outdoor paddocks with hotspot areas with high environmental problems (Quintern & Sundrum, 2006). Being widely accepted as a nutrient use indicator in Europe, several studies have reported the N surpluses in Danish grazing paddock used by sows being as high as 300 – 600 Kg N/ha (Eriksen, 2001). The N surplus estimate in our study was in a close range with about 261 Kg N/ha, where 36 % of the total N input was estimated to be converted into both piglets and willow biomass. The 39 kg N/ha as N uptake by willow used for N balance estimation in this study have alone contributed to 10% while the other 26 % was accounted into piglets as seen in table 9.

Using the potential N uptake by willow as studied by Cavanangh et al., (2011) with a potential estimate of 110 Kg N/ha, the willow in the experimental paddock could uptake as much as 39 Kg N/ha since they occupied only 35% of the total paddock area (*see table 8*). Since grass-perennial trees within the sow's paddock involve complex relationships between soil, grass, trees and pigs, the ongoing physical and biochemical processes might include a lot of uncertainties in the estimation. The estimate only consider the total amount of N in the farm and with difficulties to both understand and quantify some internal flows increase a risks for not accounting all of the N . This is the main reason that our N balance calculation is barely an estimate and this has also been observed by studies with outdoor pigs without perennial crops for instance by Eriksen *et al.,* (2006). In addition, even though the willow might possess high uptake of the deposited mineral N, existence of hotspots may overwhelm the potential trees to uptake potential N and hence the improvement of N use efficiency. This is true since trees in the paddocks occupy only portion of the paddock area, for instance in our study willow estimated to cover 35% of the land and this leaves the other 65 % of the area prone for hotspots. The typical hotspots areas in the current investigation were where we had the highest NO_3-N close to the huts and highest NH_4-N levels near feeders (between 6.5 and 9.5 m). For the 4.5 m distance for example, there was a lot of NO_3-N in lower soil than it was in the top soil i.e. 36 Kg N/ha at 0-25 cm versus 42 Kg N/ha at 50-100 cm.

The sufficient grass cover have in grassland has been acknowledged by a number of outdoor experiments as important practice that could take several hundred kilograms of nutrients. Both NO_3-N and NH_4-N which are in plant available forms could be readily taken by grasses which are very efficient in taking nutrients mostly in the top 25 cm where most of the grass roots are found. Most grazing lands in outdoor pig farming are however associated with insignificant grass-covered land which increases the N loss risk from the urination and defecation activities by pigs (Eriksen and Kristensen 2001; Nielsen and Kristensen, 2005). NO_3-N in particular which is high soluble to water could easily transported into ground water especially in urine patches and near the huts and feeders. High NH_4-N close to feeders which makes between 70 to 91 % of total N_{min} could easily be lost through ammonia volatilization since there were some muddy pools in the paddocks. The equilibrium balance between the ammonia-N and ammonium-N will however depend on several conditions include wind solar radiation, soil temperature, moisture content and infiltration rate of ammonical N (Sommer and Hutchings, 2001). Also since NH_4-N is in readily available form they can be taken up by grass or being later oxidized by the bacteria into NO_3-N when conditions for nitrification are favorable.

The farm N efficiency of 36% with the main output being piglets and N uptake into willow biomass was however higher compared to some research results with only outdoor pigs without perennial trees. Nielsen and Kristensen, (2005) for instance reported an average of about 28.3% of herd balance in 6 different organic outdoor farms in a pilot study carried out under Danish conditions. Eriksen *at al.,* (2006) with lactating sows also found only 25% of the total N input which was 748 Kg N/ha were converted into piglets with the N surplus being 562 Kg N/ha. Some studies with outdoor sows without pigs however have reported better N efficiency better than our study. For instance, Eriksen *et al.,* (2002) with outdoor sows in sandy soil paddock, about 44% of the N input in the feed (880 Kg N/ha) was converted into piglets which was 390 Kg N/ha.

The relatively high N efficiency in the current study however might not be so meaningful and conclusive as there are high variations even with same outdoor pig farming. Such variations might be due to differences in stocking density, individual farm-specific conditions, year and season variations as well as imported feed (Ivanova-Peneva *et al.,* 2006). This has been critically analysed by Nielsen and Kristensten, (2005) during the Danish pilot study with the data available from 2 to 7 years between year 1997 and 2003, which included 6 outdoor pig farms. The statistical analysis from this study found significant differences due to year which data were collected ($p<0.001$) and effect of a specific farm under concern even though all the farms had outdoor sow settings. In this study, even when the investigation was carried out in the same outdoor farm for different years the differences were significant ($p<0.001$). This study suggested these variations due to “farm type” could however be minimised by short-term management practises such as through changing feeding regimes and manure management while also some long term practises such as spatial allocation of farm facilities including housings and crop rotation practises could be considered. Therefore in order for willow to overwhelm the effect of substantial N levels in hot spots, there is a need for regularly changing the position for feeders and huts within the paddock and closer to the willows. This is important both for the even mineral-N distribution and also maintaining the pasture stand with the later help in improving N uptake which for most of the outdoor pigs is quite low.

5.4. Nitrate leaching and Water balance

5.4.1. Potential Nitrate leaching in the sow's paddocks

Nitrate leaching from the outdoor paddocks are associated with excess NO_3-N that could result into eutrophication which is an environmental problem particularly in Denmark (Eriksen *et al*., 2002). While most NH_4-N would be attached to soil particles, the NO_3-N is highly soluble to water and high concentration in the soil with increased percolation especially from autumn and winter could increase its loss into ground water. NH_4-N with time is mineralized into NO_3-N which could either be denitrified, taken by crops or being added to the NO_3-N pool which is prone for leaching (Webb *et al.,* 2014).

In the current study, the NO_3-N in soil water was statistically significant with distance variations from willow (DF=4, $p<0.01$). When the soil sampling was done back in autumn of 2014, the nitrate-N in the soil was average the highest at 4.5 m for all the soil depths compared to other distance points (figure 4). This has been prevailed in the first four samplings of soil water between 7th November and 18th with 4.5 m having highest levels than other distances that range between 40 to 57 mg NO_3-N/litre. These extreme leaching levels could be explained by presence of higher NO_3-N concentration throughout the soil profile and high water percolation. This can be seen from climatic data in *figure 11* where the precipitation has been persistently high particularly up to late October where there was an average of 11 to 37 mm/week just a month before this experiment started. Also, apart from having highest nitrate concentrations compared to other distances, the higher nitrate-N levels at lower soil profile (50 – 100 cm) than on top soil (*table 5*) has predicted higher initial leaching. In addition, the high leaching rates from late December to late January for all distance points (with exception of 4.5 m) was a result of precipitation and melting snow. Evapotranspiration during this period could however be insignificant since both daily temperature and soil temperatures were on average of 2 and 4 ^oC respectively. At 4.5 m there was a decrease to more than half of NO_3-N from mid-January and the levels tended to slowly increase up to March. The NO_3-N leaching between November and early January was on average 47 mg/litre while from mid-Jan to March was as low as 14 mg/litre (see figure 9). The higher early percolation in autumn and early winter resulted into lower NO_3-N from mid-January. The existed nitrate-N during the soil sampling however could have been accumulated from previous production season through the mineralized organic-N and ammonium-N. This means the distribution might possible not accounted only for NO_3-N from the sows kept in the paddock during spring and summer of 2014.

The 2.5 m distance from willow which was somehow close to the sow's huts also had secondly highest NO_3-N from soil samples apart from 4.5 m as shown in *figure 4*. Unlike for 4.5 m, the 2.5 m didn't reveal higher leaching as recorded from soil water sampling. This could possibly due to NO_3-N uptake by extended roots of these perennial crops close to 2.5 m. The experiment done by Ali, (2014) found out the ^{15}N uptake by willow top-shoots was significantly higher up to 3.5 m from trees. These results shown consistent N uptake with this distance even when three different nitrogen sources were used i.e. dairy cattle manure, NPK fertilizer and sewage sludge even though the later N source had relatively lower ^{15}N uptake. With comparably lower ^{15}N from control plots, this study (Ali, 2014) suggested the importance of N source availability in the growth and abundance of willow lateral roots. The N uptake efficiency of willow is relatively high compared to many annual crops as willow have long growing season plus deep roots that could be functioning and viable even during autumn and also little during winter when there are low temperatures (Mortensen et al. 1998). Unlike the 2.5 m, the 0.5 m distance which had the second lowest NO_3-N from the soil samples prevailed lowest leaching. The lowest nitrate leaching at 0.5 m and unexpectedly highly reduced nitrate-N in soil water at 2.5 m favours our hypothesis which expected low leaching near willow zones. This could however be the result of both low excretion activities and the N uptake by willow roots even though the clear-cut influence of two could be difficult to be established as analysis for sow's excretion behaviour wasn't conducted.

On the distances which were close to the feeders (i.e. 6.5 and 9.5 m), most of N_{min} was dominated by NH_4-N particularly at 9.5 m which made us to anticipate low leaching rates. With mineralization rate being insignificant during periods of low soil temperatures, most of the NH_4-N was assumed to be adsorbed by soil particles and this has resulted into low leaching rates at 9.5 m. However, contrasting a 9.5 m distance which had only a NO_3-N total of 9.6 Kg N/ha through a 1 m soil column, the 6.5 m had 30.7 kg NO_3-N/ha with the latter having about two third of the amount (20.4 Kg N/ha) in the 50 – 100 cm soil layer. The high NO_3-N in the lower soil at 6.5 could be the reason of higher leaching more than at 9.5 m. This has made the 6.5 m to have second highest leaching next to 4.5 m with an average of 28 mg/litre throughout the soil water sampling where the highest leaching at this distance was at 44 mg/litre in mid-January and lowest levels came a month after. Mineralization rate or nitrification depends mainly with soil temperature and the moisture (Campbell and Biederbeck, 1972). The rate of nitrifier activities (of genera *Nitrosomonas* and *Nitrobacter*) responsible for mineralization decreases with low temperatures. From our experiment's soil temperature which have progressively been decreasing from an average of 13 ^{0}C in October to the lowest levels of 1^{o}C in February suggests some nitrification might have still been taking place up to autumn. The activity rate of nitrifiers is insignificant at temperatures below 5 ^{o} C while the rate increases with temperature and the significant N mineralization can be achieved from 15 ^{o}C (Wang et al. 2006). The soil moisture content may however influence the nitrifiers' activity rate and so is the N mineralization. Therefore this high NH_4-N levels remained in the grassland especially near feeders will be mineralized and being available from spring and summer.

5.4.2. Water balance between willow and grassland

The high nutrient and water demand for willow compared to most of annual crops could be better explained by their long growing season and deep root system that is viable for most of the year. These are the reasons make energy crops including willow and poplar being suitable in areas carry high risk of nutrient loss such as sanitary landfills, buffer zones and also outdoor pig grazing paddocks. Under Danish climatic conditions, the willow put their leaves in April and the high water demand throughout this period to summer coupled with high evapotranspiration may result into soil water depletion (Jorgensen and Mortensen, 2000).

Mortensen *et al.,* (1998) and Pugesgaard *et al.,* (2014) explained the risk of high leaching during the establishment phase with the low root uptake since roots are still not well established. Pugesgaard *et al.,* (2014) in particular with the sandy loam soil found lower N leaching with old willow than in younger ones with 42 and 65 Kg N/ha/year respectively. Similarly, Mortensen *et al.,* (1998) reported high nitrate-N concentration of nearly 100 ppm NO_3-N in the first year of establishment which was then reduced to as low as 5 ppm NO_3-N in the next 4 years since establishment. This reduction from the second year with course sand soil was similar for 0 Kg N and even when 75 Kg N/ha fertilization was applied. Unlike this rapid reduction, the similar experiment with loamy sand have shown slowly reduction of NO_3-N concentration as the levels in the two soils matched after 4th year since establishment. This hence recommended that fertilization during establishment should be evaded as most of the applied N doesn't increase the willow productivity but rather nitrate-N leaching. However since the willow in the current experiment are 6 years old which are regarded as "old willow" (AGFORWARD, 2014), we assumed there was high N uptake particularly at 2.5 m. This is why even though there was high soil NO_3-N at 2.5 m, the leaching levels was on average lower compared to 6.5 m (see figure 10b). With a mild winter where temperature is slightly above 0 ^oC, the melting snow could carry high risk of leaching because of increased percolation and lowered N uptake.

When comparing leaching from willow with that of annual crops such as grass, cereals, rape or pea, the energy crops have considerable lower leaching rates. Jørgensen and Hansen, (1998) report shown lower percolation in willow compared to wheat with 404 versus 522 mm for 1993-94 year and 537 versus 648 mm in the 1994-95 when water balance EVACROP model was used. The low percolation which indicates higher water uptake in willow was estimated using the soil water content and climate data which suggests the importance of the energy crops in protecting ground water quality. Under Danish conditions, a mixture of mischanthus-willow both as summer and winter crops carry leaching potential of 15 -30 Kg N/ha which can be of similar or slightly lower levels compared to grassland (26 Kg N/ha). However, since the sow's grassland in our study was nearly bare from autumn to winter, it is quite obvious that the leaching will be higher than 26 Kg N/ha. Comparing willow and other annual crops, the nitrate leaching levels are even higher in grain crops with 70 – 100 Kg N/ha even though there might exist variations due to replication number used in the experiment, soil properties and winter crop. In addition to that, Jørgensen and Hansen, (1998) shown effect on animal manure presence in the winter following the cereals as a summer crop that it carries the highest leaching of up to 120 Kg N/ha.

CHAPTER VI: Conclusions and Perspectives

6.1. Conclusions

The perennial trees within sows paddocks have been found in earlier studies to influence the defecation behaviour of pigs close to willow zone which could result into higher N_{min} near this zone (Sorensen, 2012: Horseted et al. 2012). In the current study however both N_{min} and P were lower at closer distances to the trees with the high levels found near the huts and feeders. Apart from the known high water and N_{min} uptake by willow, the other possible explanation for this contradictive finding was the influence spatial allocation of feeders, willow and huts. Pigs were assumed to spend most of their activities between the huts (4.5 m) and the feeders (between 6.5 and 9.5 m) since the grass cover was insignificant feed source and they almost entirely depended their feed intake from the feeders.

With the N balance estimation, only 26 % (104 Kg N/ha) of the N input which was 404 Kg N/ha was converted into piglets, while about 10% (39 Kg N/ha) were estimated to be taken by willow. Since the N uptake by willow was not experimentally analysed, it was estimated using the standard values from the literature by considering only the total area covered by willow which was 35 % of the paddock area. Low N conversion into piglets is quite common under organic pig farming settings due to high mortality rates which under Danish conditions is 20.2% of piglets from farrowing to weaning.

With the main primary objective of the experiment, the nitrate leaching as expected was the highest at 4.5 m with an average of 37 mg NO_3-N/litre followed by 28 mg NO_3-N/litre at 6.5 m with the lowest levels found at 0.5 m with 13 mg/litre. The reduced leaching at 2.5 m than what have been anticipated may be explained with high uptake by extended willow roots could extend their lateral roots for N uptake up to 3.5 m from the trees. Willow high water use and N uptake may have influenced lower leaching rates at 2.5 m. However the lower NO_3-N at 0.5 m in soil samples and hence soil water could possibly be due to both lower excretion near the trees and/or higher uptake by willow. It is therefore difficult to conclude that lower leaching near willow zone was due to high uptake as the NO_3-N from the soil samples were low. With the N_{min} concentrations at 9.5 m in which 90% was NH_4-N and 79% of it being at top soil (0-25 cm), the low leaching at this distance was presumed to be due to adsorption of NH_4-N with soil particles since the mineralization rate could be insignificant with very low temperatures.

The last thing was to conclude whether the 18.5 m apart for willow rows would help reducing the nutrient loss and also proposing the optimal or better design. Firstly, the stocking density for pigs in the current study which is 38 sows/ha where the willow and grassland estimated to cover 35% and 66 % of the paddock, respectively. This stocking density isn't far from the optimal density as suggested from other outdoor studies which was estimated to be between 20 and 30 by (Williams et al. 2000).

By using the results of this study and experience from a paddock design by Horsted et al. (2012), we could suggest a type of paddock design that will maximize the potential N uptake by trees in willow zone. This is since the aim of energy crops as far as free-range pig system is concerned is not only to improve animal welfare but also reduce nutrient loss into environment. Perennial crops could be used to separate feeders and huts in a way that will influence excretion near the trees so as to take advantage of high nutrients demand the crops have. The first possible design may be to allocate troughs in one side of the two close willow and a hut on the other as seen in figure 11 b below. The placement of huts and troughs along one side of willow row may also be an alternative design with both suggested designs having the same area as the current paddocks. These two designs might increase the excretory activities near willow zone which in return reducing the excess load that might have been deposited on the grassland. In addition to improved paddock design, other management options that could help reducing nutrient loss including frequent reallocation of feeders and huts as this reduce the enormous loss from hotspot areas as well as improving grassland cover. The last mentioned suggestions have been also recommended by several studies with outdoor pigs without perennial crops which include Salomon *et al*., (2007), Stern and Andresen, (2000) and Eriksen *et al*., (2002).

Figure 13 a: The current experiment paddock layout where the single willow row was located at each side of the paddock. Note the black line between the willow rows separates the paddock.

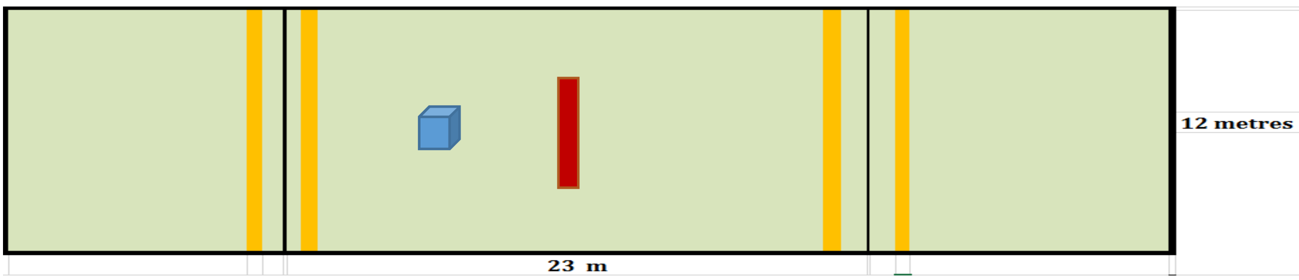


Figure 13 b: The first proposed paddock design whereby the two close willow rows separate the feeders in one side and huts in the other side of the paddock

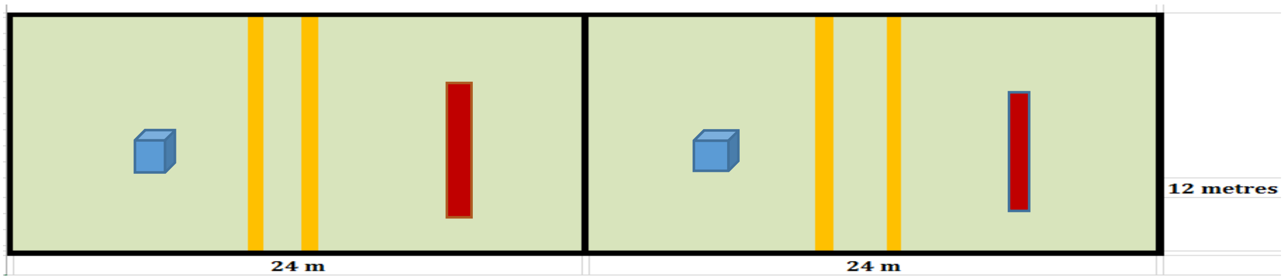
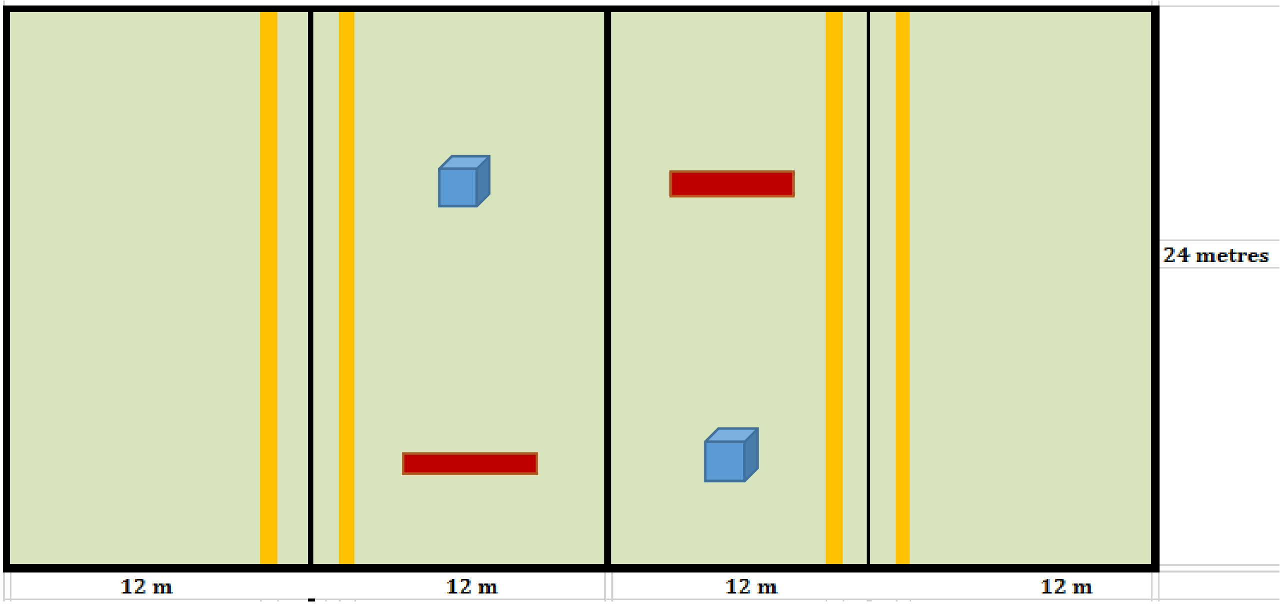
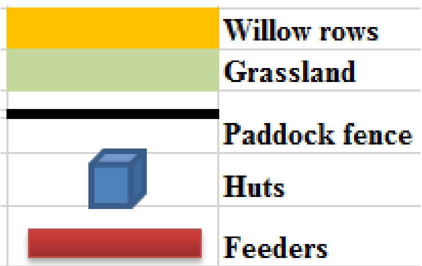


Figure 13 c: The second proposed paddock design where the feeders and huts will be allocated along a 23 m long willow row



Legend:



6.2. Perspectives

The complex interaction of different components in free-range sows integrated with energy crops might bring some concerns which some related to management while others are natural. Firstly, some of the variations due to distance changes might not reflect the actual N_{min} distribution for couples of reasons. For instance the placement of huts in the experimental paddock during autumn (early November) were not at uniform distances from willow (see *figure 12*). And since the lactating pigs in the paddocks with willow are being rotated after every 24 weeks, and this includes the frequent reallocation of huts and feeders within the paddock, the one-time sampling could have a lot of uncertainties. The existing N_{min} with one-time sampling could be due to previous accumulated N_{min} which suggests the importance of having "before and after" study experiments. The use of reference points alone in the outdoor experiments that involves one-time sampling could however not overcome the effect of accumulated N_{min} in the paddock which have been mineralized from the previous herds. The before and after experiments could be able to trace these variations at a particular investigation time or season(s) for N_{min} and phosphorus plus the associated losses with references being the seasonality differences, stocking density or the amount of imported feed.

Secondly, the nutrients in both soil samples and soil water were taken at barely a small soil volume. In our study we understand that there existed high N_{min} variations even at the same distance within different measurement rows. This has been prevailed from our sample results for both soil water and soil samples. For instance;

For nitrate-N soil water: On 9th Jan 2015 sampling for 0.5 m from willow, the four measurement rows had 43, 37, 15 and 2.2 mg NO_3-N/litre even though the measurements was done at the same day and at uniform distance from willow.

For N_{min} in soil samples: The NO_3-N in the top soil (0-25 cm) at 4.5 m on the other hand had shown a high variations in the four measurement rows with 28, 93, 11 and 13 Kg N/ha. Therefore these variations are natural with the outdoor grazing paddock and they should be handled. Some of these variations may be minimized through management options as suggested in the conclusion part which were frequent reallocation of feeders and huts, rotation of pigs into new paddock and consideration of appropriate paddock design so maximize the benefits of system's components.

Lastly, the existing complexity of willow, pigs and pasture could be scientifically important to be thoroughly investigated with variations due to allocation of feeders and huts and seasonality. It is clear that pig's activities and especially excretory behaviour could not only be influenced by the presence of shelter provided by willow, but also varies with the location of the feeders and huts like current experiment observed. The high N_{min} and phosphorus distribution in this study was higher between the huts and feeders while there were less close the willow and this has been prevailed in both phosphorus, N_{min} and the NO_3-N in the soil water. One of the two major reasons was the estimated high water and N_{min} uptake by the well-established willow particularly during the summer. But the other reason was the high pig activities close feeders and huts which were closer compared to the distance from the feeders to the willow. In order to establish clear-cut relationship whether it's the influence of high N uptake by willow or less excretory activities close to the willow it is therefore important to conduct both the analysis for excretory big behaviour and N & P uptake by the perennial crops.

CHAPTER VII: References and Appendices

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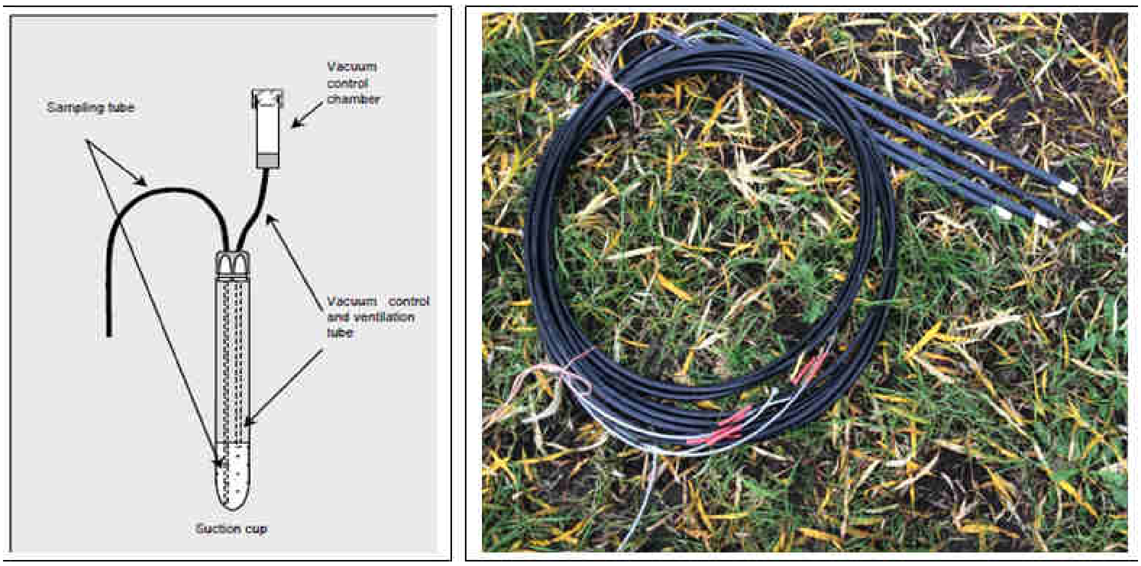
7.2. Appendices

Appendix 1: *A table showing variations in depth of ceramic suction cups with the average depth for all the cups being 1.45 metres from the soil surface*

Suction cup number	**Row 1**	**Row 2**	**Row 3**	**Row 4**
1	1.35	1.40	1.42	1.42
2	1.43	1.43	1.45	1.46
3	1.5	1.5	1.46	**XX**
4	1.4	1.55	1.55	1.49
5	1.5	1.43	1.45	1.37

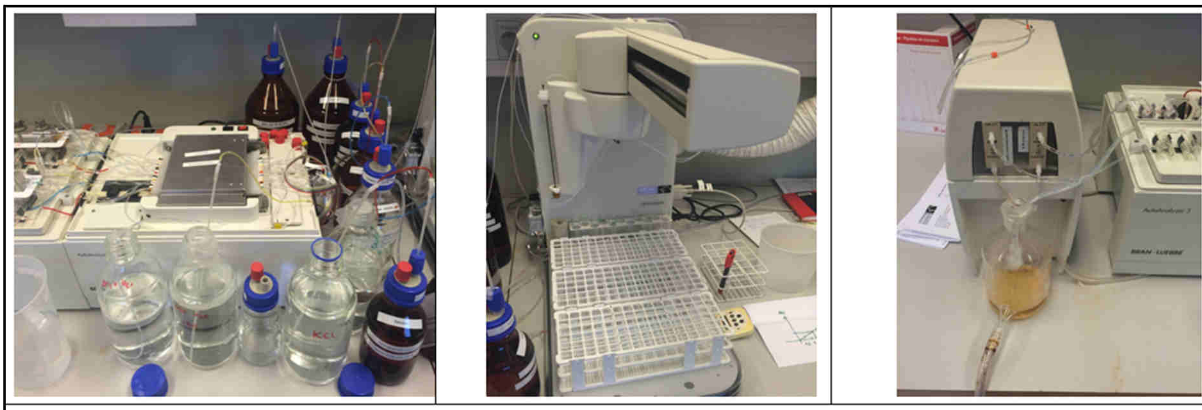
NB: XX indicates a defective suction cup

Appendix 2*: A typical diagram of suction cup showing its components and the control chamber (below-left) and the actual suction cups used in the experiment (below-right) where the tubes were insulated and were of different length. In each measurement row, the length of the tubes varied from 4.5, 6.5, 10.5, 12.5 and 15.5 metres and this was due to differences in distances of each suction cup to the vacuum control chamber*



Appendix 3: *A vacuum control chamber as seen after sampling and vacuum control tubes of five suction cups in one measurement row are already connected*

Appendix 4: *The Laboratory set up for Spectrophotometry with Autoanalyser machine in (a), the sampler in (b) and spectrophotometer in picture (c).*



(a) (b) (c)

Appendix 5: *The average nitrate-N concentrations in soil water for all suction cups as measured from 7th November 2014 to 5th March 2015. Note the missing values at suction cup number 3 which was defected during installation.*

Suction cup number	Distance from willow (m)	Nitrate-N Concentration (Mg NO3-N /Litre)								
		7th Nov	21st Nov	4th Dec	18th Dec	9th Jan	19th jan	28th jan	19th Feb	5th March
1	0,5	15	16	12	2.2	43	40	31	12	12
2	2,5	8.6	9.4	11	11	14	12	11	8.9	13
3	4,5									
4	6,5	18	12	15	18	17	37	13	6.2	12
5	9,5	2.6	8.1	6.4	8	9.2	11	12	12	10
6	0,5	6.9	8.0	6.8	8.4	37	21	22	25	18
7	2,5	8.1	11	11	3	14	26	32	28	15
8	4,5	28	17	27	50	10	9.0	13	14	16
9	6,5	4.5	7.3	7.8	3.7	7.2	9.7	8.6	6.0	10
10	9,5	12	12	14	14	14	15	16	17	17
11	0,5	5.3	4.4	6.0	7.4	15	11	8.0	12	5.6
12	2,5	23	22	24	41	74	71	29	54	52
13	4,5	99	96	110	81	48	17	27	39	43
14	6,5	42	29	40	45	25	51	25	3.1	6.9
15	9,5	15	13	22	6.5	6.2	12	8.6	3.2	18
16	0,5	15	13	6.0	4.8	2.2	2.7	4.8	6.1	5.7
17	2,5	11	15	9.9	3.9	7.5	8.6	5.3	10	11
18	4,5	1.3	7.1	11	39	9.9	9.1	10	13	16
19	6,5	31	46	53	57	84	78	71	39	55
20	9,5	24	21	21	15	22	29	31	32	24

Appendix 6: *Conversion of soil mineral N and phosphorus concentrations from mg/Kg of soil into Kg/ha*

The formula used in the conversion was as used by (Hach Company, 1992) whereby;
Nutrient distribution in Kg/ha = Concentration (mg/Kg of TS) x Bulk Density (g/cm^3) x Soil Thickness (m) x (0.000001 kg/1 mg) x (1,000,000 cm^3/ 1 m^3) x (0.001 kg/1 g) x (10,000 m^2/ 1ha). Considering the bulk density was not analyzed from the soil samples, 1.55, 1.5 and 1.5 g/cm^3 for 0-25, 25-50 and 50-100 cm were assumed with the references being a typical Danish loamy sandy soil. For example, when converting 10 mg NO_3-N/ Kg of topsoil (0-25 cm) using the above formula, the calculation was 10 mg/ Kg x 1.55 g/cm3 x 0.25 m x 10 = 39 kg N/ha.

Appendix 7: *The distribution of mineral N and phosphorus from the 60 sampled soils for all the four measurement rows with the variations due to depth and distances expressed in both mg/ Kg TS and Kg /ha*

Measurement Row number	**Distance from willow (m)**	**Soil Depth (cm)**	**Nitrate-N (Mg N /kg TS)**	**Nitrate-N (Kg/ha)**	**Ammonium (Mg N/kg TS)**	**Ammonium-N (Kg N /ha)**	**Mineral Kg/ha**	**Phosphorus (Mg P/kg TS)**	**Phosphorus (Kg P/ha)**
1	0.5	0-25	2.07	7.76	4.53	16.99	24.75	6.6	24.83
1	0.5	25-50	1.52	5.69	1.52	5.69	11.37	3.1	11.64
1	0.5	50-100	0.86	3.21	0.34	1.27	4.48	0.3	1.20
1	2.5	0-25	4.79	17.98	7.28	27.31	45.29	6.9	25.78
1	2.5	25-50	2.12	7.94	0.52	1.94	9.88	1.8	6.79
1	2.5	50-100	1.92	7.19	0.19	0.70	7.89	0.3	1.09
1	4.5	0-25	7.39	27.72	3.80	14.25	41.97	6.8	25.56
1	4.5	25-50	20.12	75.45	0.92	3.45	78.90	2.3	8.48
1	4.5	50-100	22.80	85.51	0.23	0.87	86.38	0.5	1.83
1	6.5	0-25	0.38	1.44	24.02	90.08	91.52	8.3	31.20
1	6.5	25-50	0.43	1.61	7.17	26.89	28.50	6.1	22.82
1	6.5	50-100	7.76	29.09	1.03	3.87	32.96	2.5	9.22
1	9.5	0-25	0.00	0.00	32.17	120.65	120.65	5.4	20.29
1	9.5	25-50	0.16	0.58	6.60	24.73	25.31	8.4	31.47
1	9.5	50-100	1.01	3.78	0.60	2.23	6.02	0.5	1.83
2	0.5	0-25	2.11	7.91	4.71	17.65	25.56	6.7	25.25

2	0.5	25-50	0.94	3.51	1.12	4.21	7.72	0.9	3.38
2	0.5	50-100	0.93	3.48	0.16	0.59	4.08	0.3	1.30
2	2.5	0-25	5.19	19.45	3.98	14.92	34.37	6.7	25.25
2	2.5	25-50	1.68	6.31	0.28	1.04	7.35	0.9	3.38
2	2.5	50-100	1.92	7.18	0.15	0.58	7.76	0.3	1.30
2	4.5	0-25	24.80	93.00	8.01	30.03	123.03	9.1	34.21
2	4.5	25-50	18.30	68.61	2.24	8.42	77.03	5.1	19.02
2	4.5	50-100	2.96	11.09	0.25	0.93	12.02	0.4	1.62
2	6.5	0-25	1.44	5.41	14.82	55.57	60.98	8.6	32.10
2	6.5	25-50	0.46	1.71	3.05	11.44	13.15	3.8	14.38
2	6.5	50-100	2.28	8.56	0.40	1.49	10.05	1.4	5.10
2	9.5	0-25	0.32	1.22	14.47	54.27	55.49	8.7	32.53
2	9.5	25-50	1.05	3.93	5.76	21.59	25.52	4.5	17.02
2	9.5	50-100	1.76	6.59	0.39	1.46	8.05	0.4	1.31
3	0.5	0-25	2.96	11.10	6.04	22.65	33.75	7.3	27.25
3	0.5	25-50	3.99	14.98	1.84	6.91	21.89	4.0	15.12
3	0.5	50-100	1.49	5.60	0.20	0.74	6.34	0.5	2.04
3	2.5	0-25	4.71	17.68	4.20	15.77	33.45	10.7	40.01
3	2.5	25-50	8.57	32.12	0.62	2.31	34.43	2.2	8.16
3	2.5	50-100	5.16	19.34	0.20	0.74	20.08	0.5	1.73
3	4.5	0-25	2.86	10.71	5.31	19.91	30.62	8.1	30.21
3	4.5	25-50	6.04	22.67	0.73	2.72	25.39	2.5	9.53
3	4.5	50-100	9.78	36.68	0.35	1.32	38.01	0.7	2.57
3	6.5	0-25	1.25	4.71	13.73	51.47	56.17	7.4	27.86
3	6.5	25-50	1.94	7.29	2.04	7.66	14.95	5.8	21.77
3	6.5	50-100	4.62	17.32	0.16	0.61	17.93	0.9	3.41
3	9.5	0-25	0.29	1.09	18.46	69.22	70.31	8.8	33.16
3	9.5	25-50	0.25	0.93	5.94	22.27	23.20	6.2	23.24
3	9.5	50-100	2.42	9.08	0.28	1.04	10.12	0.7	2.46
4	0.5	0-25	1.46	5.49	3.26	12.22	17.71	6.4	23.88
4	0.5	25-50	0.66	2.49	1.24	4.64	7.13	4.2	15.65
4	0.5	50-100	0.38	1.41	0.35	1.32	2.73	0.9	3.20
4	2.5	0-25	5.99	22.47	3.56	13.35	35.82	8.9	33.26

4	2.5	25-50	12.02	45.07	0.48	1.79	46.86	2.4	8.85
4	2.5	50-100	15.08	56.55	0.21	0.78	57.33	0.2	0.88
4	4.5	0-25	3.50	13.14	3.55	13.32	26.46	8.0	30.10
4	4.5	25-50	4.45	16.69	0.55	2.05	18.74	2.0	7.42
4	4.5	50-100	9.31	34.92	0.09	0.33	35.25	0.2	0.67
4	6.5	0-25	3.20	12.01	7.23	27.12	39.13	8.9	33.26
4	6.5	25-50	1.90	7.11	1.37	5.13	12.24	2.4	9.00
4	6.5	50-100	7.06	26.46	0.17	0.65	27.11	0.3	1.09
4	9.5	0-25	0.70	2.64	11.01	41.29	43.93	7.3	27.46
4	9.5	25-50	0.93	3.48	0.81	3.05	6.53	1.6	5.84
4	9.5	50-100	1.37	5.13	0.15	0.58	5.71	0.4	1.46