

CUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

**Design and Manufacturing of an Injection System for the
Application of Liquid Fertilizers and the Assessment of its
Efficiency**

Laleh GHANIZADEH HESAR

Agricultural Machinery and Technologies Engineering Department

March, 2024

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Design and Manufacturing of an Injection System for the Application of Liquid Fertilizers and the Assessment of its Efficiency

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Department of Agricultural Machinery and Technologies Engineering

ABSTRACT

Liquid manure is a rich source of nutrients for crops, but when applied by traditional methods (floating spread) causes loss of important nutrient such as nitrogen by evaporation and leaching simultaneously causes environmental and groundwater pollution. In this study, a liquid manure applicator for the sustainable agricultural system was designed, manufactured and its effectiveness was measured. The prototype injection wheel consists of a prototype liquid distributor wheel that injects the liquid subsurface at certain amounts and intervals without cultivating the soil. Since the liquid manure is injected subsurface, so does not remain on the soil surface, does not need to be mixed, and alternative to other methods in terms of nitrogen loss and availability to the plant.

The design, manufacturing, assembly and functionality trials of the prototype injection wheel were carried out in laboratory conditions, and the trials to determine efficiency and nitrogen loss were carried out in the soil channel. Functionality trials were carried out in six replicates each, using water and liquid fertilizer at four different system pressures and three different forward speed, and efficiency and ammonia loss trials were conducted in four replicates using by liquid manure as material. Wind tunnel system was used to determine ammonia loss. Ammonia loss experiments were carried out in four replicates, using 500 kpa system pressure and 2 km h⁻¹ forward velocity, at soil depths of 50 mm and 100 mm, based on the 85 kg ha⁻¹ of total N norm. The statistical analysis was carried out on ammonia emissions across different application methods.

In this study, 4000 and 20000 liters of liquid fertilizer per hectare were successfully injected depending on the system pressure and forward speed. The statistical analysis was carried out on ammonia emissions across different application methods. Peak ammonia flux within the treatment area, particularly in the initial hours following the application was observed. The surface application method was recorded 12 kg NH₃-N ha⁻¹ d⁻¹ within the first three hours. The analysis revealed a notably high correlation coefficient, suggesting a strong relationship between the experimental emissions and the application technique used. The machine demonstrated its performance by successfully injecting liquid manure into the soil and preventing nitrogen losses since the fertilizer had minimal contact with the air.

Keywords: Liquid fertilizer, Point injection, Liquid Fertilizer applicator, Nitrogen loss, Wind Tunnel.

SIVI GÜBRE UYGULAMALARI İÇİN BİR ENJEKSİYON SİSTEMİ
TASARIMI, İMALATI VE ETKİNLİĞİNİN BELİRLENMESİ

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Tarım Makinaları ve Teknolojileri Mühendisliği Anabilim Dalı

ÖZ

Sıvı gübre, bitkiler için zengin bir besin kaynağıdır. Ancak sıvı gübrenin genenekselle yöntemlerle (yüzeyle serpmeye) uygulanması azot gibi önemli bir besin maddesinin buharlaşarak kaybına ve aynı zamanda çevre ve yer altı suların kirliliğine neden olmaktadır. Bu çalışmada, sürdürülebilir tarım kapsamına uygun olarak bir sıvı gübre sisteminin tasarımı ve imalatı yapılarak, etkinliği belirlenmiştir. Prototip enjeksiyon tekeri, ana hatlarıyla biri tek delikli diğeri oniki delikli iki parçadan oluşan dağıtıcı forya ve oniki adet enjektörden oluşmaktadır. Vakum basıncı ile hareketlendirilen sıvı gübre dağıtıcı forya yardımıyla enjektörlere iletilerek, basınç ve ilerleme hızına bağlı olarak toprak altına belirli miktar ve aralıklarla enjekte edilmektedir. Böylelikle belirli bir derinliğe enjekte edilen sıvı gübre toprağın karıştırılmasına gerek kalmadan özellikle toprak işlemez tarım çerçevesinde mevcut uygulamalara alternatif teşkil etmektedir.

Prototip enjeksiyon tekerinin tasarım, imalat, montaj ve fonksiyonellik denemeleri laboratuvar ve toprak kanalı koşullarında, etkinlik ve azot kaybının belirlenmesine yönelik denemeler ise toprak kanalında gerçekleştirilmiştir. Fonksiyonellik denemeleri dört farklı basınçta ve üç farklı ilerleme hızında su ve sıvı gübre kullanılarak her biri altı tekerrürlü olarak, etkinlik ve amonyak kaybı denemeleri ise dört tekerrürlü olarak yürütülmüştür. Amonyak kaybının belirlenmesinde rüzgar tüneli sistemi kullanılmıştır. Amonyak kaybı denemeleri, 85 kg/hektar toplam N Normu sıvı gübre baz alınarak, 500 kPa basınç ve 2 km h⁻¹lik hızda 50 mm ve 100 mm'lik toprak derinliklerinde uygulama yapılarak gerçekleştirilmiştir. Bu değerler yine toprak yüzeyine doğrudan uygulamada meydana gelen azot kaybı değerleri ile karşılaştırılmıştır.

Bu çalışmada sistem basıncına ve ilerleme hızına bağlı olarak hektar başına 4000- 20000 litre sıvı gübrenin başarıyla enjekte edildiği belirlenmiştir. Farklı uygulama yöntemlerinde amonyak emisyonlarının analizi incelendiği zaman, özellikle gübrelemeden sonra ilk iki üç saatlik zaman aralığında, en yüksek amonyak kaybının gerçekleştiği belirlenmiştir. Aynı zaman aralığında yüzeyle uygulama yönteminde azot kaybı 12 kg NH₃-N ha⁻¹ d⁻¹ olarak ölçülmüştür. Analizlerde yüksek bir korelasyon katsayısına dayanarak azot buharlaşma ile kullanılan uygulama tekniği arasında güçlü bir ilişki olduğu saptanmıştır. Makinanın sıvı gübreyi başarıyla toprak altına başarıyla enjekte ettiği ve fonksiyonelliğini yerine getirdiği, bunun sonucunda gübrenin havayla temasının minimum düzeye indirilerek azot kayıplarının azaldığı belirlenmiştir.

Anahtar Kelimeler: Sıvı gübre, Noktalama enjeksiyonu, Sıvı Gübre uygulama, Azot kaybı, Rüzgâr Tüneli.

GENİŞLETİLMİŞ ÖZET

Azotun bitkiler için büyük bir önem taşıdığı bilinmektedir, bitki gelişimi ve ürün verimi için vazgeçilmez bir bitki besin kaynağıdır. Azot kontrolü çok zor olan bir elementtir. Toprağa uygulandığında buharlaşma veya yıkanma gibi yollarla kaybolabilmektedir. Sıvı gübreler yüksek oranda bitki tarafından kısa sürede kullanılabilir azot içerirler. Ancak, uygulama yöntemine tabi olarak toprağa verilen azot yüksek oranda buharlaşarak atmosfere karışmaktadır, bu sebeple pek çok araştırma, sıvı ahır gübresi uygulamasında amonyak kaybını azaltmak üzerinde yoğunlaşmaktadır. Uygun makina ve uygulama tekniği kullanılarak sıvı ahır gübresi uygulamasından kaynaklı kötü koku ve azot kayıplarını kontrol altına alma imkânı sunmaktadır. Bu çalışmada, doğrudan ekim alanlarında sıvı gübrelerin uygulanması sırasında oluşan olumsuzlukların en aza indirgenmesi için Ülkemiz iklim ve toprak şartlarına uygun, öz kaynaklarımız kullanılarak yerli bir enjeksiyonlu sıvı gübre dağıtma makinasının tasarımı, imalatı ve denemeleri yapılmıştır. Sıvı gübrenin, enjeksiyonla alt katmanlara verilmesi sırasında toprağa gübreleme makinası tarafından yapılan müdahale minimum düzeye düşürülerek, doğrudan ekim yönteminin felsefesinin de desteklenmiş olunacağı düşünülmektedir. Mevcut sıvı gübre uygulamalarında gübrenin toprak yüzeyine dağıtılması veya çizi açıcı ayaklarla açılan oluklara bırakılması yaygındır. Ancak bu yöntem doğrudan ekim yapılan alanlarda uygulanabilir değildir ve toprak işlesiz tarım yaklaşımlarıyla bağdaşmamaktadır. Bu çalışma, özellikle hayvancılık işletmelerindeki sıvı gübrenin toprak altına uygulanmasına yönelik bir prototip enjeksiyon sisteminin etkinliğini tespit etmeyi ve değerlendirmeyi amaçlamaktadır.

Prototip enjeksiyon tekerinin tasarımı, imalat ve montajı bölüm laboratuvarında tamamlanmıştır. Enjeksiyon tekerleği, taşıyıcı bir tekerlek, bir dağıtıcı valf, sıvı gübre boruları ve enjektörlerden oluşturulmuştur. Çapı 400 mm olan enjeksiyon tekeri üzerine 100 mm uzunluğunda, 12 adet enjektör eşit aralıklarla monte edilmiştir. Ana dağıtıcıdan borular yardımı ile gelen sıvı gübre tekerin merkezinde bulunan valf yönlendirilmektedir. Valf içi içe yerleştirilmiş silindirik yapıda iki parçadan meydana gelmektedir. Valfin iç parçası sabit olup tek delikli, dış parçası ise tekerlekle birlikte dönerek çalışacak ve üzerinde 12 adet delik bulunacak şekilde tasarlanmıştır. Böylece delikler karşılıklı olarak denk geldiğinde sıvının uygun olan enjektöre akışı sağlanmıştır. Enjektörlere gelen sıvı enjektörün uca yakın kısmında bulunan deliklerden toprağa iletilmiştir.

Enjeksiyon tekerinin birim alana başına uygulama miktarını ve performansını belirlemek amacıyla laboratuvar testleri ve arazi denemeleri gerçekleştirilmiştir. Laboratuvar çalışmalarında 200, 300, 400 ve 500 kPa basınçta, 1, 2 ve 3 km h⁻¹ ilerleme hızlarında su ve sıvı gübre kullanılarak her biri 6 tekrarlı 144 deneme yürütülmüştür. Denemelerde gerekli sıvı hacmini sağlamak amacıyla, 20 litrelik küçük bir tank doğrudan tekerleğin yanına yerleştirilerek 1,3 m uzunluğunda, 12,8 mm iç çaplı bir Tygon boruyla sıvı akışı sağlanmıştır. Denemeler sırasında tank içindeki hava basıncını kontrol etmek ve sabit tutmak için bir hava basıncı regülatör seti ve hava kompresörü

kullanılmıştır. İlerleme hızı hız sürücüyeye bağlı bir elektrik motoru kullanılarak simüle edilmiştir. Makinanın ön denemeleri, Çukurova Üniversitesi Ziraat Fakültesi, Tarım Makinaları ve Teknolojileri Mühendisliği Bölümü Atölyesindeki 20 metre uzunluğunda ve 2 metre genişliğindeki toprak kanalı üzerinde gerçekleştirilmiştir. Toprak kanalındaki denemeler, dört farklı basınçta ve üç farklı ilerleme hızında dört tekerrürlü olmak üzere 48 adet olarak yapılmış ve her uygulama için hektar başına düşen sıvı gübre miktarı belirlenmiştir. Sıvı gübre noktasal enjeksiyon sistemi toprak kanalının hareketli taşıyıcısına üç noktalı askı sistemi ile bağlanmıştır. Ana kontrol konsolunda bulunan invertör yardımıyla istenilen ilerleme hızı ayarlanmıştır. Denemelerde gerekli miktarda sıvının temini için hareketli arabanın üzerine 20 litre hacimli küçük tank monte edilmiştir. Testin her tekrarında tank tamamen sıvı gübre ile doldurulup ve kanal üzerinde 18 metrelik mesafe kat edildikten sonra tanktaki sıvı miktarındaki azalma belirlenmiştir.

Bununla birlikte, prototip enjeksiyon tekerleği ile yapılan gübre uygulamalarında amonyak kaybını belirlemek için rüzgar tüneli sistemi tasarlanmış ve imal edilmiştir. Rüzgar tüneli 1 m² uygulama alanını kapatacak şekilde kanopi ve silindir bölümü olarak iki ana parçadan oluşmaktadır. Şeffaf polikarbondan yapılmış kanopi bölümü, "U" şeklindeki 2 metre uzunluğunda, 0,5 metre genişliğinde ve 0,48 metre yüksekliğindedir. Bu kısım, 50×50×3 mm alüminyumdan yapılmış dikdörtgen bir çerçeve içine konumlandırılmıştır. Bu parça gübreleme alanının üstünü kapatıp içindeki hava akımının kolaylıkla kontrol edilmesini sağlamaktadır. İkinci bölüm olan sac silindir, iç çapı 25 cm, uzunluğu 100 cm boyutlarına sahiptir, bu kısım bir fan ve kesitsel hava örneklemeye cihazına yer vermektedir ve kanopi kısmına monte edilmiştir. Gübrelenmiş alanda doğal koşulları oluşturmak amacıyla tunel içinde elektrikli fan yardımıyla 0,23 m³ s⁻¹ debili (1m s⁻¹ hızda rüzgar akımı) hava akışı sağlanmıştır. Gübrelenmiş alan üzerinden akan hava, salınan amonyak ile birlikte hava tünelinin silindir kısmından tahliye edilmektedir. Bu tahliye sırasında hava akışı içerisinden küçük bir vakum pompası yardımıyla belirli bir debi ve hızda numune alınarak, içindeki amonyağı ayırmak için asit tutucuya yönlendirilmiştir. Asit tuzağı olarak 120 ml %2'lik borik asit kullanılmıştır. Amonyak salınım denemeleri toprak altı ve yüzey uygulaması arasındaki salınım farkını ölçmek için 3 farklı yöntem ve dört tekerrürlü olarak yapılmıştır. Denemler toplam Azot'un 85 kg ha⁻¹ oranında sıvı gübre geleneksel yöntem (serpme), 50 mm ve 100 mm derinlikte olacak şekilde üç farklı uygulama olarak gerçekleştirilmiştir. Denemelerde 48 saatlik periyotta her 3 saatte bir numune alınarak analiz için laboratuvara gönderilmiş ve amonyak salınımı belirli zamanlarda hektar başına kg olarak hesaplanmıştır.

Bu çalışmada sistem basıncına ve ilerleme hızına bağlı olarak hektar başına 4000-20000 litre sıvı gübre başarıyla enjekte edilmiştir. En yüksek enjeksiyon miktarı 500 kPa basınçta ve 1 km h⁻¹ ilerleme hızında, en düşük değer ise 200 kPa basınçta ve 3 km h⁻¹ ilerleme hızında elde edilmiştir. İlerleme hızının artırılmasının uygulama miktarının azalmasına neden olduğu, ilerleme hızı ve basıncının uygulama oranı üzerinde istatistiksel olarak etkisi olduğu saptanmıştır. Uygulama miktarına bağlı olarak basıncın doğrudan etki ettiği, ilerleme hızının ise ters etki ettiği

görülmüştür. Araştırma sonucunda, laboratuvar ve toprak kanalı denemelerinin uygulama miktarı arasında istatistiksel olarak fark görülmemiştir. Bu da makinanın toprakta istenilen performans ve uygulama miktarını sağladığını ortaya koymuştur. Tünel içindeki hava akış durumunu tanımlamak için hız ve basınç simüle edilmiştir. Spesifik olarak, tünel içindeki hava akış hızı farklı davranışlar sergilemiş, girişte yaklaşık 0,8 m/s olarak kaydedilmiş ve kanopi alanı içinde yaklaşık 1,2 m s⁻¹'ye kadar yükselmiştir. Yüzeye uygulama yöntemlerinde amonyak emisyonları üzerinde gerçekleştirilen istatistiksel analizde, özellikle uygulamayı takip eden ilk saatlerde, en yüksek amonyak akışının gözlemlenmiştir. Bu yöntemde ilk üç saat içinde 12 kg NH₃-N ha⁻¹ d⁻¹ ölçülerek, toprak altı 50 mm ve 100 mm yöntemlerinde bu değer sırasıyla 4,82 kg NH₃-N ha⁻¹ d⁻¹ ve 3,84 kg NH₃-N ha⁻¹ d⁻¹ olarak tespit edilmiştir. Amonyak kayıpları 50 mm ve 100 mm enjeksiyon yönteminde sırasıyla %60 ve %70 oranında azalırken, en yüksek amonyak kaybı yüzey uygulamasında ölçülmüştür. Azot emisyonlarının %30'u ilk üç saatte meydana gelmiş, ilk altı saatte %40'a yükselmiş ve ilk dokuz saatte %50-%60 olarak saptanmıştır. Analizlerde, 0,89'luk (R-kare = 0,95) oldukça yüksek bir korelasyon katsayısı hesaplanmış, uygulama tekniği ve azot salınım arasında güçlü bir ilişki olduğu ortaya konmuştur.

Çalışmada elde edilen veriler ve gözlemler sonucunda, prototip enjeksiyon tekerleklerine sahip sıvı gübre uygulama makinaları sıvıyı istenilen derinliğe enjekte ederek azot kayıplarını en aza indirebilecek, gübre içindeki besin maddelerinin bitki tarafından alımını kolaylaştırabilecek ve bununla birlikte çevre kirliliğinin azaltılmasına yardımcı olabileceği sonucuna varılmıştır.

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1. INTRODUCTION

At the onset of the twentieth century, a paramount global challenge emerged, namely the inadequacy of food provision in light of a growing world population. The major goal of all the agricultural production is to obtain more efficiency from the unit area or mass by intensify the use of inputs. Fertilization, as a critical component, plays a significant role in shaping the landscape of agricultural practices.

Within our nation, a myriad of industrial installations, residential zones, and, regrettably, some inadvertent agricultural practices contribute significantly to the degradation, pollution, and depletion of our vital natural resources—namely, air, water, and soil. According to (TÜİK, 2016) data, agricultural activities, encompassing alterations in land use, heightened utilization of chemical fertilizers, and intensive field traffic, along with industrial operations, collectively account for 11,4% of total greenhouse gas emissions. It is noteworthy that a substantial proportion, specifically 55,5% of methane (CH₄) emissions and 77,6% of nitrogen gas emissions—integral components of overall greenhouse gas emissions—originate from agricultural activities. These emissions are predominantly associated with practices related to livestock breeding and fertilization. A pivotal contributor to pollution in agricultural regions is the inappropriate structure, dosage, and form of fertilizer applications (Wagner et al., n.d.).

Developed nations exhibit a tendency to curtail the utilization of chemical fertilizers and reduce livestock numbers as part of their commitment to combating climate change induced by greenhouse gas emissions, thereby mitigating environmental pollution. According to (FAOSTAT, 2021), in Turkey, nitrogenous fertilizer usage witnessed a surge of 22,1%, and phosphorus fertilizer application increased by 18,21% in 2010 compared to the preceding decade. In contrast, European countries, through targeted initiatives to combat phosphorus pollution, experienced an 8,09% decline in the utilization of phosphorus-containing chemical fertilizers during the same period. Additionally, FAOSTAT records indicate an 18,87% reduction in the number of cattle in European countries over this timeframe.

While the indispensable use of fertilizer inputs in agricultural production is acknowledged, it is imperative to implement measures for their environmentally sustainable application. The primary objective of sustainable agricultural management is to enforce regulations guiding the judicious use of all inputs. Simultaneously, it encourages producers to adopt practices that mitigate climate change by safeguarding precious natural resources like soil, air, and water—resources that are challenging and expensive to recycle. Sustainable agriculture encompasses a spectrum of practices, ranging from soil preparation, irrigation, fertilization, and spraying to adept management of machinery and labor. Additionally, the transformation of plant and animal production residues and wastes within the system constitutes integral facets of sustainable agriculture. The adoption of direct sowing methods, which have gained prominence in recent years in our country, serves to

foster innovative fertilization techniques. It incentivizes producers to employ fertilizers generated within their enterprises. Adhering to this system not only safeguards vital carbon stocks in the soil but also prevents nitrogen loss, particularly arising from erroneous fertilizer applications.

Records indicate that the number of agricultural enterprises in our country has surpassed three million, with approximately 2,1 million engaged in cattle breeding activities. These enterprises, particularly those involved in animal production, witness intensive fertilizer production. As an illustration, a dairy cattle farm boasting a capacity of 100 cattle yields around 4 tons of solid animal manure daily, totaling 120 tons per month and 1440 tons annually. While some enterprises repurpose their animal waste as liquid or solid fertilizer or compost, more often it is left to nature without being valued at all (DBFZ, 2011)

Nevertheless, when neglected or untreated within any agricultural operation, the animal manure, despite its intrinsic value, transforms into an environmental hazard. The outdoor accumulation of manure and other waste materials can result in noxious odors, gradual decomposition, and the release of detrimental gases and dust into the surrounding environment. Consequently, a pressing need emerges for innovative systems and machinery capable of transforming these materials into easily manageable forms for practitioners, safeguarding their valuable constituents and streamlining the burial process. The implementation of such systems not only enhances the economic profitability of businesses through the utilization of organic fertilizers but also aligns with numerous research findings demonstrating improvements in soil structure and increased plant productivity in areas where these fertilizers are applied. It is widely acknowledged that in sustainable agricultural systems, the success of individual practices is interdependent. Consequently, collaborative efforts are imperative to ensure that newly devised sustainable agricultural cycles incorporate practices that safeguard human, animal, and plant ecosystems. These systems fundamentally aim to mitigate the impacts of climate change, with objectives such as preserving soil structure, achieving high productivity, and recycling agricultural waste through methods like direct sowing and organic fertilization.

Mineral fertilizers, emerging as a result of the Industrial Revolution, were instrumental in addressing the surging food demands of a growing population. However, upon meticulous scrutiny of their environmental effects, these fertilizers expose drawbacks, contributing to water and soil pollution and intensifying global warming. Considering that a substantial segment of the world's population depends on products cultivated with synthetic fertilizers (Jan Willem Erisman et al., 2008), the considerable global consequences of this adverse impact become apparent. This scenario poses threats to the accessibility and sustainability of crucial resources such as soil, water, and air. Fertilization, a longstanding agricultural practice aimed at enhancing crop production efficiency, involves replenishing essential plant nutrients (such as nitrogen, phosphorus, potassium, etc.) in the soil. These nutrients are administered in the form of solid and liquid farm manure or inorganic chemical mineral fertilizers. While the application of mineral fertilizers employs

straightforward methods and machinery, the use of liquid fertilizers necessitates more intricate technologies and logistics.

Nitrogen stands as an indispensable source of plant nutrients crucial for plant development and optimal crop yield. However, controlling nitrogen poses a considerable challenge, as it can be lost through processes such as evaporation or leaching when applied to the soil. The predominant mode of nitrogen loss occurs through emissions into the atmosphere, taking the form of gases like N_2O , NH_3 , and N_2 . Ammonia nitrogen, notably present in liquid barnyard manure applications, tends to evaporate and disperse into the atmosphere.

Liquid fertilizers, containing substantial nitrogen concentrations readily available to plants in a short timeframe (Bechini and Marino, 2009), contribute to nitrogen loss, with approximately 46% of the nitrogen supplied to the soil evaporating and mingling with the atmosphere in such applications (Meisinger and Jokela, 2000). Consequently, numerous studies focus on mitigating ammonia loss in liquid barn manure application (Meisinger and Jokela, 2000). Emphasizing the importance of new fertilization techniques to enhance nitrogen use efficiency, the literature underscores their significance in obtaining high-quality yields from bread wheat varieties (Bulut, 2012).

Employing suitable machinery and application techniques can substantially reduce bad odor and ammonia emissions resulting from liquid farm manure application by approximately 95% (Warner et al., 1991). Recent applications on various products have further contributed to the popularity of these fertilizers. For instance, in a study by (Rasmussen, 2002) involving the application of liquid fertilizer, a mixture of animal feces and urine, a 26% increase in barley yield and a 39% decrease in weed density were observed, highlighting the potential benefits of such innovative fertilization approaches.

In general, barn manures having the composition of feces, urine and bedding material and consist of 75% water, 17% organic matter and 6% inorganic matter. The nitrogen and potassium in urine are the most valuable part of the waste because they are in a form that plants can easily absorb. Since the plant immediately benefits from the potassium and phosphorus in the urine, it is desirable that the amount of urine in the fertilizer be high. With the use of this fertilizer, the water retention capacity and amount of organic matter of the soil increases, pH and salinity levels are balanced, and microorganism activities are accelerated (Val and Yetg, 2010). Hiltbrunner et al. (2005) determined that the application of farmyard manure to wheat increased stem weight and protein amount, improved soil structure and had positive effects on wheat grain yield and soil fertility. It was reported that one of the most important reasons for this situation was that liquid fertilizers had a high nitrogen content that can be used by the plant in a short time (Bechini and Marino, 2009).

The direct application of liquid fertilizer to the land is considered highly inappropriate, particularly due to its propensity to increase nitrogen loss. In clay soil conditions characterized by

low permeability, liquid fertilizer tends to flow across the soil surface, leading to the pollution of natural water resources. Conversely, in soils with high permeability or shallow composition, water may penetrate deeply, potentially contaminating groundwater (Barker, 1996; Karaman, 2005). Depending on the application method of liquid fertilizers, the most significant ammonia nitrogen loss occurs within the initial hour (Huijsmans et al., 2001), with more than 50% of the total loss occurring within the first five hours, as reported by (Misselbrook et al., 2002). Therefore, it is imperative to apply such fertilizers subsurface at a specific depth and quantity using appropriate equipment. Studies indicate that adjusting the injection depth during soil application can lead to an approximately 80% reduction in odor emissions compared to surface applications of liquid fertilizer (Pain et al., 1991). Additionally, injecting fertilizer into the soil serves to protect the product from contamination and exposure to disease-causing factors (Warner and Godwin, 1988).

To harness the advantages of barn manure, its efficient distribution across agricultural fields is imperative. The absence of essential mechanization tools poses a considerable challenge, rendering the dissemination of fertilizer to the fields arduous or, in some cases, unfeasible. Regrettably, within Turkey, there is a notable scarcity of manufacturers specializing in the production of both solid and liquid manure dispersal machinery. Of particular concern is the limited recognition and understanding among our agricultural community regarding the benefits of liquid barnyard manure. Presently, liquid farm manure is often left unused, instead finding its way into streams and water bodies. This negligent disposal not only represents a wasted resource but also escalates environmental concerns, posing a tangible threat to human and animal health through the contamination of water sources. Addressing this issue is paramount to mitigate the adverse impact on both the environment and public well-being.

Numerous foot types of soil tillage equipment, including sweep, disc, blade, and chisel, have been developed for injecting liquid fertilizer into the soil in various studies. These foot types are generally categorized as either winged (e.g., sweeps) or wingless (e.g., disc, blade, and chisel). Among these, sweeps are widely used for manure injection because they provide a more even distribution of manure (Rahman et al., 2005).

1.1 Liquid Manure

Liquid manure, often referred to as slurry, is a blend of animal waste and organic matter utilized as an agricultural fertilizer, occasionally diluted with water. This slurry is collected from barn floors using a scraper and then processed through a separator. It can undergo maturation in a slurry pit, where farmers consolidate all animal waste, along with other unusable organic materials like hay and water run-off from cleaning dairies, stables, and barns. This process aims to convert and concentrate the mixture over an extended period. Liquid farm manure, characterized by a specific gravity ranging from 1,1 to 1,6 g cm⁻³, and containing 4,7 N kg m⁻³, 2,4 P kg m⁻³, and 5,9 K kg m⁻³, serves as a significant nutrient source for crop production (Mikled et al., 2002).

1.2 Liquid Manure Applicator

The development of liquid manure spreading tanks aims to efficiently absorb liquid animal manures from farms and evenly distribute them across fields in a homogeneous manner. Various methods exist for the land application of liquid manure, including surface application and direct injection through different systems. Animal manure is rich in nitrogen essential for plant growth. N losses depend on farm practices. H. A. Aguirre-Villegas et al. (2014) reported 30-53% N loss throughout manure land application. They applied liquid manure on soil surface and subsurface and compared nitrogen lost from different application methods. Various types of injection tools, including knives, chisels, sweeps, and discs, are employed in manure application. Recent trends in fertilizer application machinery selection emphasize a heightened awareness of nitrogen losses and environmental preservation. In the context of manure injection, factors such as soil profile, soil moisture content, and manure application rates play pivotal roles in determining the most suitable injection tool. This consideration aligns with the contemporary emphasis on sustainable agricultural practices and environmental stewardship.

Existing literature on the evaluation of manure injection performance predominantly focuses on aspects such as manure distribution in the soil (Rahman et al., 2004), crop responses to different injection methods, and the assessment of ammonia volatilization and odor emissions from the soil subsequent to manure application (Chen et al., 2001). These studies contribute valuable insights into optimizing manure injection practices, with implications for enhancing agricultural efficiency and minimizing environmental impact.

1.2.1 Surface Application

- Traditional Surface Application (Broadcast spreader): This method is preferred by farmers due to its cost-effectiveness compared to other methods. Tank spreader systems, employing impinging pressurized liquid on equipment such as a splash plate mounted at the back of the tank, are commonly used for liquid manure dispersal. High amount of ammonia nitrogen loss and non-homogeneous distribution are disadvantages of this method (European Commission, 2015). (Figure 1.1)



Figure 1. 1. Example of a broadcast spreader with a splash plate.

- Irrigation water application: These systems involve mixing liquid manure into irrigation water for land application through methods like sprinkler irrigation or a drag-hose tractor-mounted applicator. This approach is cost-effective, with lower energy and labor requirements. However, it tends to result in a high amount of ammonia nitrogen loss (Risse and Sheffield, 2003). (Figure 1.2)



Figure 1.2. Example of apply liquid manure by irrigator.

- Band application: These spreaders apply slurry at the surface and between rows of growing crops. The spreader boom, connected to several hoses, distributes the slurry close to the ground in strips or bands. While providing a more homogeneous distribution compared to traditional surface methods, it may lead to the release of bad odors and loss of ammonia nitrogen as the fertilizer comes into contact with the air. Nevertheless, this method offers the advantage of spreading in growing crops without contaminating them (Webb J.M. et al., 2009). (Figure 1.3)



Figure 1.3. Example of a band spreader.

1.2.2 Sub-Surface Application

Manure injection, a practice involving the utilization of ground openers such as discs, cultivator shovels, or narrow knives, is recommended to mitigate several drawbacks associated with surface manure application. These drawbacks include nuisance odor, potential damage to forage, ammonia volatilization, and surface runoff. Injectors, classified into two main categories, contribute to the optimization of subsurface manure application. Open slot shallow injection, reaching depths of up to 50 mm, and deep injection for depths exceeding 150 mm, represent these categories (Rahman et al., 2005). (Figure 1.4)

Disc injectors operate by cutting a slit in the ground and injecting manure with minimal soil disturbance. Some disc injectors are equipped with closing disks to ensure the prompt closure of the slit post-manure injection, particularly for instances involving disc injectors. The closure of the slit is crucial to prevent ammonia (NH_3) losses into the atmosphere (R. Maguire et al., 2006). On the other hand, chisel injectors induce greater soil disturbance as they traverse the soil with a vertical chisel, injecting manure in its wake. The objective of this sweeping action is to encourage horizontal mixing of manure with the soil, facilitating horizontal tillage that disrupts macropores and subsequently reduces nitrogen (N) leaching losses. The configuration and shape of the chisels play a pivotal role in determining the extent of soil disturbance, highlighting the importance of selecting appropriate tools to achieve optimal results in manure injection practices.

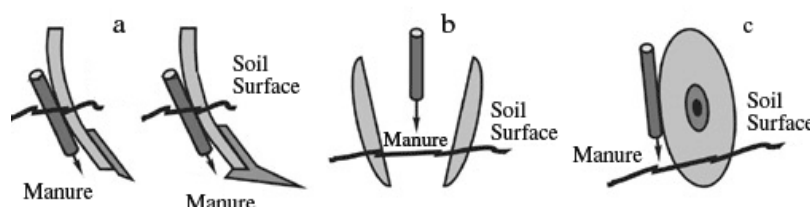


Figure 1.4. Typical manure applicator: a) chisel and sweep injectors; b) disk-type applicator; and c) coulter-type applicator (Shelton, 2004).

1.3 Livestock's Statistics in Turkey

As per the data provided by the Turkish Statistical Institute (TUIK) in 2015, the cattle category recorded a total of 13 million 994 thousand heads, whereas in the small Cattle category, the number of sheep and goats stood at 31 million 508 thousand heads. When comparison to the preceding year, there was a decrease of 1,5% in the number of cattle, whereas the number of small cattle experienced a growth of 1,1%.

Table 1.1. Farmed animal (cattle, sheep and goat) in Turkey. (FAOSTAT)

	2010	2015	2020	2023
Cattle	11454526	14127837	18157971	16687768
Sheep+ Goat	29382924	41924100	54112626	53274118

Upon analysis the data provided by the FAOSTAT, there was a notable increase of 37% in the combined number of small and large cattle in 2015 compared to 2010, followed by a 28,9% increase in 2020. Examining more recent table the count of cattle in this category reached 16 million 688 thousand heads in 2023. However, by the end of June, there was a marginal decline of 2,0% compared to December of the previous year, resulting in a total of 16 million 521 thousand heads. In the small ruminant category, the count stood at 53 million 274 thousand heads in June 2023. Within this category, the number of sheep decreased by 4,7%, totaling 42 million 565 thousand heads, while the count of goats decreased by 7,5%, reaching 10 million 709 thousand heads. These statistical insights shed light on the dynamics within the livestock sector, indicating an announced trend with a decline in the larger cattle category and a modest increase in the smaller cattle category. Such data is instrumental for agricultural planning, resource allocation, and understanding the broader trends in the livestock industry.

According to FAO data, the number of cattle shelters per agricultural area (LSU ha⁻¹) demonstrated a significant increase between 1990 and 2020. Over this thirty-year span, the rise amounts to approximately 57%, underscoring noteworthy changes in livestock management practices and their spatial distribution over time (Figure 1.5).

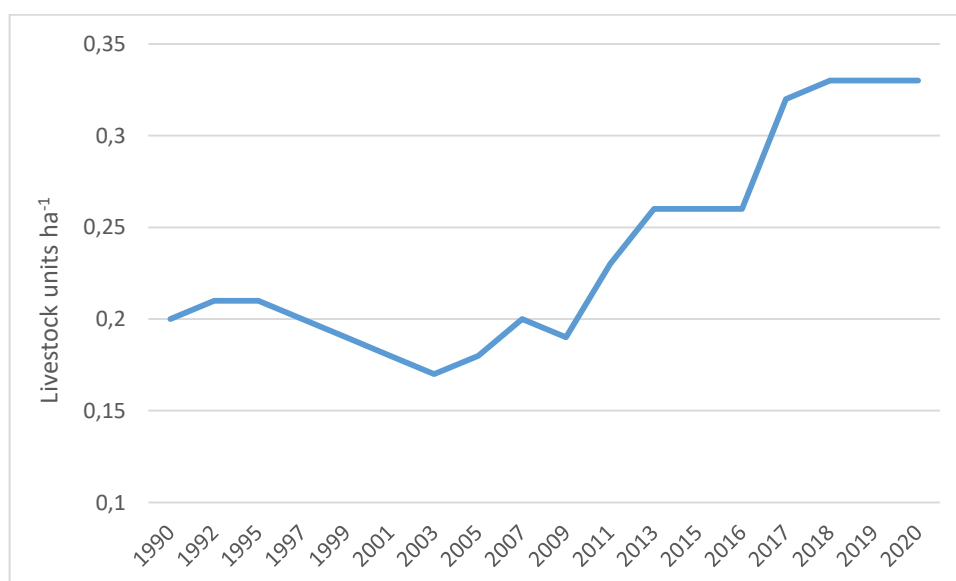


Figure 1.5. Livestock density: cattle units per agricultural land area (FAOSTAT).

1.4 Livestock Waste Potential and Liquid Manure Management In Turkey

The livestock sector in Turkey is predominantly characterized by small-scale farms, and the challenge of managing animal waste presents a significant issue from the onset of waste collection. In regions with prolonged grazing periods, particularly in the eastern areas, the collection of waste becomes a formidable task. Typically, animal waste is gathered in pits within barns, and these accumulations are subsequently discharged from the farm with water. The prevalent method of utilizing the collected waste involves spreading it onto fields. Alternatively, farmers, often perceiving animal manure as waste, seek empty areas for temporary storage. However, the temporary storage areas frequently lack the impermeability features mandated by standards, leading to a substantial environmental problem and groundwater pollution. Another prevalent disposal method for animal waste in Turkey involves discharging it into the nearest aquatic environment. This practice, if not carefully managed, can contribute to environmental degradation and poses a potential threat to water quality. Addressing these challenges in waste management within the livestock sector is crucial for promoting sustainable agricultural practices and mitigating adverse environmental impacts (DBFZ, 2011).

The size distribution of cattle farms in Turkey, encompassing both buffaloes and cattle, reveals a concentration of enterprises within the farm size group housing 1-4 cattle, accounting for 59,7% of all examined enterprises. Another notable segment is the farm size group with 10-19 animals, constituting 25,4% of the total (Tuik, 2010). Within the Turkish context, data indicates that for enterprises with 1-5 and 6-10 cattle capacity, there is an absence of structures dedicated to the accumulation of liquid manure. 60% of enterprises with 11 or more cattle do not have any storage facilities for proper manure disposal (Boyacı et al., 2011). A study conducted across 197 cattle breeding facilities, encompassing both dairy and fattening cattle enterprises in Adana, Mersin, and Burdur provinces, revealed a concerning negligence toward auxiliary compartments, especially those designated for the storage of solid and liquid manure. In 80% of the enterprises investigated, it was observed that manure, typically regarded as animal waste, was disposed of in open areas and heaps, indicating a prevalent lack of proper waste management practices (Atilgan et al., 2006). This underscores the need for improved waste management infrastructure and practices within the cattle farming sector in Turkey.

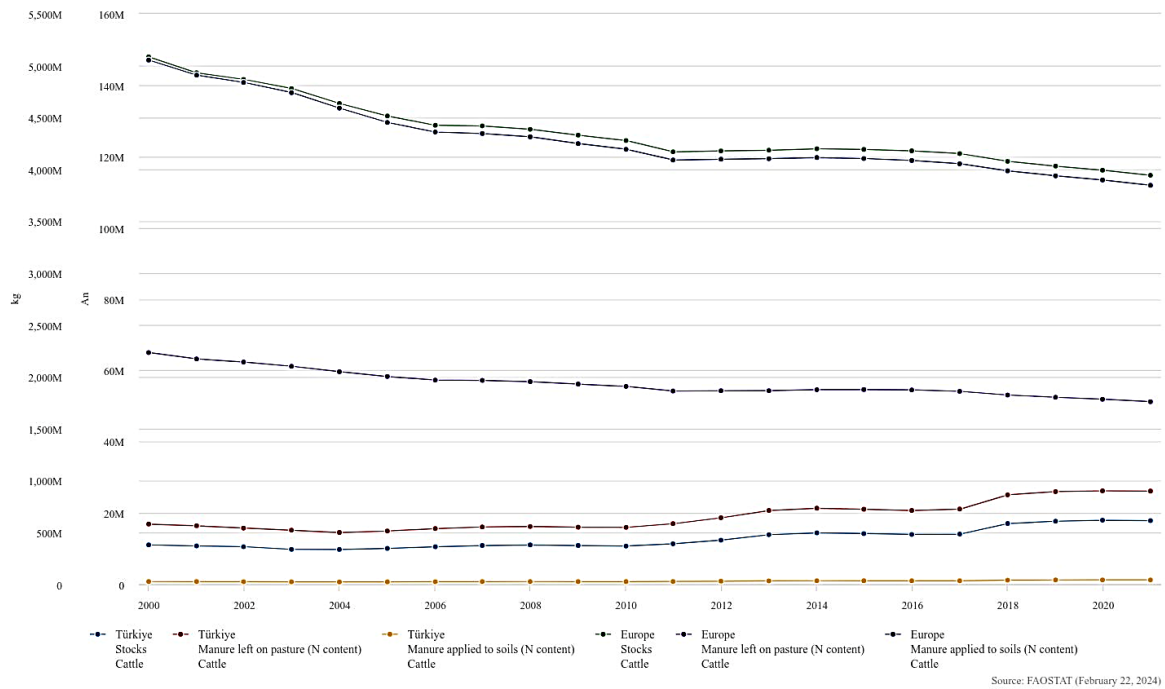


Figure 1.6. Manure management worldwide (FAOSTAT).

The analysis of livestock manure data spanning the years 2000 to 2021 for cattle in Turkey and Europe presents valuable insights into the dynamics of agricultural waste management practices (Figure 1.6).

Notably, the temporal trends in cattle manure stocks exhibit discernible patterns, with a period of decline from 2000 to 2005 followed by an upward trajectory until 2015, and a subsequent marginal decline. These fluctuations could be indicative of shifts in livestock population, farming practices, or environmental policies. Concurrently, the consistent increase in the quantities of manure left on pasture and applied to soils, both accounting for nitrogen content, implies a potential intensification of agricultural activities or alterations in manure disposal methods. This observation accentuates the necessity for sustainable manure management strategies to mitigate environmental impacts and optimize agricultural productivity.

The detailed analysis of the livestock manure data prompts further academic inquiry into the driving factors behind the observed trends. Investigating the interplay between livestock demographics, agricultural policies, and ecological considerations could shed light on the complexities of waste management in the studied regions. Additionally, the observed rise in nitrogen-rich manure left on pasture and applied to soils underscores the importance of assessing the environmental consequences, such as nutrient runoff and soil health. Future research endeavors could delve into the specific mechanisms influencing these trends, offering a comprehensive understanding of the intricate dynamics between livestock management practices and environmental sustainability in Turkey and Europe (FAOSTAT).

1.5 The Evolution of Liquid Manure Applicator Machines Global Perspective

The period between 2000 and 2022 witnessed significant advancements in agricultural practices, particularly in the domain of liquid manure application machinery. As sustainability and environmental concerns gained prominence, farmers sought more efficient and eco-friendly ways to manage livestock waste. During this timeframe, several countries embraced and expanded the use of liquid manure applicator machines, contributing to transformative changes in agricultural practices. The United States emerged as a prominent adopter of liquid manure applicator technology. The implementation of precision agriculture techniques, driven by the need for more targeted and efficient nutrient application, led to the widespread adoption of liquid manure applicator machines across American farmlands (Smith et al., 2015). This technology allowed farmers to apply liquid manure more precisely, reducing environmental impact and optimizing nutrient utilization for crops. Similarly, in Europe, countries such as Germany and the Netherlands became frontrunners in the use of liquid manure applicator machines. Stringent environmental regulations prompted farmers to invest in advanced equipment for managing manure effectively. The adoption of low-emission systems and incorporation of sensor technologies improved the accuracy and efficiency of liquid manure application in these regions (European Commission, 2015). China, with its rapidly growing agricultural sector, also witnessed a surge in the adoption of liquid manure applicator machines. The government's focus on sustainable agriculture practices and the need to address soil health and pollution concerns contributed to the increased use of precision applicators (Li et al., 2019). The Chinese experience exemplifies the global trend where countries, regardless of their agricultural practices, recognized the importance of advanced liquid manure management.

The types of liquid manure applicator machines varied across regions. While some countries favored liquid manure injectors for direct soil incorporation, others opted for liquid fertilizer applicators or spreaders for surface application. The choice often depended on factors such as soil types, crop varieties, and regulatory requirements. In conclusion, the period from 2000 to 2022 marked a transformative era in the use of liquid manure applicator machines globally. The adoption of precision agriculture, driven by environmental and sustainability concerns, led to the widespread use of these machines in countries such as the United States, Europe, and China. The variety in machine types showcased the adaptability of the technology to diverse agricultural landscapes and regulatory environments (European Commission & Joint Research Centre, 2007).

1.6 Measuring Field Ammonia Emission

Animal manure, particularly liquid manure, serves as a valuable nutrient source for crops. However, the release of ammonia (NH_3) from animal manure, especially at high concentrations and

emission rates, poses a significant environmental challenge with implications for human and animal health, leading to ecological damage. The loss of nitrogen (N) in the form of ammonia (NH_3) can occur before it is taken up by plants, representing a key concern in agriculture. Livestock, particularly through animal manure, stands out as a primary source of NH_3 emissions in agricultural activities. Agriculture as a whole is a major contributor to ammonia emissions, accounting for 94% of the total emissions in the EU-28 in 2016 (Eurostat, 2017).

Reports indicate that within livestock practices, ammonia losses occur as follows: 6% during housing activities, 28% during storage, 53% during land application, and 6% in other processes (Aguirre-Villegas et al., 2017). It is imperative to assess and improve manure management and application practices to minimize agriculture's adverse impact on the environment. To achieve this objective, the quantification of ammonia loss is essential. Studying ammonia volatilization demands specialized research equipment, as the process is influenced by various factors such as soil pH, soil temperature, tillage, manure composition, wind speed, soil texture, plant uptake, and leaching (Yang et al., 2018). Comprehensive research in this area is crucial for developing effective strategies to mitigate ammonia emissions and enhance sustainable agricultural practices.

1.7 Methods to Determine Ammonia Emission

There are various methods employed to determine ammonia flux from farmland following fertilization, categorized into indirect and direct methods. Indirect methods primarily involve assessing soil ammonia balance through factors like soil residue, plant absorption, and leaching. Direct methods include micrometeorology, closed chambers, and small wind-tunnel techniques (Yang et al., 2018).

- **Micrometeorology Method:** This system is based on measuring the density of vertical gas flux in the free air above the fertilized surface (Denmead, 1983). Widely accepted, but it requires large treatment areas of uniform topography (>50 m diameter circles) and stable wind profiles. The need for extensive areas often limits replication and confines investigations to a single treatment (Figure 1.7).



.Figure 1.7 Micrometeorology method for measuring whole - farm emissions.

- Closed Chamber Method: Involves cylindrical chambers with an open-ended bottom, covering the treatment area (Figure 1.8). Ammonia emission measurement is based on an acid trap system. Advantages include small size, lightweight, ease of transportation, and relatively low cost (Aneja et al., 2006).

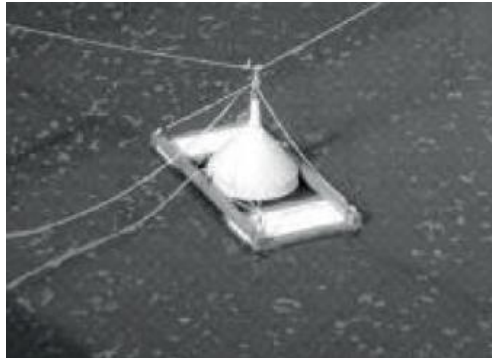


Figure 1.8. Chamber method for measuring emission.

- Small Wind-Tunnel Techniques: This system offers advantages of replicating environmental conditions, easy transportation, studying multiple treatments, and facilitating comparisons. The basic design, as given by Lockyer (Lockyer, 1984), has been extensively used to measure ammonia emissions over surfaces, enabling the comparison of emission rates between different treatment areas and application methods (Figure 1.9). Christensen B. (1989) studied the recovery efficiencies of this technique, reporting recoveries of 70-80% with slurry.

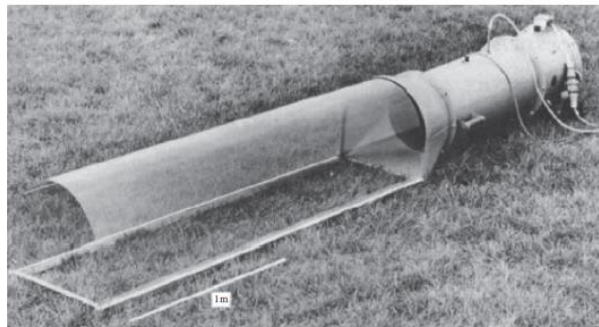


Figure 1.9. Wind tunnel method for measuring emission.

Each method has its own set of advantages and limitations, and the choice of method depends on factors such as the scale of study, available resources, and specific research objectives.

1.8 Purpose of The Study

However, to implement this application effectively, there is a need for specialized machinery capable of underground injection of liquid fertilizers. (Baker, 2006) highlighted that significant challenges in direct seeding methods include fertilization management and application techniques. The objective of this study is to address the application of liquid fertilizers directly to

the soil, aligning with the principles of the direct seeding system—a core component of sustainable agricultural practices.

In the context of sustainable agricultural systems, it is well-established that the success of agricultural practices is interconnected. Consequently, concerted efforts are necessary to ensure that new sustainable agricultural cycles are implemented without causing harm to human, animal, and plant ecosystems. These systems primarily aim to mitigate the impact of climate change, focusing on goals such as preserving soil structure, achieving high productivity, and recycling agricultural waste through practices like direct sowing and organic fertilization.

In current liquid fertilizer applications, the distribution of fertilizer to the soil surface or dropping it into furrows opened by digger feet is common. However, this method is not feasible in areas with direct cultivation practices and is incompatible with no-till agricultural approaches. This study aims to design and assess the effectiveness of a prototype injection system specifically for applying viscous liquid manure from livestock enterprises to the subsoil. This system is expected to support the philosophy of the direct seeding method by minimizing soil intervention during liquid fertilizer injection into lower soil layers. The ultimate goal is to inject liquid fertilizer into the soil in the most suitable and effective manner, addressing a gap in current agricultural practices both in the country and globally.

2. PREVIOUS STUDIES

In the literature review, relevant studies addressing the subject matter have been identified, and their key findings are presented under distinct subheadings.

2.1 Machine-Related Research

In the realm of machine-related research, the application of liquid manure has gained recognition as a sustainable approach to manure management. Utilizing liquid manure as a substitute for chemical fertilizers showed the higher crop yields (Chen and Tessier, 2001). Surface application has been the preferred method among farmers due to its cost-effectiveness, simplicity, and lack of specialized equipment requirements, unlike technologies such as manure injection that demand more expensive equipment (Maguire et al., 2011). However, surface applications of liquid manure may give rise to odor-related issues. To optimize returns from liquid manure and minimize its environmental impact, the injection of fertilizer into the soil has proven to be one of the most effective methods.

Tassell et al. (1998) Delved into the realm of nitrogen (N) fertilizer management and its correlation with root yield, crop quality, and pricing, using sugar beets as the focus of their study. Managing nitrogen proves to be more intricate for sugar beets compared to many other crops, as even modest N excesses can significantly impact crop quality. Over the course of a three-year study, their objectives included evaluating the economic efficiency of N application options, namely broadcasting, knife banding, and point injection. The study assessed equipment costs, sucrose yields, and recoverable economic aspects. Nitrogen fertilization rates were consistently lower for point injection and consistently higher for broadcasting under the four management goals. The optimum N rate ranged from 187 to 200 lbs/acre for point injection, 187 to 224 lbs/acre for knife banding, and 220 to 266 lbs/acre for broadcasting. Profit rates associated with each management goal and alternative fertilization methods revealed that point injection generated \$67/acre more revenue than broadcasting and \$94/acre more than knife banding. Fertilization costs were highest for the broadcasting system. Economically, sucrose yields amounted to \$869/acre in knife banding, \$896/acre in the broadcast method, and \$965/acre in point injection method.

Siemens et al. (2011) Conducted a study to assess the effectiveness of point wheel injection technology in enhancing plant growth, nutrient uptake efficiency, and crop yield. The focus of this investigation was on lettuce planting, and the system was designed to deliver soil-applied pesticides post-emergence. The spike wheel injection technology employed in the study consisted of twelve ½-inch diameter spikes on each wheel, intended to inject liquid fertilizer and/or pesticides at a depth of 3 inches below the soil surface. The spacing and geometry of the spikes were such that a spike entered the soil and injected the liquid product every six inches during operation. The study revealed notable improvements associated with the spike wheel applicator. Mid-season plant

growth, quantified by plant weight, was significantly enhanced compared to conventional knife blade application. Additionally, plant nutrient uptake, as indicated by midrib $\text{NO}_3\text{-N}$ levels, showed a significant increase after the second side dress when the spike wheel applicator was utilized. The efficacy trial for the fertilizer applicator demonstrated that the use of the spike wheel applicator significantly improved mid-season plant growth in terms of plant weight when compared to the conventional knife blade application. These findings suggested that the spike wheel injection technology can be an effective means to enhance plant growth and nutrient uptake in lettuce planting.

Nilahyane et al. (2018) Conducted a study to investigate the impact of variable irrigation and nitrogen application rates on silage corn yield. The study involved the side-dressing of liquid nitrogen fertilizer, urea ammonium nitrate, at different rates (0, 80, 160, 240, and 320 pounds per acre) using a point injection wheel at the growth stage. Three irrigation treatments were applied to silage corn, involving five nitrogen fertilizer rates. The irrigation treatments included Sub-Surface Drip Irrigation (SDI), On-Surface Drip Irrigation (ODI), and Sprinkler (SPR) irrigation systems. The study demonstrated that both irrigation water and nitrogen fertilization had positive effects on nutrient uptake and yield in silage corn. Additionally, the research highlighted that limited irrigation, when combined with appropriate nitrogen fertilizer rates, could help reduce the likelihood of nitrogen losses through leaching. Over the course of three years of experimentation, the results indicated that drip irrigation systems, particularly sub-surface and on-surface drip irrigation, could contribute to significant water savings—up to 50 percent—while still providing high yields and water use efficiency. Specifically, sub-surface and on-surface drip irrigation systems were shown to save at least 38 percent of water compared to sprinkler irrigation systems. This suggests that implementing drip irrigation methods can be beneficial for optimizing water usage and enhancing crop yield in silage corn cultivation.

Iragavarapu and Bock, (n.d.) conducted an evaluation of the spoke-wheel injector as a precision tool for placing UAN (Urea Ammonium Nitrate) in a ridge-till system, particularly in fields where corn follows soybeans. The study aimed to determine the effects of nitrogen (N) placement methods (banding, broadcasting, and injection) and timing (single vs. split) on various parameters including corn yield, net economic return to nitrogen, N uptake, and N recovery. The investigations on grain yields were reported over three years. The findings revealed that the highest average grain yield over the three years occurred when 100 lbs/acre of UAN was spoke-wheel injected at preemergence into the ridge. The calculation of net economic return was based on the three-year average of corn grain yield, corn price, anhydrous ammonia price, and application cost per time for each application method (banded, broadcast, and spoke-wheel). The evaluation indicated that the highest net economic return to nitrogen was observed when UAN was spoke-wheel injected at preemergence into the ridge. Furthermore, spoke-wheel injection of UAN resulted in greater total N uptake compared to surface banding of Urea Ammonium Nitrate on the row. The

total N uptake consistently showed higher values for UAN spoke-wheel injection compared to band application. These results suggest that utilizing the spoke-wheel injector for UAN placement at preemergence in a ridge-till system could optimize corn yield, net economic return, and N uptake, emphasizing the efficacy of this precision application method.

Pote et al. (2011) Conducted a study focused on optimizing the application of dry poultry litter to mitigate nutrient losses to air and water while enhancing soil productivity, particularly in the context of no-till corn production. The experiment, implemented in 2008 and repeated in 2009, involved three replicates of 3 m × 6 m plots on 1 to 3% slopes. Broiler litter was applied at 6,7 Mg ha⁻¹ using three different methods: surface broadcast, broadcast manually followed by disking, or subsurface application using the Adjustable-Band Implement. An unamended treatment served as a control. Corn yields were assessed by harvesting the center rows of each plot, and statistical analysis, such as Duncan's Multiple Range Test, was employed to identify significant differences between the means. The experimental results revealed that the subsurface application using the band applicator significantly increased corn yield by 36% compared to equivalent surface applications of the litter. Additionally, subsurface application substantially decreased NH₃-N losses by more than 95% when compared with surface-applied litter. This is a significant finding as ammonia volatilization is a common pathway for nitrogen losses. Given that the P/N ratio in poultry litter is typically higher than necessary for plants, increasing N losses to the atmosphere through NH₃ volatilization can lead to a rise in soil P levels. This, in turn, may contribute to increased phosphorus concentrations in runoff. Over the 3-year study, cumulative phosphorus loss was found to be 55% less in the watershed that received subsurface litter applications compared to the one that received surface-broadcast litter applications. This suggests that the subsurface application method not only enhances corn yield but also reduces nutrient losses, particularly phosphorus, offering potential benefits for soil and water management in no-till corn production systems.

Rahman et al. (2005) Study aimed to explore and evaluate methods for assessing manure exposure in liquid manure injection tools through laboratory and field studies. The laboratory investigation employed a randomized factorial experiment (3 × 3 × 2 × 2) with three replications. The experiment involved three sweeps (small, medium, and large) at three injection depths (50, 100, and 150 mm), two tool forward speeds (0,6 and 1,4 m/s), and two soil moisture contents (14 and 18%). Sweep dimensions were 225, 255, and 330 mm for small, medium, and large sweeps, respectively, with a common length of 220 mm. Rake angles for small, medium, and large sweeps were 16°, 18°, and 20°, respectively. Laboratory tests utilized an indoor soil bin (1,5 m wide, 15 m long, and 0,6 m deep) containing loamy sand soil. In the field study, a different set of 13 sweeps was used, spaced 540 mm apart and arranged on a 7-m toolbar in two ranks. Sweep dimensions were 100 mm in width and length, with a rake angle of 26°. Liquid manure (3% solid content) was delivered from storage to the injector through a hose system. Manure exposure risk was assessed by

measuring cover profiles using a laser profiling system, defining two parameters: line-transect (LT) and image analysis (IA). These parameters, expressed as the ratio:

$$C_m = \frac{N_m}{N_t} \times 100$$

Served as performance indicators for liquid manure injection tools. where: C_m = manure cover (%), N_m = number of intersections over the manured surface and N_t =total number of intersections in the mesh quadrant.

Odor concentration measurements were conducted using a wind tunnel technique, covering an area of 0,3 m² (0,75 m long by 0,4 m wide). The odor emission rate (E) was calculated using the formula

$$E = \frac{C \times V \times A_c}{A_s}$$

Where C is the odor concentration (OU(odor unit)/m³), V is the air velocity in the tunnel (ms⁻¹), A_c is the cross-sectional area of the main chamber (m²), and A_s is the surface area covered by the tunnel (m²).

Statistical analysis of variance (ANOVA) was performed to examine the effects of experimental factors and their interactions. Results indicated that a 150 mm injection depth was optimal for minimizing manure exposure, although it required a relatively high power for tool cutting. Manure cover was significantly affected by the application rate, with an increase from 8% to 22% when the rate doubled. Odor concentrations measured at the manure storage and soil surface ranged from 670 to 1616 OUm⁻³, with the high concentrations attributed to cold weather during field trials. The study reported no significant effect of manure application rate on odor.

Wagner et al. (n.d.), conducted a research, by on the use of band spreader, band spreader with incorporation rotary cultivator, and shallow closed slot injector methods for manure application. This study delves into the impact of field acidification and various application methods on ammonia emissions and crop yield. The study spans 10 hectares of loamy sand fields, with a focus on pH 6, used cattle slurry as material (85 kg ha⁻¹ NH₄⁺-N) at seeding Spring barley and on standing barley for comparing application methods. For comparing slurry types used (85 kg ha⁻¹ NH₄⁺-N) pig slurry, mink slurry, cattle, digestate/separated as materials for applied at end of tillering stage and application at beginning of flag leaf emergence. Ammonia emissions are measured using closed chambers and Dräger tube methods. Christian Wagner's research reveals notable findings, emphasizing a 60% reduction in ammonia emissions with band spreader + incorporation rotary cultivator, compared to band spreader methods. Furthermore, injection

methods result in a 96% reduction compared to band spreading and a 72% reduction compared to band spreader + incorporation rotary cultivator during seeding Spring barley. Acidification in winter wheat reduces ammonia loss by up to 60%, with injection demonstrating the highest reduction effect at 96%. The combination of band spreading, incorporation, and acidification of cattle slurry shows no significant difference to injection. Noteworthy reductions are observed in ammonia emissions for specific slurry types, such as cattle slurry (61%), anaerobic digestate (57%), and mink slurry (74%), attributable to acidification. NH_3 abatement can be increased with a certain slurry type and the best combination of ammonia abatement methods. (cattle slurry + band spread. + incorp. + acid).

In a parallel investigation, (Huijsmans, 2003), focuses on ammonia volatilization from field-applied manure, considering factors like weather conditions, manure characteristics, soil type, soil moisture content, and grass height. Application techniques, including broadcast surface spreading, narrow-band application, and shallow injection, were evaluated. Results indicated that the NH_3 volatilization rate peaks in the first hours after spreading, gradually decreasing thereafter. NH_3 volatilization was measured on 110 experimental grassland plots in 45 separate field experiments in the growing seasons. The experiments included different soil types (clay, peat and sand), two manures (cow manure and pig manure) and broadcast surface spreading, narrow-band application methods was used. Plots were differed in application technique, application rate, type of manure applied or grass height. Application methods 1- Surface spreading was carried out by a tanker fitted with a splash-plate. The manure was pumped through an orifice onto a splash-plate from where it was spread onto the soil and the grass. 2- Narrow-band application was carried out by trailing narrow sliding feet (also called 'shoes') over the soil surface, pushing aside the grass cover but not cutting the sward. Each foot was 0,37 m long and 0,02 m wide and kept horizontally by a parallelogram construction. 3- Shallow injection (open slot) was carried out with injection coulters. Coulters and discs were used to cut vertical slots into the grass sward. Manure was released into the slots, which were left open. The slots were up to 0,05 m deep and were spaced 0,20 m apart. As results, the NH_3 volatilization rate from applied manure was not linear with time but peaks the first hours after spreading. After an initial peak, the rate gradually dropped, the rate of NH_3 volatilization at the end of the experimental period (96 hours) was virtually zero. The effect of the application techniques was analyzed by using the volatilization profiles with volatilization expressed as the percentage of Total Ammoniacal Nitrogen applied as $\text{kg NH}_3\text{-N ha}^{-1}$ per hour. Cumulative NH_3 volatilization varied significantly among application methods, ranging from 27% to 98% for surface application, 8% to 50% for narrow-band application, and 1% to 25% for shallow injection. The statistical model attributed approximately 50% of the variation in NH_3 volatilization to the application technique. Wind speed emerges as a significant factor, influencing volatilization rates across all methods, with varied impacts based on the specific application technique employed.

The study underscores the importance of considering both application methods and environmental factors in optimizing nutrient management practices for enhanced agricultural sustainability.

2.2 The Ammonia Emission Related Researches

Nitrogen, a pivotal plant nutrient, holds paramount importance in enhancing productivity, and its deficiency can significantly affect plant production (Jansson and Persson, 2015). Numerous studies have focused on evaluating ammonia emission measurements to optimize nutrient management practices.

In the research conducted by (Nyord et al., 2012), the objective was to assess the influence of different soil injection tools on NH_3 emission and their subsequent impact on crop yield. The experiments employed anaerobically digested and solid–liquid-separated slurry as test materials. Various soil injection tools were employed, including a simple tine, a winged tine, a single disc injector, and a combined disc and tine injector. The simple tine which was injected 7–12 cm below soil surface, the winged tine which can inject slurry approximately 7 cm subsurface, the single disc injector consists of a 400-mm diameter disc angled 3° off vertical with 25 mm deep cuts at the edge which cuts to 5–7 cm below the soil surface and can inject slurry 2–3 cm below. Combined disc and tine injector consists of angled 400-mm (diameter) sharpened discs with a discharged tine for inject slurry 2–3 cm subsurface. The study utilized a wind tunnel technique to measure ammonia emissions, with each tunnel covering an area of 0.85 m^2 and air exchange occurring 23 times per minute. NH_3 concentration in the air was analyzed using an NH_3 absorber by drawing a subsample of the air through an NH_3 absorber (gas-washing bottle containing 100 ml 0.02 M H_3BO_3) at a rate of 2 L min^{-1} , and emissions were quantified over six-time intervals up to 120 hours after application.

Emissions of NH_3 were quantified using

$$A = \sum_{j=1}^n (C_{\text{out}j} - C_{\text{in}j}) \times V_j$$

Where A is the total NH_3 emission in mg, j is the interval number, n is the total number of intervals, V is the volume of air flow in m^3 , and C_{out} and C_{in} are the concentrations of gas in the outlet and inlet air in mg m^{-3} air, respectively. Results indicated that the type of application technique significantly influenced NH_3 emissions. Soil injection, particularly using the simple tine, demonstrated a notable reduction in NH_3 emissions from land-applied pig slurry compared to surface application. Specifically, surface application with trailing hoses resulted in the highest N_{max} value, approximately 20% of applied Total Ammoniacal Nitrogen (TAN). In contrast, injection with the simple tine led to a cumulative NH_3 loss of around 10% of applied Total Ammoniacal

Nitrogen, about three times lower than that observed with the winged tine. While no significant difference in grain yield was observed across the experiments, consistently increased protein content was noted as a result of slurry injection. This increased protein content was attributed to the reduced NH_3 volatilization, signifying a greater availability of Total Ammoniacal Nitrogen for plant uptake. The study spanned three years, providing a comprehensive understanding of the nuanced interactions between soil injection tools, NH_3 emissions, and crop yield, emphasizing the potential benefits of adopting precision nutrient management practices in agriculture.

Ndegwa et al. (2009) Determined ammonia concentrations in ambient air using a dynamic chamber method with sulfuric acid as a trapping agent. The research focused on examining various factors, including acid volume, acid depth, and airflow rate, to identify their impacts on the efficiency of sulfuric acid traps. The study also provided recommendations for researchers and users to ensure the reliability of results obtained through this method. To evaluate trap efficiency over a range of ammonia concentrations, two different amounts of acid, acid depths, and airflow rates were tested. Ammonia flux was measured using concentrations of 200, 600, 1000, 1400, 1800, and 2300 $\text{mg NH}_4^+ \text{L}^{-1}$, representing six different ammonia fluxes. The study explored the effects of acid volume, with trap systems having acid volumes of 470 mL and 150 mL while maintaining consistent acid depth. Additionally, the impact of acid depth on trap efficiency was investigated by employing two different depths of acid. Results indicated that maximizing the depth of acid in the trap system was crucial for enhancing efficiency. Increasing the acid depth by approximately three times (from 110–310 mm) using a smaller diameter acid bottle led to an average 8% improvement in absolute efficiency. Furthermore, reducing the airflow rate by half, from 1,0 to 0,5 L min^{-1} , resulted in an average 4% increase in trap efficiency. These findings underscore the importance of careful consideration of acid volume, depth, and airflow rate in ammonia measurement methods using sulfuric acid traps. Implementing the recommended adjustments can significantly contribute to the reliability and accuracy of results in ambient air ammonia concentration studies, providing valuable insights for researchers and users alike.

Liu et al. (2009) Conducted a study to develop a mechanistic emission model for estimating ammonia flux from broiler litter and subsequently evaluated the model at the laboratory scale. The proposed model incorporated various factors influencing ammonia flux, including the total ammoniacal nitrogen content, moisture content, pH, and temperature of the litter. Additionally, parameters such as the Freundlich partition coefficient, mass transfer coefficient (KG), ventilation rate, and emission surface area were considered. The experimental setup involved a specially designed wind tunnel measuring 2,30 m in length, 0,20 m in width, and 0,20 m in height, constructed with stainless steel and Lexan polycarbonate sheet. Airflow within the tunnel was generated by a centrifugal blower capable of a maximum airflow rate of 0,12 $\text{m}^3 \text{s}^{-1}$. Velocity profiles inside the wind tunnel were meticulously measured using a rotating-vane anemometer and a hotwire anemometer employing the log-Tchebycheff traversing method, with data collected at six

measuring points. Broiler litter samples were strategically placed on the 0,75 m long emission section of the wind tunnel to a depth of 0,02 m. The calculation of ammonia fluxes from these litter samples within the wind tunnel's emission section was accomplished using a specific equation. This study contributes to the understanding of ammonia emissions from broiler litter by providing a comprehensive model that considers multiple influencing factors. The laboratory-scale evaluation ensures the reliability and applicability of the proposed model, offering valuable insights for further research in the field of ammonia flux modeling and emission control strategies in poultry farming.

$$J = (Q/A) (C_{\text{outlet}} - C_{\text{inlet}})$$

Where C_{outlet} and C_{inlet} are the ammonia mass concentrations (mg m^{-3}) at the outlet and inlet of the wind tunnel, respectively. Air profiles were measured for nominal velocity values of 0,15, 0,50, 1,00, 1,50, and 2,00 m s^{-1} .

Özbek and Lu (2010) assessed the impacts of different application methods of liquid manure, particularly surface application and injection with wide-type feet at a depth of 10 cm, on ammonia nitrogen loss and corn yield based on studies conducted by various researchers. The ammonia nitrogen loss in surface application of manure ranged between 48-68%, whereas in soil injection, this rate varied between 4-8%. Similarly, the corn yield in surface application was found to be 829 kg ha^{-1} , while in injection application, it was determined to be 1382 kg ha^{-1} .

In the study by (K. A. Smith et al., 2000) focusing on reducing ammonia loss through liquid manure application techniques, four different distributor types were used: collision plate, band spreader, tined cultivator, and injection distributor that injects liquid manure into the soil. Over a period of 2 years and 16 total applications, they continuously modified the application techniques to reduce NH_3 loss. The reduction rates were reported as 17% for the collision plate, 23% for the band spreader, 25% for the tined cultivator, and 40% for the injection distributor, respectively.

Wu and Zhang (2007) focused on the evaluation of a wind tunnel as a sampling tool for odor emission from liquid emission surfaces. The assessment incorporates air velocity measurements within the hood, smoke testing, Computational Fluid Dynamics (CFD) simulations to visualize air movement, and the estimation of pick-up rates (recovery efficiency). The wind tunnel, with its higher airflow rate compared to a flux chamber, offers a more defined wind direction. Advantages over traditional flux chambers include a larger covered surface area and air exchange rates resembling ambient conditions. Smith and Watts (1994), along with Jiang and Kaye (1996), recognized the wind tunnel as the optimal method for sampling odor emissions from area sources. The odor emission rate from an area source is mathematically represented as the product of the measured odor concentration and the flow rate.

$$E = CV_t \frac{A_t}{A_x}$$

where: E: odor emission rate (OU/s-m²), V_t: bulk wind speed in the tunnel (m/s), A_t : cross-sectional area of the tunnel (m²), A_x : surface area covered by the tunnel (m²). A major disadvantage of wind-tunnel type hoods arises from the relatively large airflow used. These result in dilution of the emitted gasses, so that wind tunnel methods can lack sensitivity and be unsuitable for very low emission rates.

Lockyer, (1984) introduced an early wind tunnel system designed for measuring ammonia volatilization from grass swards. Constructed with transparent polycarbonate in the measurement section to allow sunlight penetration, the wind tunnel's air velocity matched the wind speed at 25 cm outside, ensuring realistic exposure for growing plants. With a transparent plastic canopy covering 1,0 m² and an attached sheet metal cylinder housing a variable-speed DC motor, the wind tunnel could mimic natural wind speeds, offering potential applications in realistic environmental conditions.

R. J. Smith and Watts, (1994) investigated odor emissions in relation to bulk tunnel wind speed, revealing an increase in emissions from 0,2 m/s to 2,0 m/s. They developed a power equation

$$\frac{E_v}{E_1} = 1,05V^{0,63} \quad R_2:0,685$$

Where: v: given bulk tunnel velocity (m s⁻¹), E₁: is the base odor emission rate measured at tunnel, E_v: is the odor emission rate at tunnel V. Describing the correlation between emission rate and wind speed. This highlights that odor and ammonia emissions tend to rise with increased tunnel wind speed.

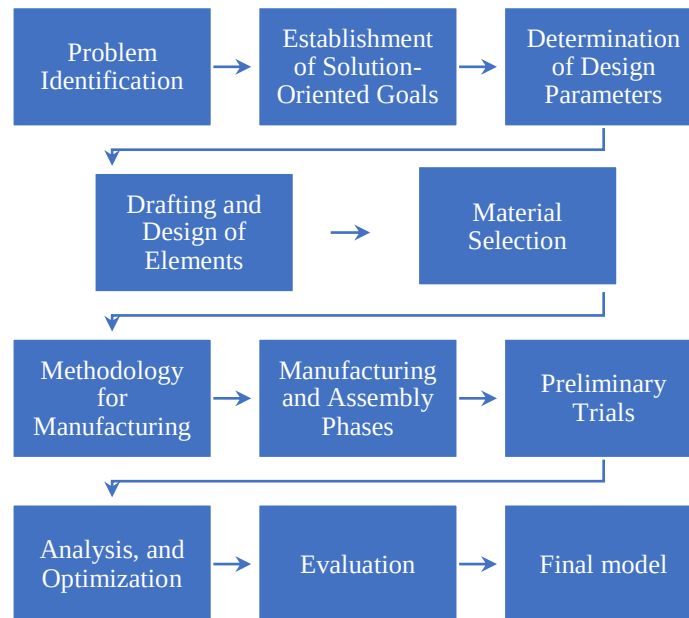
Yang et al. (2018) evaluated various methods for determining ammonia volatilization in farmland. They detailed the operation processes, advantages, and disadvantages of each method, emphasizing the importance of simplicity, cost-effectiveness, ease of use, control over conditions, error reduction, and speedy, accuracy results. The venting methods such as the continuous airflow enclosure method, the wind tunnel method and the micro- meteorological method were reviewed. The wind tunnel method, among others, was noted for providing consistent environmental conditions, making it suitable for multi-processing, multi-repeat measurements in a small-scale range, and particularly applicable for multi-factor contrast experiments. However, limitations, such as the inability to simulate static wind and precipitation conditions, were acknowledged. Additionally, concerns about errors during low wind speeds condensation affecting measurements were highlighted. The recovery rates for wind tunnels varied between 97% and 103%, with Lockyer's design showing rates of 77% to 87%.



3. MATERIALS AND METHODS

The experimentation and research were conducted at Cukurova University, Faculty of Agriculture, specifically within the Department of Agricultural Machinery and Technologies Engineering, Adana, Turkey, situated at coordinates 37° 03'26'N, 35° 21'21 E, under a Mediterranean climate. The focus of this study involved the design, construction, and performance evaluation of a prototype logistics operating system engineered for the injection of liquid manure into the soil. The machine's construction commenced in 2020, with relevant measurements and tests spanning from 2022 to 2023.

The progression of this study adhered to a structured methodology, encompassing various procedural steps:



These steps were categorized into three key stages:

1. Design and Manufacturing of the System
2. Evaluation of Injection Ability
 - a) Laboratory Study
 - b) Field trial
3. Emission studies
 - a) Design and Construction of the Wind Tunnel
 - b) Estimation of Ammonia Volatilization

The assessment of injection ability occurred in two stages: initially, within controlled laboratory conditions where the injector wheel was affixed to a base, utilizing an electric motor to replicate forward speed. The subsequent phase involved field trials conducted in a soil bin channel measuring 20 meters in length and 2 meters in width, characterized by a clay loam soil structure.

3.1 Materials

3.1.1 Design Drawings

Design and technical drawings for the prototype were meticulously created using the SolidWorks 3D CAD modeling program, specifically the 2020 version. (Figure 3.1)

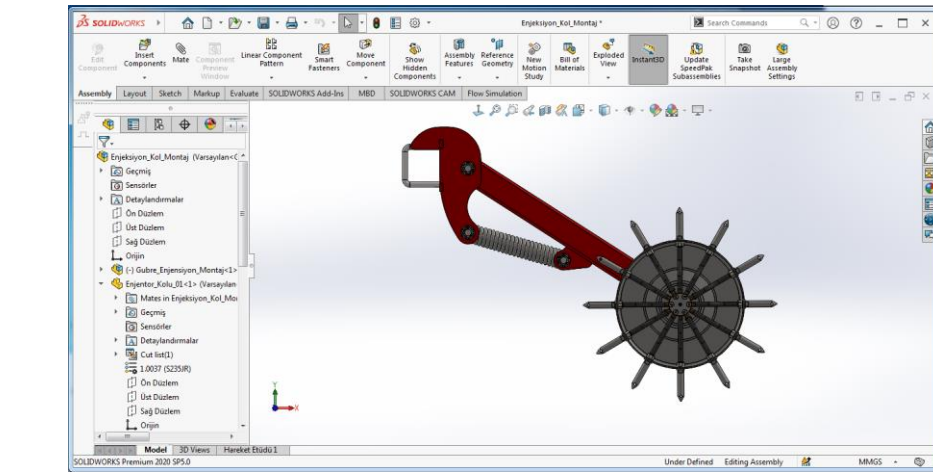


Figure 3.1. Sample design in solidworks software

3.1.2 SPSS Statistics Software

SPSS Statistics is a statistical software suite developed by IBM for data management, advanced analytics, multivariate analysis and business intelligence. SPSS the 22-version program was used to analyze the collected data in this study.

3.1.3 Physical and Chemical Properties of The Liquid Manure Used

For this study, liquid manure sourced from the Eastern Mediterranean Agricultural Research Institute was utilized. This particular type of manure was obtained from barn floors through a scraping process and subsequent separation. The liquid manure content contains nitrogen (N) within the range of 0,3% to 1%. (Figure 3.2)



Figure 3.2. Liquid manure with volume of 1 ton.

Table 3.1. Properties of liquid manure in the experiment.

Parameters	Values
pH	6,88
NH ₄ -N (mg kg ⁻¹)	209,89
NO ₃ -N (mg kg ⁻¹)	28,62
Total N (%)	0,84
P (%)	0,09
K (%)	0,21
Density (ton m ⁻³)	1,03
Viscosity (Dynamic)(cp)	13,20

3.1.4 Viscosity Meter

The viscosity of the liquid manure used in the study was measured using the rotational viscometer PCE-RVI 2. This instrument accurately determines the mechanical resistance of the liquid. (Figure 3.3)



Figure 3.3. Viscometer

Table 3.2. Technical specifications of the used viscometer

Measuring range	15 ... 100,000 cp, 1 ... 100,000 cp with L0 spindle configuration
Accuracy	$\leq \pm 2$ % of measuring range
Resolution	0.01 cp
Repeatability	$\pm 0,5$ %
Temperature measurement measuring range	0 ... 100 °C / 32 ... 212 °F
Adjustable speed	6, 12, 30, 60 RPM
Sample volume	250 ... 400 ml / 8.4 ... 13.5 fl oz (depending on the spindle)
Power supply	primary: 100 ... 240 V AC, 50 / 60 Hz, secondary 12 V DC, 2 A
Ambient conditions	5 ... 35 °C / 41 ... 95 °F, <80 RH, non-condensing
Dimensions	400 x 200 x 430 mm / 15,7 x 7,8 x 16,9"

3.1.5 Inverter (Variable Frequency Drive - VFD)

A Variable Frequency Drive (VFD) functions as a motor controller, regulating an electric motor's speed by adjusting the frequency and voltage of its power supply. In this study, the VFD utilized was the Mitsubishi Electric (Model FR-CS82S-100-60, featuring specifications: 2.2 kW) (Figure 3.4). For simulated forward speed in laboratory section of study used an electric Motor for rotating wheel. For the change electric motor's RPM could be adjusted by changing the voltage, was accomplished with the aid of the variable frequency drive (Inverter).



Figure 3.4. Inverter (variable frequency drive - vfd).

Table 3.3. Technical specifications of the VFD inverter

Series	FR-CS80 SERIES
Type	FR-CS82 COMPACT INVERTER
Minimum Rated Voltage (V)	200
Current Type	AC
Rated Output Current ND (A)	10
Rated Motor Capacity ND (kW)	2,2
Control Method	ADVANCED MAGN. FLUX VEC. CTRL
Motor Type	INDUCTION MOTOR

3.1.6 Electric Motor

An electric motor, essential for converting electrical energy into mechanical energy, was incorporated into the study. The 1,5 kW (2 hp) variable-speed DC motor from Gamak Electric Co., model 5CD123UE002B, was utilized for experimentation purposes (Figure 3.5). In laboratory section of study for simulated forward speed used the electric Motor for rotating wheel.



Figure 3.5. Electric motor.

3.1.7 Tachometer

Tachometers serve the purpose of measuring the rotational speed of a shaft or disc during machine operation. In this study, a Mini Laser Photo Tachometer Counter was employed to measure the operational speed of an engine, typically in revolutions per minute (RPM) (Figure 3.6)



Figure 3.6. Tachometer.

3.1.8 Pressure Regulator Set

The pneumatic regulator used, specifically the STNC TW Series Air Filter Regulator (model TW5000-10 – TW Series Air Filter Regulator – 1), is controlled by two valves. One valve regulates inlet control while the other manages exhaust. This type of regulator combines filtration, cleansing the air by capturing solid particulates and separating liquids, along with precise control over fluid flow. Air Lubricator: The STNC air lubricator (model TL2000-2, Stainless Steel) functions by reducing friction, ensuring smoother and more slippery surfaces within the pneumatic system (Figure 3.7)



Figure 3.7. Pressure regulator set.

3.1.9 Air Compressor

An air compressor, a machine that intakes ambient air and increases its pressure, was utilized in the experimental setup. In this study, the compressor utilized was the Sarmak compressor-pump (Figure 3.8)



Figure 3.8. Air compressor.

Table 3.4. Technical specifications of the Sarmak compressor-pump.

Series	15/1005
Maximum operating pressure (bar)	8
Safety valve operational pressure (bar)	9
Volume (lt)	200

3.1.10 Soil Channel

The soil bin channel having with 20 meters in length and 2 meters in width was situated in the Workshop of Cukurova University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. This specialized setup with clay loam soil served as a platform for studying soil-tool interaction. A moving carriage on rails, operated by an electric drive system controlled by an inverter, facilitated the movement within this soil channel (Figure 3.9)



Figure 3.9. Soil bin where experiments were conducted

3.1.11 Penetrometer

To ensure homogeneous measurement areas and assess soil penetration resistance, an Eijkelkamp brand penetrometer (Penetrologger) was employed. This instrument measures the soil's resistance, reflecting its capacity and ease for root penetration. The resistance depends on various factors such as humidity, density, and compound strength (Figure 3.10)



Figure 3.10. Trial area penetration measurement.

Table 3.5. Technical specifications of the penetrometer.

Maximum Applicable pressure	10000 kPa
Maximum measuring depth	0,80 m
Measured parameters	penetration resistance
Measuring accuracy	$< \pm 1\%$
Measuring range	0...10000 kPa
Measured parameters	penetration resistance
Measuring accuracy	$< \pm 1\%$
Measuring range	0...10000 kPa

3.1.12 Electric Fan

For the small wind tunnel, an electric fan with a 25-cm diameter aluminum impeller equipped with seven blades, set at a 15-degree pitch, was utilized. The fan's velocity ranges from 0.5 to 5 meters per second (Table 3.6) (Dundar model DTA 250D). (Figure 3.11)



Figure 3.11. Electric fan

Table 3.6. Technical specifications of the electric fan.

Diameter (cm)	Voltage (V)	Power (W)	Revolution (r.p.m)	Pressure (mmH2O)
25	230 V ~ 50 Hz.	55	800	5

3.1.13 Anemometers

Hot-wire anemometer: A thermal transducer, the hot-wire anemometer, was employed to measure instantaneous flow velocity. This device calculates instantaneous flow velocity from electric voltage measurements, allowing for precise wind speed measurement. In this study, the wind speed within the tunnel was monitored using a thermal anemometer (TSI, Inc., Model 8386A-M-GB) (Figure 3.12). In order to measure the air velocity in tunnel, two holes were set at the top

center and side center of the canopy section of tunnel and the air velocity was measured with the help of hot-wire air anemometer.



Figure 3.12. Hot-wire anemometer.

Table 3.7. Technical specifications of the hot-wire anemometer.

Max Air Velocity	50m/s
Min Air Velocity	0 m/s
Air Velocity Accuracy	±3% of reading or (± ,015 m/s)
Static/Differential Pressure Range	5-5 to +15 in. H2O (-9.3 to +28.0 mmHg, or -1245 to +3735 pa

Digital Anemometer- Rotating-Vane: For measuring atmospheric effects—specifically wind velocity, temperature, and humidity—a Digital Anemometer and Air Quality Meter (HLP CONTROLS Inc., model 8919) was utilized in this study. This device resembles a small wind turbine with 8 rotating blades and a handle (Figure 3.13). Its features include the ability to measure air velocity, volume, temperature, humidity, dew point, and wet bulb temperature. In order to measure the air velocity in entrance of tunnel was used this kind of anemometer.



Figure 3.13. Rotating-vane anemometer.

Table 3.8. Technical Specifications of Digital anemometer.

Temp range	-20 ~ 60°C
RH range	0,1 ~ 99,9% RH
Wind speed metric and imperial units are selectable	speed 0,2 ~ 30 M S ⁻¹

3.1.14 Air Flow Meter

An air flow meter is a device that measures air flow, i.e. how much air is flowing through a tube. It measures the mass of air flowing through the device per unit time. An airflow meter (Airflow Yanmis Inc., model B07XL3T6BK) was utilized in the study for measuring and analyzing airflow (Figure 3.14).



Figure 3.14. Air flowmeter.

Table 3.9. Technical specifications of the air flowmeter.

Material	Acrylic+ plastic+ metal
Range	2.5~25LPM
Pressure	0.6MPa
Temperature	0~60°C

3.1.15 Vacuum Pump

Vacuum pumps are mechanical devices that enable the removal of air from a sealed area to create an area devoid of air and/or gas. A vacuum pump was employed as part of the experimental setup. This small vacuum pump is a DC 12V mini oil-less vacuum pump of -80kPa vacuum degree (Figure3.15).



Figure 3.15. Vacuum pump.

Table 3.10. Technical specifications of the mini vacuum pump.

Max Flow Rate	0~15 L/min
Max Vacuum	10~80kpa
Max Vacuum	10~80kpa
power	10 W

3.2 METHODS

3.2.1 The Design of Point Injection Liquid Manure

The design and simulation of the Point Injection Liquid Manure system was executed using SolidWorks 2020 software. This system, based on a circular array of spokes, is a tractor-pulled wheel device designed to meter and inject homogeneous liquid manure into the ground. Consisting of 12 hollow spikes attached to a rotatable wheel, the liquid manure flows from these spikes as the wheel rotates. This system injects fluid below the ground surface to disperse it into the soil. The wheel's diameter is approximately 400 mm, each spoke is 100 mm in length, and the distance between separated depots around it is about 140 mm (Figure 3.16).

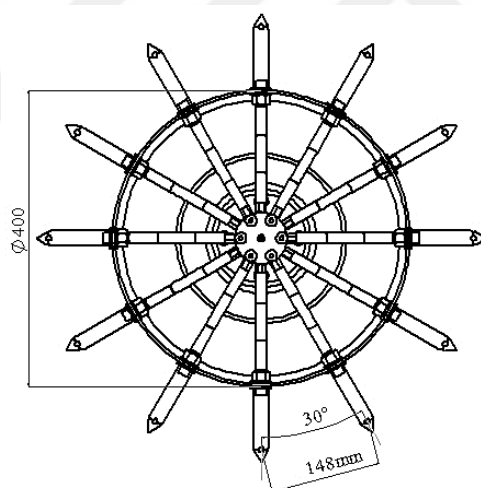


Figure 3.16. Side view of the Point Injection Liquid Manure system's wheel assembly.

The spoked wheel assembly comprises a hub portion and twelve Tygon tubes extending radially outward from the hub. Each Tygon tubing is connected to spikes. Wheel disposes of 12 hollow spikes, the so-called spoke. The spoke, hollow rods (7 mm inner diameter, 20 mm outer diameter) penetrate the soil as the wheel turns. Each spoke designed to inject liquid fertilizer as a solid stream jet up to a depth of 100 mm below the soil surface (Figure 3.17). Shortly after the spoke is in the soil, a duct will be opened by mechanical hub control, and fertilizer will be deposited in the ammonium depot there. The fertilizer is deposited at intervals of 140 mm and a maximum of 100 mm subsurface. To facilitate better penetration into the soil, two 7 mm diameter holes were designed on each side of the rod tip, cut angularly for improved soil penetration.

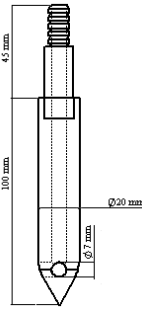


Figure 3.17. The spoke.

- Hub Control Mechanism**

The mechanical hub control, situated at the center of the wheel, manages the deposition of fertilizer into the suitable spokes. The hub portion is formed of a housing having a bearing that is secured to permit rotational movement of the housing with respect to the axle. The fixed inner part (bearing) with a single hole and one outer part designed for rotation featuring 12 holes—the hub operates using a rotary valve. When these holes align with each spoke, which occurs only when the spoke is perpendicular to the ground, the system allows for fertilizer discharge. Injection is completed as the liquid manure enters the soil through two slits on the sides of each spoke. (Figure 3.18)

Each spoke is perpendicular to the ground, thus allow the system to discharge of fertilizer in the spokes. Injection is completed by the liquid coming to the soil through two slits on the sides of the spoke

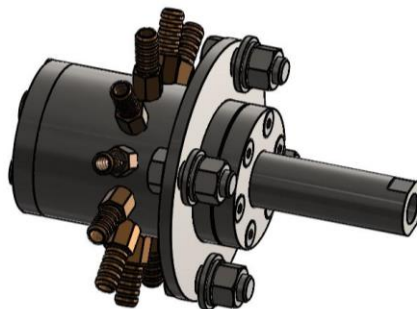


Figure 3.18. The mechanical hub.

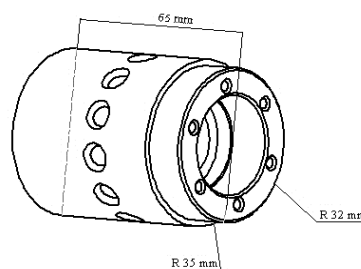


Figure 3.19. The outer port of the mechanical hub.

The outer port of the mechanical hub (Figure 1.19 and 3.20) contains 12 holes evenly distributed around it as a ring. This part enabling rotational motion in synchronization with the wheel.

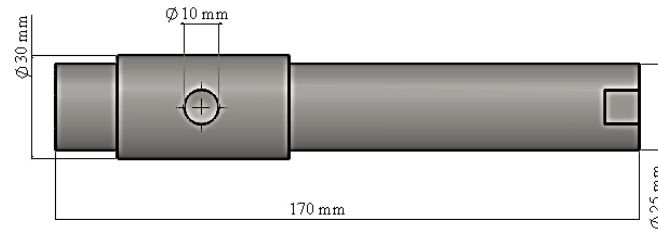


Figure 3.20. The inner port of the mechanical hub.

The inner port, a fixed part, measures 170 mm in length and 30 mm in diameter in the central part, featuring a 10 mm diameter hole (Figure 2.21) The hub subassemblies appear under explode.

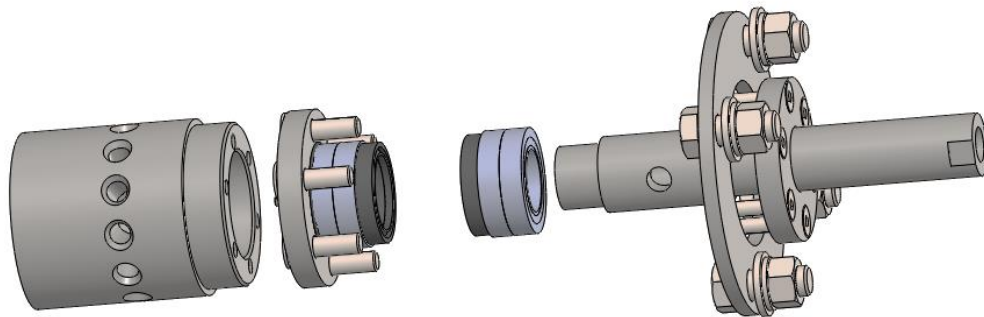


Figure 3.21. Exploded view of hub assembly.

A liquid manure tank connects to the hub via Tygon tubing, allowing the direct pumping of liquid manure to the hub. This distribution system links to all 12 hollow spikes through Tygon tubes, ensuring the discharge of liquid manure into the appropriate spoke when the wheel rotates. (Figure 3.22)

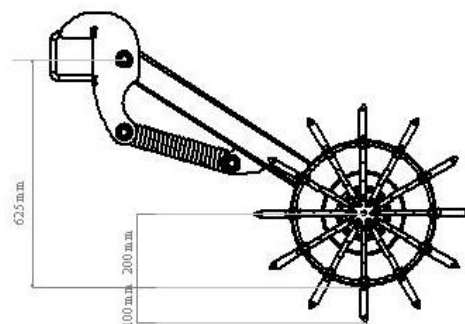


Figure 3.22. Side view of assembled Point Injection Liquid Manure system.

3.2.2 Manufacturing and Assembly

The prototype's manufacturing and assembly took place in the C.U.A.F Workshop. Processes involved laser cutting, machining, and welded joining methods. Various pictures of the manufacturing process are provided in Figure 3.23.

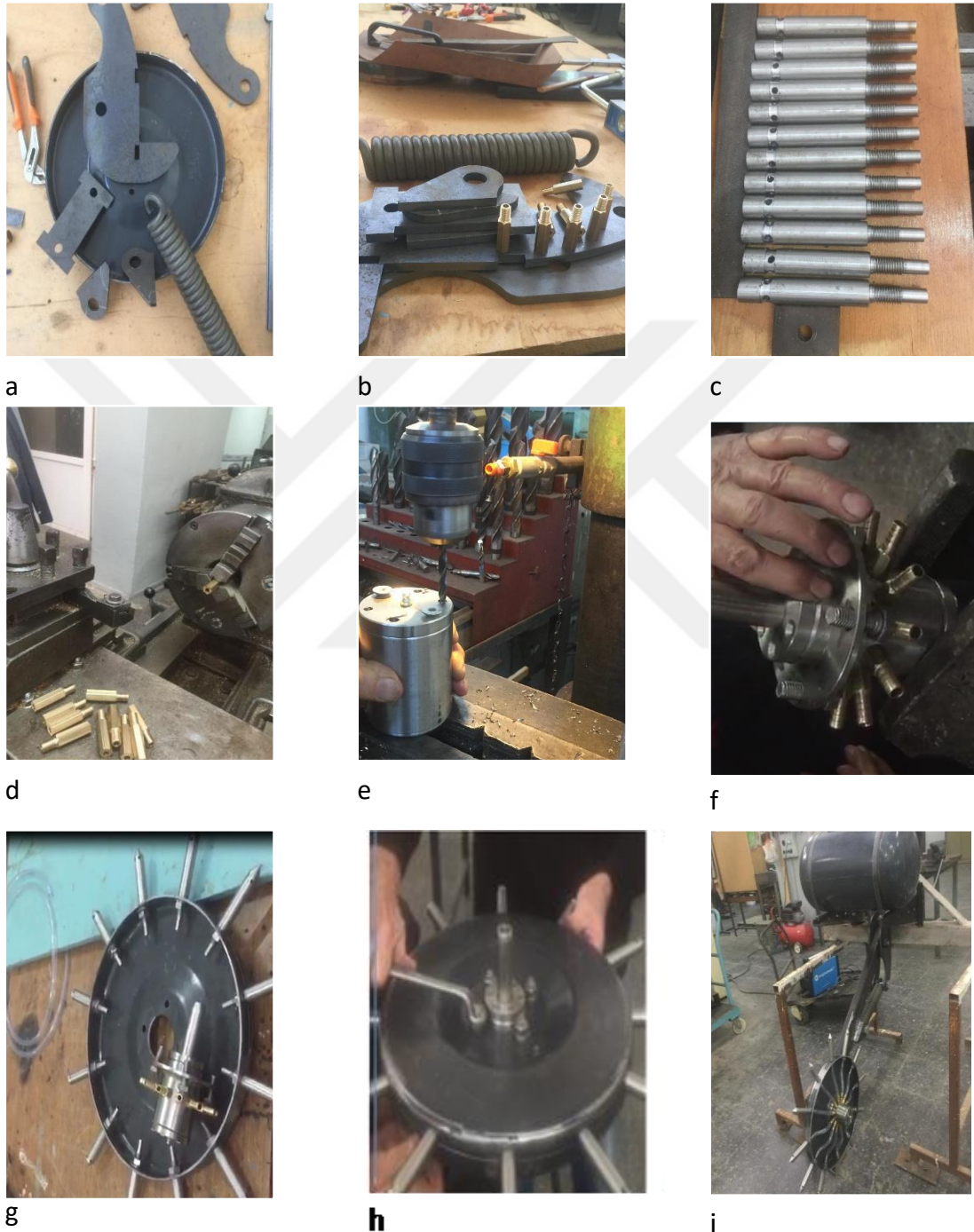


Figure 3.23. Manufacturing process of the Point Injection Liquid Manure.

Final status of the Point Injection Liquid Fertilizer system (Figure 3.24)



Figure 3.24. Point Injection Liquid Manure

3.2.3 Determination of The Injection Ability.

3.2.3.a. Laboratory study

At this stage of the study, the goal was to determine the application rate and regulate the Point Injection Liquid Manure performance. The experiment setup in laboratory conditions comprised:

- Tank
- Pressure Regulator
- Injector Wheel
- Electric Motor

The trials were arranged in a completely randomized factorial design ($4 \times 3 \times 6 \times 2$) involving four different pressures and three forward speeds, with six replications. Water and liquid manure were used as materials.

A total of 144 experiments were conducted using water and liquid manure at pressures of 200, 300, 400, and 500 kPa, and forward speeds of 1, 2, and 3 km h⁻¹, each with six replications. The assembled wheel was fixed to a pedestal base. To supply the required liquid volume for the experiments, a small 20-liter tank was positioned directly beside the wheel, connected to it by a 1,3 m long, 12,8 mm inner diameter Tygon tubing. An air pressure regulator set and air compressor were used to control and maintain consistent air pressure within the tank during the trials (Figure 3.25).

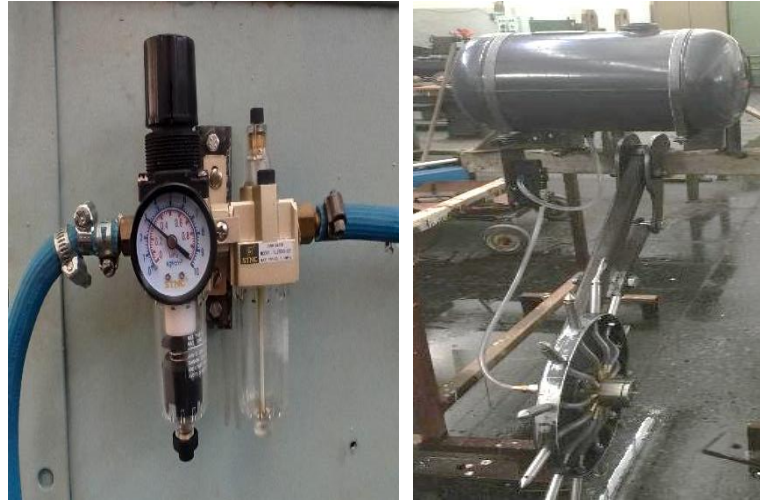


Figure 3.25. The assembled wheel fixed to a pedestal base and air pressure regulator set.

Forward speed was simulated using the Electric Motor. It was set to three different rotation speeds to conduct the experiments. The electric motor's revolution was adjusted by changing the voltage, accomplished with the aid of a variable frequency drive (Inverter). The revolution was determined by using an axial shaft to connect the wheel to the electric motor (Figure 3.26)



Figure 3.26. Forward speed simulated set.

Forward speed and shaft rotation speed were equalized as determined by the formula:

$$\vartheta = \frac{V \times 100}{P \times 6} \quad (3.1)$$

- V : Forward speed (km h⁻¹).
- P : Wheel perimeter (m).
- ϑ : Wheel rotation velocity (rev min⁻¹).

Table 3.11. Conversion RPM to speed in a line.

Forward speed km h ⁻¹	Wheel rotation velocity Revolutions per minute	Inverter frequency Hz
1	13,28	3,22
2	26,51	6,35
3	39,65	9,40

In the first case, the tank was filled with 5 L of liquid material. It was pressurized for all four pressures considered in the experiment (200, 300, 400, and 500 kPa). Simultaneously, the injector wheel was rotated at each speed determined during the test program by an electric motor (1, 2, and 3 km h⁻¹). This process was repeated for each experimental material (water and liquid manure). The time taken for the known volume (5 L) of liquid material to empty from the tank at different speeds and pressures was measured using a chronometer. Experiments were conducted in 6 repetitions, and the time required for the injection of the known volume was recorded. (Figure 4.27)



Figure 3.27. System setup in laboratory condition.

The application rate was calculated using Equation (3.2)

$$N = \frac{600 \times Q}{V \times B} \quad (3.2)$$

N Manure Application rate (l ha⁻¹)

Q Flow rate (l min⁻¹)

V Forward speed (km h⁻¹)

B Swath width of each ejection wheel (m)

In this study, swath width was considered as 0.7.m per injection disc wheel.

3.2.3.b. Field Trials

At this stage of study, the goal was to determine application rate and inject ability of the Point Injection Liquid Manure. The system was carried out on a soil bin channel with a length of 20 meters and width of 2 meters in the Workshop of Cukurova University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering (Figure 5.28). The Experiment setup was prepared on this soil bin, consists of:

- Tank,
- Pressure Regulator,
- Injector Wheel.

The injection wheel is a tractor-pulled equipment. The moving carriage on the rail system in the soil channel provided the movement of Point Injection Liquid Manure. Experiments were arranged completely randomized factorial ($4 \times 3 \times 4 \times 1$) at four different pressures and at three different forward speeds with four replications. The liquid manure was used as material. Forty-eight experiments were accomplished at the base of determined injection ability of the Point Injection Liquid Manure. The experiments were arranged on four different pressures (200, 300, 400, and 500 kPa) and three different forward speeds (1, 2, and 3 km h⁻¹), and the liquid manure was injected with a 100 mm subsurface.

The wheel was fixed on the soil channel's moving carriage by the three-point hitch. The inverter that is located at the main control console was set to the desired forward speed. For the supply of the required amount of liquid in the experiment, the small tank with a volume of 20 liters was mounted on the moving carriage and with 1,3 m of 12,8-mm i.d. Tygon tubing was connected to the system's wheel exactly like the previous stage of study. An air pressure regulator set and air compressor were used to control and maintain air pressure consistency within the tank at trial levels.



Figure 3.28. Installed Point Injection Liquid Manure system, little tank and air compressor on soil bin channel's moving carriage.

The effective working length of the soil channel is 20 meters. Application rate was calculated at different pressures and forward speeds based on 18 meters travel time. The injection wheel comprises 12 hollow spokes that penetrate the soil as the wheel turns. The spike spacing and wheel geometry allow each spike to inject liquid manure at the desired subsurface at every 140 mm interval during operation. For each repetition of the test, the tank was completely filled with test material (liquid manure). The decrease in the amount of liquid in the tank was determined after traveling a distance of 18 meters. This method was repeated for the desired speeds and pressures. (Figure 6.29)



Figure 3.29. Field trail.

The amount of liquid manure per hectare was determined for each application. The application rate was calculated using the (3.2) formula.

3.2.4 The Emission Studies

- a) Design of the wind tunnel
- b) Manufacture of the wind tunnel
- c) Estimating Ammonia Volatilization

In this section of studies concerning the Point Injection Liquid Manure system, the aim is to determine the system's performance in reducing nitrogen loss compared to surface applications.

The effectiveness of this application system in reducing nitrogen was evaluated by quantifying the amount of volatile ammonia nitrogen.

3.2.4.a. Design of The Wind Tunnel

The Solidworks 2020 software was utilized to design the small wind tunnel and simulate its ventilation performance. The wind tunnel comprises two main sections: the canopy section and the cylinder section. The canopy section, made of clear polycarbonate, measures 2 meters in length, 0,5 meters in width, and 0,48 meters in height. It is flexed into a U shape and is positioned within a rectangular frame made from 50×50×3 mm aluminum (thickness), covering a 2 m² treatment area.

The "U" shaped canopy is attached to the second section, the sheet metal cylinder, which has an internal diameter of 25 cm and a length of 100 cm. This section houses a fan and a cross-sectional air-sampling device. (Figure 7.30)

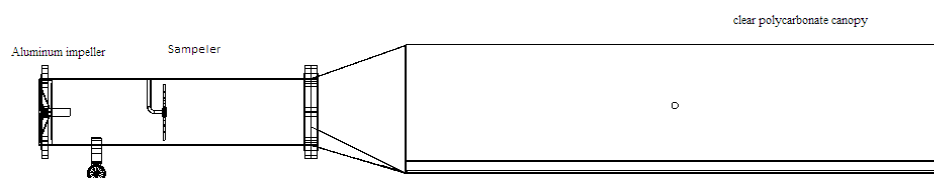


Figure 3.30. Wind tunnel side view.

The aim was to create natural environmental conditions in the experiment, so an electric fan with a 25-cm diameter aluminum impeller was used to draw air across the enclosed area, providing a velocity range from 0,5 to 5 m s⁻¹. This exhaust fan was designed for the outlet of the tunnel, providing ventilation with a flow rate of 0,23 m³ s⁻¹.

A sampler was considered to extract samples from the passing air inside the cylinder. The star sampler device with eight legs was mounted in the cylinder section. Each leg extends 9 cm from a hollow hub that serves as a vacuum manifold. Air enters through the end of each leg and two holes drilled on the legs at equal distances from the hub (see Figure 3.31). The sampler is positioned 60 cm from the inlet of the cylinder to minimize interference from turbulence streams. A greater distance from the inlet helps reduce the inlet expansion effect, ensuring a more stable flow (Scotto Di Perta et al., 2015).

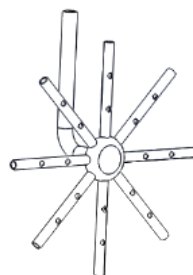


Figure 3.31. Star sampler device.

The star sampler is connected to the gas scrubbing bottle. Ammonia concentrations in the air are measured using acid traps, flow meters, and vacuum pumps.

3.2.4.b. Manufacturing and Assembly Of The Wind Tunnel

The manufacturing and assembly of the small wind tunnel were conducted in the Ç.U.A.F Workshop. Laser cutting, machining, and welded joining methods were employed in manufacturing. Some pictures of the manufacturing process are provided (Figure 3.32).



Figure 3.32. Wind tunnel manufacturing and assembly proses.

3.2.4.c. Estimating Ammonia Volatilization

The aim of this study section was to determine the effects of liquid manure application methods on NH_3 emissions rate from farmland. The experiment was conducted on a soil bin channel in the Workshop of Cukurova University , Faculty of Agriculture concurrently with the Point Injection Liquid Manure The experiments were arranged in a completely randomized factorial design (3×3) involving two different application methods: applying liquid manure on the surface (traditional method) and injecting liquid manure subsurface. Two different depths were considered for the injection method: 50 mm subsurface and 100 mm subsurface. The experiment was repeated three times for each method during each measurement interval.

- **Preparation of The Experimental Area**

The treatment area was established on the soil bin channel, with 2 square meter sample areas designated for each method. Treatments were typically applied to a 1.7 m length of the 2 m canopy [harper-L]. Bovine slurry was used as the material, collected from the barn using a scraper and passing through the separator. The application rate was set at 85 kg ha⁻¹ of total N (Wagner et al., n.d.). In the traditional method, liquid manure (slurry) was sprinkled on the surface in a certain ratio, while in subsurface methods, it was injected using an injection machine. Three-point linkages were utilized to provide lifting and lowering arms for adjusting the injection depth. (Figure 8.33)



Figure 3.33. The treatment area.

- **Sampling Sections**

To determine ammonia concentrations in ambient air, a sample of air was pulled through an acid solution that traps the ammonia. (Ndegwa et al., 2009). The gas scrubbing set consists of an acid trap, flow meters, and vacuum pump. The gas scrubbing bottle (acid trap) containing 120 ml of %2 boric acid, was used as a trap to reaction with ammonia in the sampling air (Rongoei and Outa, 2016). A small vacuum pump bubbled sampling air through this trap. The air flow rate through the acid traps was set at 5 L min⁻¹. The volume of air passing through the gas scrubbing bottles was measured with a gas-flow meter, mounted in the entrance of the acid trap tube which monitors sampling air volume flow rate through the acid trap (Balsari et al., 2005). The amount of

ammonia flowing in the medium was found by the amount of ammonia trapped in the boric acid divided by area on the basis of time.

Installation and Commissioning of The Tunnel

After the treatment areas are ready, the wind tunnel was placed in such a way that the canopy section covers the prepared area. Measurements were commenced within 15 min of completing the treatment application (Harper, 1996). The star sampler was connected to the gas scrubbing bottle with 0,8 m of 12,8–mm i.d Tygon tubing. The tunnel set-up involves attaching all electrical connections to power at the same time as activated vacuum pumps to bubbled sampling air in the gas scrubber. The fan was set to allow air flow velocity in the middle of the canopy as 1 ms^{-1} . The air speed along the X-axis and along the Y-axis was measured with hot wire anemometer, over the time interval sampled. for this aim considered two holes in the middle of the canopy, one inside and the other on top as references. They allowed estimation of both the average and the variance of wind speed in the middle section of the tunnel. Inlet air flow speed was measured by Digital Anemometer. (Figure 3.34)



Figure 3.34. Installation the wind tunnel.

The assessment of NH_3 volatilization following different slurry application methods in soil occurred under constant and controlled environmental conditions. The experiments ran for 48 hours, with samples collected every 3 hours throughout the duration. Every 3 hours, the acid trap containing the trapped acid was sent to the laboratory for analysis to determine the ammonia solution, and new acid was replaced, maintaining continuous collection. In this process, the distilled ammonia trapped in 2% boric acid was titrated with standard 0.005 N H_2SO_4 (Balsari et al., 2005; K. A. Smith et al., 2000). The amount of ammonia flowing in the medium ($\text{kg NH}_3\text{-N ha}^{-1}$

¹d⁻¹) was calculated by dividing the amount of ammonia trapped in the boric acid trap by the area over the period of time. The flux was then calculated using Equation (3.3) (Woodley et al., 2018).

$$f = \frac{(r \times c_a)}{A} \quad (3.3)$$

$$c_a = \frac{(c_s \times v_s)}{v_a} \quad (3.3)$$

f (kg NH₃N ha⁻¹d⁻¹) net daily ammonia volatilization flux, atmospheric concentration of NH₃-N (mg N m⁻³) at the wind tunnel, c_s (mg N L⁻¹) is the measured concentration of NN₃-N in the acid trap solution, v_s (L) is the measured volume of acid trap solution, v_a (m³) is the measured volume of air passed through the acid trap solution, r (m³ d⁻¹) is the air volumetric flow rate through the wind tunnel and A (m²) is the soil area covered by the wind tunnel.



4. RESULTS AND DISCUSSIONS

4.1 The Point Injection Liquid Manure Study

4.1.1 Laboratory Tests

4.1.1.a. Utilization of Water as A Material for Assessing Application Rates

The determination of the application rate for the machine occurred within a controlled laboratory setting, where measurements relied upon both the pressure applied and the forward speed. Water was employed as the substance in this particular phase of evaluation, and the resulting values have been documented in Table (4.1).

Table 4.1. Application rate (l ha^{-1}) as a function of forward speed and pressure for water (Lab study).

		Pressure (kPa)			
		200	300	400	500
Forward speed (km h^{-1})	1	11055,6	13449,9	16655,6	19112,8
	2	5773,0	6951,9	8099,4	8865,7
	3	4076,6	5367,4	6724,8	7698,5

Table 4.1 displays the quantity of application (l ha^{-1}) under four distinct pressures within the system and across three varying of forward speed. These values represent averages derived from six repetitions and were obtained using water as the primary material. The analysis of Table 4.1, revealed that the highest application quantity, using water as the material, was observed at 500 kPa pressure and a forward speed of 1 km h^{-1} , reaching approximately 19000 l ha^{-1} . Conversely, the lowest amount recorded was 4076 l ha^{-1} , noted at 200 kPa pressure and a forward speed of 3 km h^{-1} . Examining both the table 4.1 and Figure 4.1, it becomes apparent that an increase in speed leads to a notable decrease in the application rate. This reduction amounted to 48% when the speed was raised from 1 km h^{-1} to 2 km h^{-1} under constant pressure of 200 kPa.

Additionally, the data indicates that increasing the pressure results in an increased application rate. For instance, there was a approximately 20% rise in application rate by elevating the pressure from 200 kPa to 300 kPa at a speed of 1 km h^{-1} . These observations suggest a significant correlation between speed, pressure, and the resulting application rate when using water as the medium for measurement.

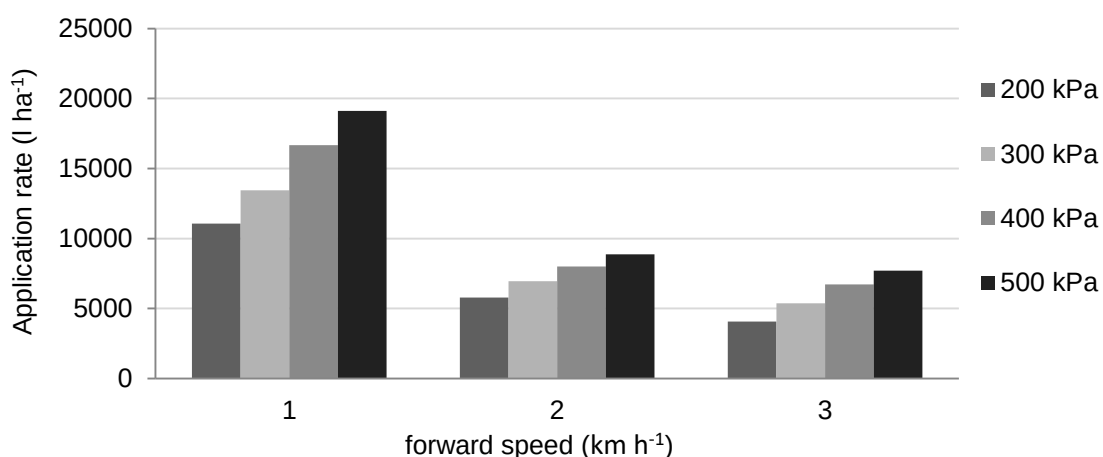


Figure 4.1. Application rate as a function of forward speed and pressure for water (Lab study).

4.1.1.b. Utilization of Liquid Manure as A Material For Measuring Application Rates

The determination of the application rate for the Point Injection Liquid Manure machine with Liquid Manure as material, occurred within a controlled laboratory setting. The Attained Values and calculated application rates are Detailed in Table 4.2.

Table 4.2. Application rate as a function of forward speed and pressure for liquid manure (Lab study).

		Pressure (kPa)			
		200	300	400	500
Forward speed (km h ⁻¹)	1	12289,4	16125,3	18026,5	19956,9
	2	6378,5	8125,8	9588,4	10390,0
	3	4573,0	5435,7	6591,2	7051,9

Table 4.2 shows the application quantities (l ha⁻¹) across four distinct pressures within the system and at three varying of forward speed. These values represent averages obtained from six repetitions and were measured using liquid manure as the material. The analysis of Table (4.2) indicated that variations in application rate occurred with increases in both the forward speed and the pressure within the tank. For instance, when considering application rate in 2 bars, the average injection per hectare at a speed of 1 km h⁻¹ was 12289,4 l ha⁻¹, which notably decreased to 6378,5 l ha⁻¹ at a speed of 2 km h⁻¹ and further dropped to 4573 l ha⁻¹ at 3 km h⁻¹. Conversely, an increase in the fertilizer tank's pressure consistently led to a visible rise in the application rate. Specifically, when the system pressure increased from 200 kPa to 300 kPa, from 300 kPa to 400 kPa, and from 400 kPa to 500 kPa at a constant forward speed of 2 km h⁻¹, there were corresponding percentage increases of approximately 31%, 11.8%, and 10.7%, respectively. (Figure 4.2)

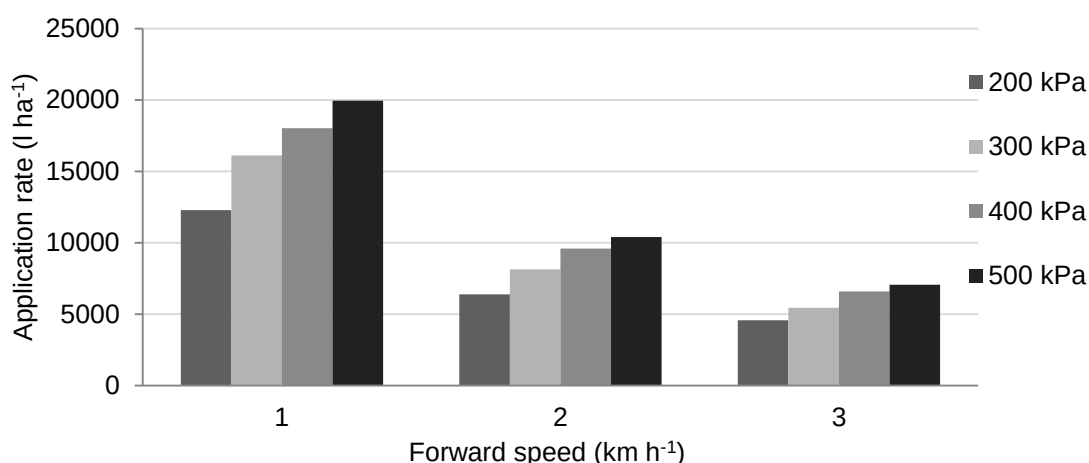


Figure 4.2. Application rate as a function of forward speed and pressure for liquid manure (Lab study).

4.1.1.c. Statistic for The Relationship Between Application Rate and Forward Speed, Tank Pressure for Laboratory and Field Experiment

Augmenting the forward speed resulted in a decrease in this application rate value. This demonstrated the relationship between forward speed, tank pressure, and the resultant application rate when utilizing liquid manure and water as the measurement material.

Table 4.3. Compare means application rate (l ha⁻¹) of materials.

material	Mean	N	Std. Deviation	Minimum	Maximum
Manure	10377,7194	72	4974,29022	4346,40	20311,40
Water	9485,9393	72	4543,34413	3687,20	20571,40
Total	9931,8294	144	4768,04857	3687,20	20571,40

Table (4.3) presents a comparative analysis of descriptive statistics, focusing on the application rate (l ha⁻¹) between two distinct materials, liquid manure, and water, utilized in the Point Injection Liquid Manure experiment. This table summarizes and contrasts the mean, maximum, and minimum application rates observed for each material during the experiment.

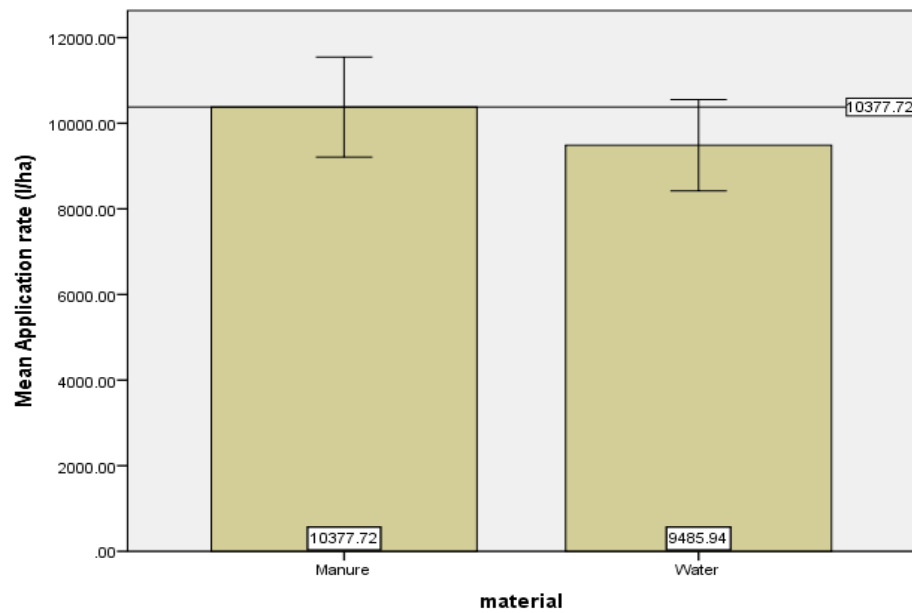


Figure 4.3. Mean of Application rate comparison between two experimental groups water and liquid manure (Lab study).

Examining the Figure 4.3 and Table 4.3, the highest application rate, observed with water as the material, occurred at 500 kPa pressure and 1 km h⁻¹, reaching approximately 20571,40 l ha⁻¹ (maximum). Conversely, the lowest application rate stood at 3687,20 l ha⁻¹ (minimum), noted at 200 kPa pressure and a forward speed of 3 km h⁻¹ significant trends emerge. When considering the application of liquid manure, a similar trend emerged. The highest application rate was observed at 500 kPa pressure and 1 km h⁻¹, reaching 20311,40 l ha⁻¹, while the lowest rate was recorded at 4346,40 l ha⁻¹, noted at 200 kPa pressure and a forward speed of 3 km h⁻¹.

These findings underscore the clear impact of both forward speed and tank pressure on the application rate, as in the statistical analysis presented in Table (4.4), a noteworthy interaction emerged between the application rate (considered the dependent variable) and the independent variables, namely forward speed and pressure. It was observed that pressure had a direct impact, while forward speed exhibits an inverse relationship concerning the amount of application rate.

Table 4.4. The regression analysis conducted with forward speed, pressure and the application rate.

		p	Correlation
Application rate (l ha ⁻¹)	Forward speed	,000	- ,850**
	System pressure	,000	,380**

**. Correlation is significant at the 0,01 level.

Table 4.4. Shows the results of the regression analysis conducted with forward speed and pressure as independent variables and the application rate as the dependent variable. The statistical analysis outlined in the table demonstrated a clear relationship between forward speed, system pressure. By using correlation device measured the strength and degree of the supposed linear association between variables.

The results showed that There was relationship between application rate and two independent variables forward speed and pressure. The correlation index for the relationship between application rate and forward speed was -0,850 indicating that strong and a negative correlation. A positive and moderate correlation was detected between pressure and the application rate of 0,380 correlation index.

4.1.2 Field Trails

In field conditions, the determination of the Point Injection Liquid Manure machine's application rate was conducted. Measurements were taken with reference to both the pressure applied and the forward speed.

Table 4.5. Application rate ($l\ ha^{-1}$) as a function of forward speed and pressure for liquid manure (Field trail).

		Pressure (kPa)			
		200	300	400	500
Forward speed ($km\ h^{-1}$)	1	12790,0	16360,0	18622,0	20776,0
	2	6074,0	8020,0	9304,0	10366,0
	3	4110,0	6284,0	7194,0	7194,0

In Table (4.5), presents the application quantities ($l\ ha^{-1}$) across four distinct pressures within the tank and at three varying forward speeds. These values represent averages obtained from four repetitions and were measured using liquid manure as the material. the highest application rate, observed at 500 kPa and $1\ km\ h^{-1}$, reached approximately $20776\ l\ ha^{-1}$, while the lowest was recorded at 200 kPa and $3\ km\ h^{-1}$, standing at $4110\ l\ ha^{-1}$. An evident interaction was noted between the application rate (as the dependent variable) and forward speed and pressure (as independent variables). The results showed that increasing forward velocity from $1\ km\ h^{-1}$ to $2\ km\ h^{-1}$ and from $2\ km\ h^{-1}$ to $3\ km\ h^{-1}$ resulted in reductions of approximately 52% and 32%, respectively, at a constant pressure of 200 kPa. Conversely, augmenting pressure exhibited a reversed effect, leading to an increased application rate. For instance, elevating pressure from 200 kPa to 500 kPa at a speed of $1\ km\ h^{-1}$ resulted in a roughly 62.4% increase in the application rate.

4.1.2.a Effectivity of Forward Speed And System Pressure Over Application Rate

Used Univariate analyzed in SPSS to explained forward speed and system pressure affect over application rate. Effectivity of forward speed and system pressure as independent variables

alone and combination over application rate (l ha⁻¹) as dependent variable determined in utilization of liquid manure in field tests. As in the statistical analysis presented in Table (4.6), “Sig.” in the chart (P) values were sufficient to accept or reject the hypotheses.

Table 4.6. Effectivity of forward speed and system pressure alone and combination over application rate (l ha⁻¹) in Utilization of Liquid Manure in field tests.

Dependent Variable: Application rate (l ha ⁻¹)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Speed	1134521898,667	2	567260949,333	15813,082	,000
Pressure	172870938,667	3	57623646,222	1606,329	,000
Speed * Pressure	28615701,333	6	4769283,556	132,950	,000
Error	1291424,000	36	35872,889		

(Adjusted R Squared = ,999)

As table 4.6 the results showed that the speed variable is considered to have a significant effect on the application rate. The same applied to the pressure variable, the P value was 0.000. It was accepted that the system pressure variable had a significant effect on the application norm. And the interaction between the two factors forward speed*system pressure (0.00) were less than the threshold value (0.05), leading to the conclusion that both forward speed and system pressure alone and the combination of forward speed and system pressure affected on application rate.

4.1.2.b Comparison Performance of Point Injection Liquid Manure In Laboratory And Field Conditions

Used Spss software for analyses the machine performance compare the mean scores in two test conditions. Table 4.7. and Figure 4.4 shows the results of the contrasts the means between liquid manure application in laboratory conditions and soil injection, summarizing the application rate (l ha⁻¹) for both methods using the Point Injection Liquid Manure in the experiment.

Table 4.7. The T-test to contrasts the means between application rate (l ha⁻¹) in Utilization of Liquid Manure laboratory and field.

		Mean Difference	Std. Error Difference	Sig. (2-tailed)	95% Confidence Interval of the Difference		Levene's Test for Equality of Variances	
					Lower	F	F	Sig.
Machin performance in lab.	Machin performance in soil	-65,737	1051,773	0,95	-2154,058	2022,583	.307	.581
Machin performance in soil	Machin performance in lab.	65,737	1051,773	0,95	,307	2022,723		

Dependent factor is application rate (l ha⁻¹)

Table 4.7 shows the results of independent sample T-test was used to determine the likelihood that two independent groups (mean different of application rate in Utilization of Liquid

Manure laboratory and field). The descriptive statistics, encompassing mean, maximum, and minimum application rates for both methods, were compared to ascertain any significant differences.

The results showed that application rate in laboratory and inject in soil, the value of p is (Sig.) $P > 0,005$, the null hypothesis isn't rejected. So, that were not significantly different indicating between means of groups. As the base of Levene's Test, results showed that the p-values for both cases are considerably high (0.58 respectively). So, the null hypothesis wasn't rejected and the assumption of equal variances seems valid based on these results.

The results showed that, no significant difference in variances or means between the groups based on the 'application rate' variable in laboratory and field test.

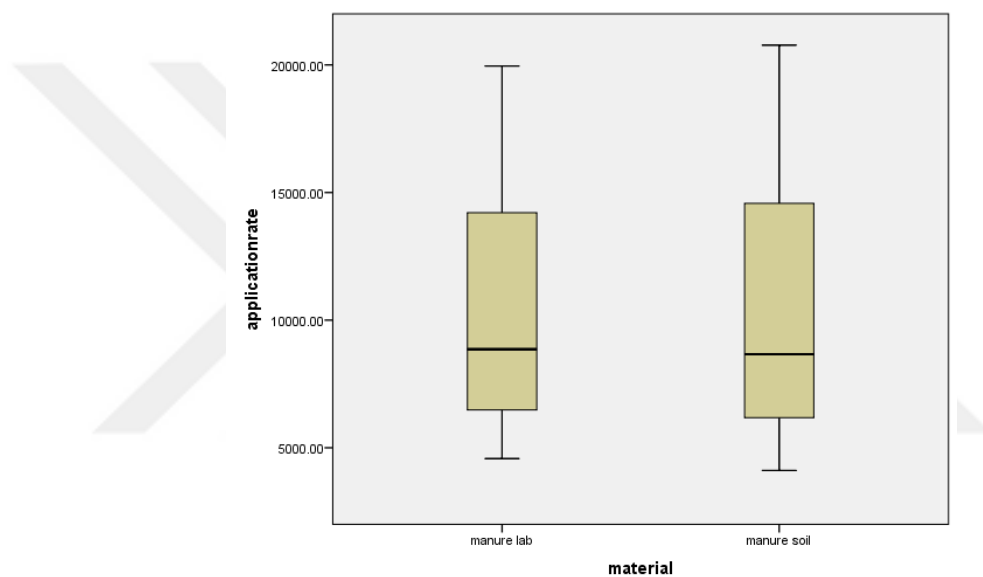


Figure 4.4. Comparison of performance parameters between two samples.

4.1.2.c Comparing the Mean Scores of Application Rate Between Groups Based of Forward Speed And System Pressure.

In the field tests, groups were divided 12 groups based of forward speed and system pressure. Used One-Way Anova data file represent of the 48 plates (three different forward speed, four different system pressure with four repetition). Table (4.8) represented the detailed analysis focusing on evaluating the influence of forward speed and system pressure on application rate ($l\ ha^{-1}$), conducted through ANOVA and Duncan testing to know specifically where these differences exist.

Table 4.8. Duncan test analyses of variance of application rate ($l\ ha^{-1}$) between 12 groups based of forward velocity and system pressure.

		Pressure (kPa)			
		200	300	400	500
Forward speed ($km\ h^{-1}$)	1	12790,00 ^a	16360,00 ^b	18622,00 ^c	20776,00 ^d
	2	6074,00 ^{*a}	8020,00 ^{*b}	9304,00 ^{*c}	10366,00 ^{*d}
	3	4110,00 ^{**a}	5384,00 ^{**b}	6284,00 ^{*a}	7194,00 ^{**d}

As table 4.8 shows the results of comparing groups of means between application rate sets. Between the all groups there were large mean differences with significance value of 0,000. According to the table, there was a statistically significant difference in the mean application rate between the groups. Except between application rate as $2\ km\ h^{-1}$ forward speed, 200 kPa system and $3\ km\ h^{-1}$ forward speed, 400 kPa system. The value of p in this two groups was (Sig.) $P > 0,005$, the null hypothesis isn't rejected. According to the results, the averages of these two groups were not statistically different.

4.1.2.d Penetration Results

Penetration measurement values were averaged over 15 measurements for the soil channel and given in Figure (4.5).

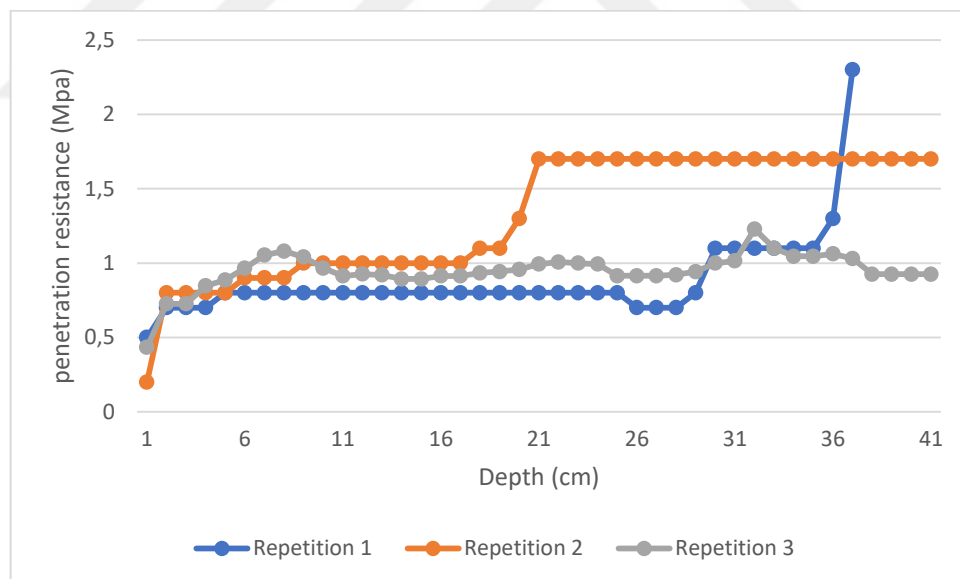


Figure 4.5. Penetration measurement results graph

4.2 Estimating Ammonia Volatilization

In this research, the wind tunnel method was used as a standard measurement for ammonia emissions from a source area. To assess the efficacy of the Point Injection Liquid Manure machine, efforts were made to replicate environmental traits by maintaining a consistent wind speed within a confined space resembling a small-scale wind tunnel. This approach allowed for the determination of the ammonia emission rates between surface application and the subsurface injection of manure.

4.2.1 Air Flow Simulation in Tunnel

The Solidworks software was employed to assess ventilation efficiency. Through simulation, velocity and pressure parameters were utilized to characterize the aerodynamic environment within the tunnel.

The outcomes depicted a symmetric flow pattern, as illustrated in the Figure 4.6. Velocity and pressure were performed, to define the air flow condition inside the tunnel. Specifically, the flow speed within the tunnel showed distinct behaviors: registering approximately $0,8 \text{ m s}^{-1}$ at the entrance and escalating to approximately $1,2 \text{ m s}^{-1}$ within the canopy area.

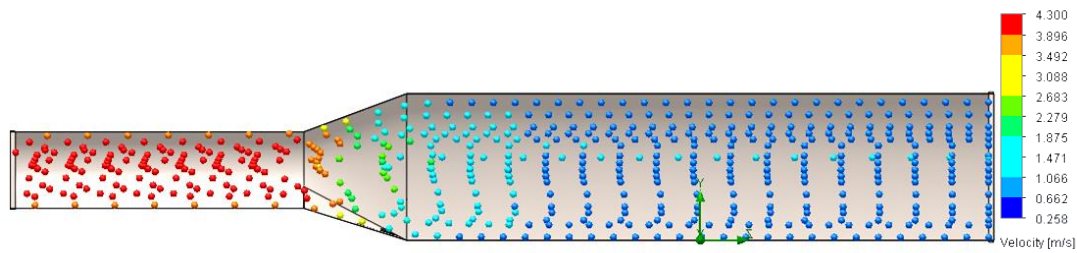


Figure 4.6. Simulated of air velocity profile inside the wind tunnel.

Throughout the tunnel length, a consistent state was observed in both velocity and pressure. Within the canopy section, the air pressure remained nearly uniform. These conditions, presenting near-constant boundary parameters along the primary flow, suggest the likelihood of a sustained, steady wind speed across this section. Figures (4.7) and (4.8) illustrate the detailed profiles of air velocity and pressure.

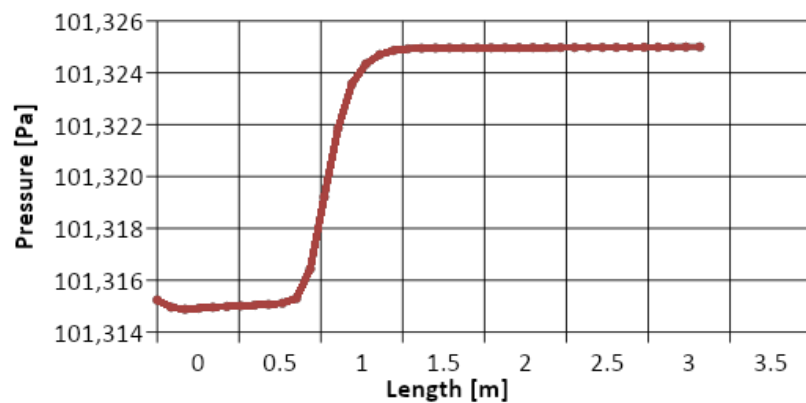


Figure 4.7. Simulated of pressure profile inside the wind tunnel.

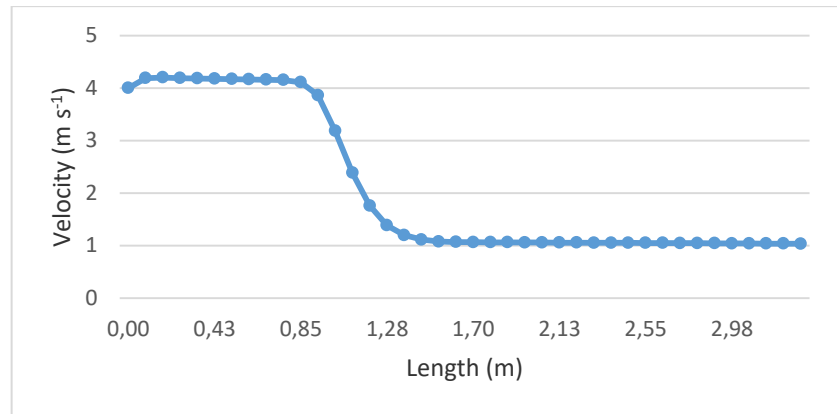


Figure 4.8. Simulated of velocity profile inside the wind tunnel.

Measurements were conducted at four vertical cross-sections within the tunnel: the intervals of 1/4 ($x=50$ cm), 1/2 ($x=100$ cm), 3/4 ($x=150$ cm) entrance along the canopy's length and concluding at the canopy's output. At each of these points, pressure, velocity averages, and mass flow rates were determined and recorded, as illustrated in Figure 4.9.

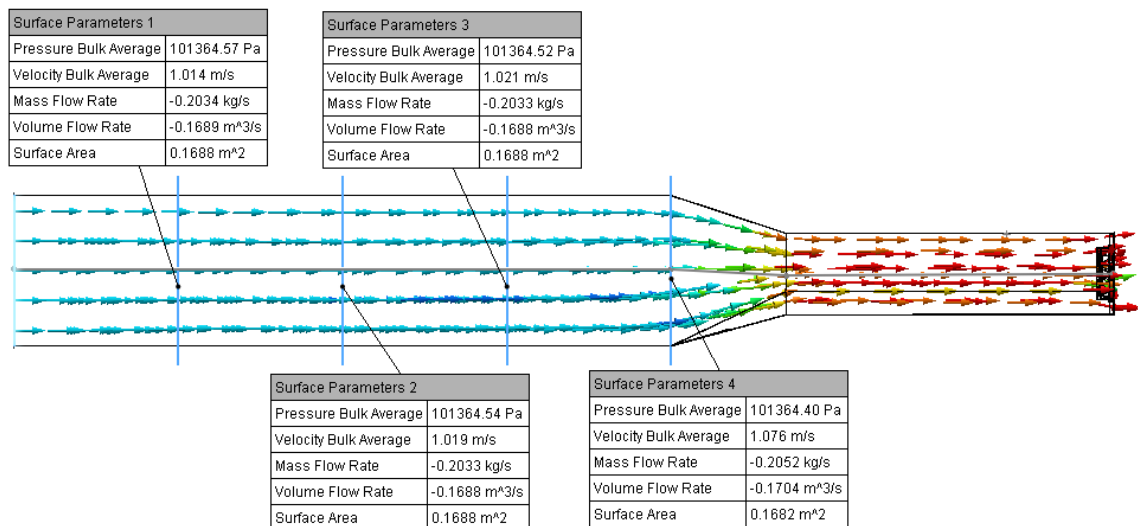


Figure 4.9. Displays the profiles of pressure averages, velocity averages, volume flow rate and mass flow at four locations in the wind tunnel.

Figure 4.9 displays the profiles of pressure bulk averages, velocity averages, and mass flow at specific locations: the equidistant points within the canopy section, and the endpoint of the emission area within the wind tunnel. These measurements were taken at nominal velocity values of $1,2 \text{ m s}^{-1}$.

4.2.2 Air Velocity Profile Testing

One crucial standardized parameter is the wind velocity profile within the tunnel, ensuring a uniform flow. Using both rotating-vane and hot-wire anemometers, wind velocity was measured at the entrance and middle of the tunnel. The velocity near the lower section of the tunnel exhibited

a slightly lower magnitude compared to measurements taken at the middle and upper portions. Notably, there was no noteworthy variance observed in the height of the velocity boundary layer within the small wind tunnel. Specifically, the velocity was recorded at approximately $1,2 \text{ m s}^{-1}$ in the middle section (refer to Figure 4.10).

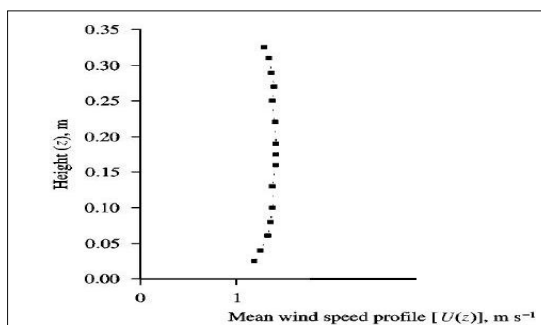


Figure 4.10. Mean vertical air velocity measured in canopy at m s^{-1} .

The values measured in this study were 0.8 on the bottom boundary layer of the tunnel (above the treatment area), 1.5 in the middle and 0.89 on the top boundary layer. The same values and air velocity constancy in tunnel were also seen in the study of Liu. Liu et al. (2009) measured Air profiles in wind tunnel for nominal velocity values of 0,15, 0,50, 1,00, 1,50, and 2,00 m s^{-1} . They determined that, there was no significant difference between the height of the boundary layer in the tunnel.

4.2.3 Statistical Analysis on Ammonia Emission

The statistical analysis carried out on ammonia emissions across different application methods revealed comparable performance among the three approaches. The first was involved conducting an Analysis of Variance (ANOVA) using the application type as the dependent factors. Table 4.9, represents the detailed analysis focusing on evaluating the influence of fertilizer applicator types on ammonia emission, conducted through ANOVA and post hoc testing.

Table 4.9. The statistical association between distinct application methods on the observed levels of ammonia loss.

	Ammonia emission Mean $\text{kg NH}_3\text{-N ha}^{-1} \text{ d}^{-1}$
Surface apply	3,0056 ^a
50 mm subsurface apply	1,4662 ^b
100 mm subsurface apply	0,7438 ^b

Table 4.9 shows that, a statistically significant difference ($p=0.05$) was observed in ammonia emission between the surface application method and the soil injection method. However, no significant distinction was noted in the ammonia emission levels between the different depths of

subsurface injection methods (100 mm and 50 mm). Both 50mm and 100mm Subsurface methods exhibit significantly lower ammonia loss compared to the On-Surface method. However, while the 100 mm Subsurface method shows a slightly larger effect in reducing ammonia loss compared to the 50 mm Subsurface method, the difference between these two Subsurface methods is not statistically significant. {Formatting Citation}, conducted a study to investigate the impact of spoke wheel on ammonia emission. The same results as the application method effectivity the emissions of ammonia were also seen in other literatures. Belzer (1954), were employed point injection system for applied chemical fertilizer subsurface. They applied at rates of 272 kg ha⁻¹ (dryland) and 227 kg ha⁻¹ (irrigated) fertilizer in pressurized up to 100 kPa. the effect of the machine on nitrogen losses compared to surface application, recording a loss of 26 kg ha⁻¹ in the surface application and 3,63 kg ha⁻¹ in the injected application. Rodhe et al. (2009) reported for an application rate of 35000 kg ha⁻¹ at 8 cm depth of manure used the medium-sized tubulators and double disc tine Ammonia losses after injection with the tubulator were 16% and for the double disc tine 27% of applied ammonia nitrogen.

The Figure 4.11 and Table 4.10, show describes the relative cumulative ammonia volatilization (kg NH₃-N ha⁻¹ d⁻¹) over time (h) after application of liquid manure.

Table 4.10. Presents the outcomes of polynomial regression analyses characterizing ammonia emission (kg NH₃-N ha⁻¹ d⁻¹) across various treatment methods.

		Unstandardized Coefficients		Sig.	Adjusted R Square R ²
		B	Std. Error		
surface method	time	-1,416	,177	,000	0,93
	time ** 2	,046	,008	,000	
	time ** 3	,000	,000	,000	
	(Constant)	15.383	1,072	,000	
50 mm Subsurface	time	-,383	,081	,000	0,87
	time ** 2	,012	,004	,006	
	time ** 3	,000	,000	,018	
	(Constant)	5,090	,492	,000	
100 mm Subsurface	time	-,481	,050	,000	0,94
	time ** 2	,016	,002	,000	
	time ** 3	,000	,000	,000	
	(Constant)	4,697	,304	,000	

In Table 4.10. presents analyses the polynomial regression characterizing ammonia emission across various treatment methods, specifically at 100 mm and 50 mm subsurface depths, as well as the On-Surface application method. The study considers ammonia emission as the dependent variable, with the independent variable being the duration elapsed in the experimental period, measured in hours. This analysis aims to model and elucidate the relationship between the duration of the experiment and the emitted ammonia levels under distinct treatment methods.

Equation 4.1.

Surface method	$y = 15,383 - 1,416x^{-i} + 0,046x^2 + e_i$	$R^2 = 0,93$
50 mm subsurface	$y = 5,09 - 0,383 x^{-i} + 0,12x^2 + e_i$	$R^2 = 0,87$
100 mm subsurface	$y = 4,697 - 0,481x^{-i} + 0,016x^2 + e_i$	$R^2 = 0,94$

The ammonia emission post-land spreading of liquid manure showed dependency on the application technique, as evidenced in Figure 4.10, and Table 4.10, To interpolate the emitted NH_3 across each application method, three distinct mathematical models were employed. The optimal fitting cubic polynomial equation 4.1, describing the relationship is given by: " $y = f(X_i)$ " where " y " represents ammonia emission and " X_i " denotes application time. In all of the three models, the coefficients for time, time squared, and time cubed are all significant predictors ($p < 0.05$) and All models show significant relationships between the predictors (time, time squared, and time cubed) and the dependent variable. These cubic models exhibited strong relationships, demonstrating R-squared values of 93%, 87%, and 94% (refer to the figure). In surface application model R-squared is 0,93 its means that 93% of the variance in the dependent variable is explained by the predictors in this model, in the 50 mm subsurface method this value is 87% and for the 100 mm subsurface method is 94%. The negative coefficients for time in each model indicate a decreasing effect over time on the dependent variable, while the positive coefficients for time squared and time cubed suggest a non-linear relationship.

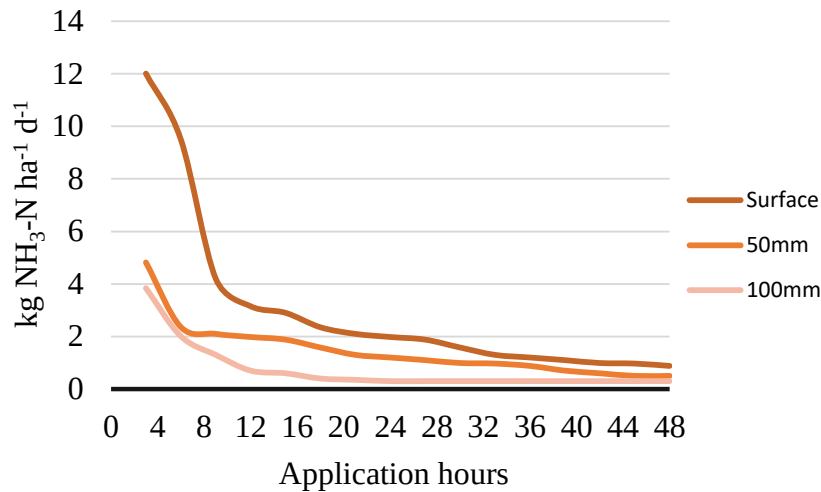


Figure 4.11. The outcomes of polynomial regression analyses characterizing ammonia emission across various treatment methods.

Observations post-application highlighted the peak ammonia flux within the treatment area, particularly in the initial hours following the application. Notably, the surface application method recorded 12 kg NH₃-N ha⁻¹ d⁻¹ within the first three hours, whereas the 50 mm subsurface method and 100 mm subsurface method measured 4,82 kg NH₃-N ha⁻¹ d⁻¹ and 3,84 kg NH₃-N ha⁻¹ d⁻¹, respectively. Roughly 30% of ammonia emissions occurred within the initial three hours, escalating to 40% within the first six hours and reaching 50%-60% within the first nine hours. (Figure 9.10). Rodhe et al. (2004) observed accumulated nitrogen losses as ammonia, over 90 h after application of cattle slurry in grassland. N losses were measured in peak at first hours after application around 12 NH₃ kg N ha⁻¹. Huijsmans et al. (1999) determined ammonia emission happened around 60% at first 10 hours, they showed a combination of the time-lag and the volatilization and that the average volatilization and the reduction of the volatilization over time. In the study on ammonia emissions over time, which we conducted to test of point injection liquid manure's performance, high losses were detected during the first hours after application.

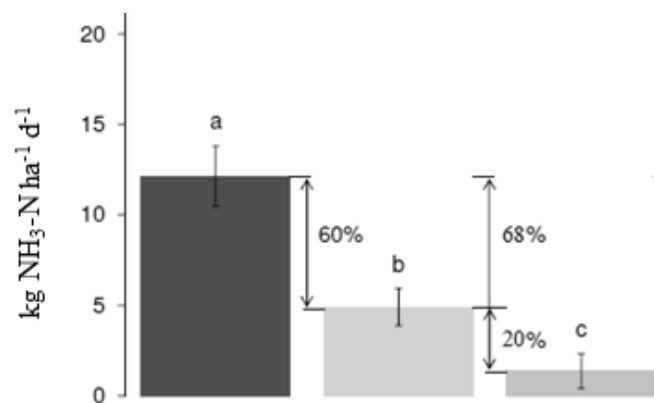


Figure 4.12. The cumulative quantity of emitted ammonia resulting from various treatment methods observed throughout the duration of the experiment.

The application of liquid manure on the surface led to the highest recorded ammonia emission levels, marking an approximate 70% increase compared to the injection of manure at a depth of 100 mm. The noticeable nitrogen losses were most pronounced in surface application, surpassing those observed in 50 mm and 100 mm subsurface injection by 60% and 70%, respectively (Figure 4.11). The similar results also reported in the literature as following. Nyord et al. (2012) determined percentage loss of total applied Total Ammonia Nitrate through emission over 116 h after application of pig slurry by trailing hoses. They reported that more than 40% of ammonia losses occurred in the first 10 hours. And they showed application methods have significant effect on this percentage. Huijsmans et al. (2001) observed during the 96 hours of an experiment, the volatilization rate varied with the time after application, after an initial peak, the rate gradually dropped. They measured 12,8 kg NH₃-N ha⁻¹ h⁻¹ over first 10 hours after manure application.





5. CONCLUSIONS

Liquid manure in our country generally applied as a surface application, resulting in up to 90% ammonia nitrogen loss due to evaporation, posing substantial environmental and economic challenges. In this study revealed that injecting liquid manure into the soil reduces nitrogen loss by an average of 70% compared to surface application method. To achieve this, a specialized liquid manure/fertilizer system, called the Point Injection Liquid Manure system, was designed and constructed. This system minimizes nitrogen volatility, making ammonium nitrogen available near plant roots almost instantly or easily accessible by the roots. A detailed description of the design, simulated, construction and physical calibration of the system is given.

The Point Injection Liquid Manure system features a 400-diameter wheel with a central mechanical hub and twelve hollow spikes for subsurface injection of liquid manure or fertilizer. It can effectively inject liquid fertilizer up to 100 mm deep below the soil surface at intervals of 140 mm. The system allows for regulating fertilizer quantity, permitting application rates ranging from 4000 to 20000 l ha⁻¹, adaptable to changes in working speeds and pressure. Calculations for animal manure and slurry in agricultural activities consider factors such as planting type, soil type, and fertilizer nitrogen content.

To monitor ammonia volatilization and assess system performance, a small mobile wind tunnel was designed and built. This tunnel covers a 1 m² experimental treatment area and maintains constant wind speeds of 1,0 m s⁻¹. Comparative analyses among experiments demonstrated the substantial reduction in ammonia emissions with the injector system compared to surface application.

The findings and recommendations are summarized as follows:

- Laboratory studies showed no significant difference in comparison between liquid fertilizer and water. Application rates were measured at 10377 l ha⁻¹ for water and 9486 l ha⁻¹ for liquid manure, with maximum rates observed at 20571 l ha⁻¹ for water and 20311 l ha⁻¹ for liquid manure.
- No significant difference was found in the comparison of application rates between lab and field studies for liquid manure.
- The system allows regulation of fertilizer quantity, with application rates ranging from 4000 to 20000 l ha⁻¹, adaptable to changes in working speeds and pressure. The reported consumption range falls between applying about 10 to 20 tons of liquid manure per hectars for most crops, considering nitrogen loss from evaporation or leaching.

- Changes in forward speed and tank pressure lead to fluctuations in the application rate. Increased tank pressure results in higher application rates, while higher speed, decreases the application rate.
- According to emission studies, ammonia emissions were reduced by an average of 60% at 50mm subsurface and 70% at 100mm subsurface. The application method significantly impacts ammonia emission, showcasing a notable difference between surface application and soil injection methods and there are a strong relationship between the experimental emissions and the application technique

The significant reduction of 70%, the difference in the amount of nitrogen loss between surface application method and injected method, stands out as an important measure of the greater retention of nitrogen in the soil. As a result of the data and observations obtained in the study, it was concluded that liquid fertilizer application machines with prototype injection wheels can minimize nitrogen losses by injecting the liquid to the desired depth, facilitate the uptake of nutrients in the fertilizer by the plant and help reduce environmental pollution.

Suggestions for improving the system:

1. Introducing and educating farmers about such methodologies holds promise for enhancing agriculture and promoting sustainable farming practices. Through proficient management of manure, these systems play a pivotal role in averting environmental pollution while preserving this valuable resource from being squandered.
2. This pioneering system was conceptualized and trialed for the first time in Turkey, crafted initially as a prototype. Future iterations could potentially yield more robust and expedient systems.
3. The versatility of this system extends to its capability to administer manure across diverse soil types. Slight modifications, such as adjusting the wheel angle, could enable tailored applications in row-based cultivation methods. Furthermore, by altering injector diameters, this system could cater to various needs, including the distribution of pesticides or low-dosage chemical manures.
4. With the advent of technology, precision agriculture emerges as a preferred approach for rate-sensitive control applications. Developing a data collection system allows for instantaneous map creation, enabling precise control over the amount of fertilizer or pesticide injected based on real-time data.

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CURRICULUM VITAE

Laleh GHANIZADEH HESAR, I completed my primary and secondary education in the city of Urmia, and completed my high school education at the Science High School in the same city. I received my bachelor's degree from Urmia University, Faculty of Agriculture, Department of Animal Science in 1995-2000. I worked at a poultry breeding center between 2000 and 2011. I started my master's degree in 2011 at Çukurova University, Faculty of Agriculture, Department of Agricultural Machinery, and completed it in 2014. I continue my doctoral studies, which I started in 2018, at Adana Çukurova University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering.









Appendix 1. Correlation between speed and pressure with application rate (**Table 4.4**)

Correlations

		Application rate (l ha ⁻¹)	Forward speed	Material tank inside pressure
Application rate (l ha ⁻¹)	Pearson Correlation	1	-.850**	.380**
	Sig. (2-tailed)		.000	.000
	N	144	144	144
Forward speed	Pearson Correlation	-.850**	1	.000
	Sig. (2-tailed)	.000		1.000
	N	144	144	144
Material tank inside pressure	Pearson Correlation	.380**	.000	1
	Sig. (2-tailed)	.000	1.000	
	N	144	144	144

** . Correlation is significant at the 0.01 level (2-tailed).

Appendix 2. Independent t-test, the Point Injection Liquid Manure machine application rate in laboratory conditions and field trail. (**Table 4.7**)

Group Statistics

			Bootstrap ^a				
			Statistic	Bias	Std. Error	95% Confidence Interval	
						Lower	Upper
Application rate (l ha ⁻¹)	Manure	N	48				
		Mean	10374.5958	-1.7656	551.9756	9304.4056	11433.3077
		Std. Deviation	4964.44537	-45.41647	355.70746	4128.98264	5546.72841
		Std. Error	716.55597				
		Mean					
	manure in channel	N	48				
		Mean	10440.3333	7.6208	590.3843	9290.5995	11595.6351
		Std. Deviation	5334.15323	-54.77794	379.80481	4513.36602	5947.57491
		Std. Error	769.91870				
		Mean					

a. Unless otherwise noted, bootstrap results are based on 1000 stratified bootstrap samples

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Application rate (l ha ⁻¹)	Equal variances assumed	.307	.581	-.063	94	.950	-65.73750	1051.77339	-2154.05822	2022.58322
	Equal variances not assumed			-.063	93.519	.950	-65.73750	1051.77339	-2154.19821	2022.72321

Bootstrap for Independent Samples Test

		Mean Difference	Bootstrap ^a				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
Application rate (l ha ⁻¹)	Equal variances assumed	-65.73750	-9.38638	1058.00234	.956	-2137.05597	1979.51816
	Equal variances not assumed	-65.73750	-9.38638	1058.00234	.955	-2137.05597	1979.51816

a. Unless otherwise noted, bootstrap results are based on 1000 stratified bootstrap samples

Appendix 3. Univariate Analysis of Variance of forward velocity and system pressure alone and combination over application rate (**Table 4.6**)

Between-Subjects Factors

		Value Label	N
forward speed	1	1 km h ⁻¹	16
	2	2 km h ⁻¹	16
	3	3 km h ⁻¹	16
Material tank inside pressure	1	2 bar	12
	2	3 bar	12
	3	4 bar	12
	4	5 bar	12

Tests of Between-Subjects Effects

Dependent Variable: Application rate (l ha⁻¹)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1336008538.667 ^a	11	121455321.697	3385.713	.000
Intercept	5232026885.333	1	5232026885.333	145849.053	.000
velocity	1134521898.667	2	567260949.333	15813.082	.000
pressure	172870938.667	3	57623646.222	1606.329	.000
velocity * pressure	28615701.333	6	4769283.556	132.950	.000
Error	1291424.000	36	35872.889		
Total	6569326848.000	48			
Corrected Total	1337299962.667	47			

a. R Squared = .999 (Adjusted R Squared = .999)

Appendix 4. Anova Test- compared application rate between groups based of forward speed and system pressure (**Table 4.8**)

ANOVA

Application rate (l ha⁻¹)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1336008538.667	11	121455321.697	3385.713	.000
Within Groups	1291424.000	36	35872.889		
Total	1337299962.667	47			

The lists of the means, standard deviation

Descriptive

Application rate (l ha⁻¹)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	Minimum		Maximum	
					Lower Bound	Upper Bound	Upper Bound		
1km h ⁻¹ *200 kPa	4	12790.0000	173.97318	86.98659	12513.1699	13066.8301	12560.00	12960.00	
1km h ⁻¹ *300 kPa	4	16360.0000	103.27956	51.63978	16195.6592	16524.3408	16240.00	16480.00	
1km h ⁻¹ *400 kPa	4	18622.0000	318.42110	159.21055	18115.3210	19128.6790	18288.00	19032.00	
1km h ⁻¹ *500 kPa	4	20776.0000	184.63658	92.31829	20482.2020	21069.7980	20520.00	20960.00	
2km h ⁻¹ *200 kPa	4	6074.0000	97.62513	48.81257	5918.6566	6229.3434	5984.00	6184.00	
2km h ⁻¹ *300 kPa	4	8020.0000	164.92423	82.46211	7757.5688	8282.4312	7840.00	8240.00	
2km h ⁻¹ *400 kPa	4	9304.0000	252.05290	126.02645	8902.9276	9705.0724	9040.00	9600.00	
2km h ⁻¹ *500 kPa	4	10366.0000	65.76727	32.88363	10261.3496	10470.6504	10296.00	10440.00	
3km h ⁻¹ *200 kPa	4	4110.0000	128.06248	64.03124	3906.2240	4313.7760	4000.00	4240.00	
3km h ⁻¹ *300 kPa	4	5384.0000	225.23469	112.61735	5025.6013	5742.3987	5096.00	5600.00	
3km h ⁻¹ *400 kPa	4	6284.0000	228.75897	114.37949	5919.9934	6648.0066	6000.00	6560.00	
3km h ⁻¹ *500 kPa	4	7194.0000	173.23587	86.61794	6918.3431	7469.6569	6960.00	7376.00	
Total	48	10440.3333	5334.15323	769.91870	8891.4567	11989.2100	4000.00	20960.00	

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1km/h*2bar	1km/h*3bar	-3570.00000 [*]	133.92701	.000	-3841.6166	-3298.3834
	1km/h*4bar	-5832.00000 [*]	133.92701	.000	-6103.6166	-5560.3834
	1km/h*5bar	-7986.00000 [*]	133.92701	.000	-8257.6166	-7714.3834
	2km/h*2bar	6716.00000 [*]	133.92701	.000	6444.3834	6987.6166
	2km/h*3bar	4770.00000 [*]	133.92701	.000	4498.3834	5041.6166
	2km/h*4bar	3486.00000 [*]	133.92701	.000	3214.3834	3757.6166
	2km/h*5bar	2424.00000 [*]	133.92701	.000	2152.3834	2695.6166
	3km/h*2bar	8680.00000 [*]	133.92701	.000	8408.3834	8951.6166
	3km/h*3bar	7406.00000 [*]	133.92701	.000	7134.3834	7677.6166
	3km/h*4bar	6506.00000 [*]	133.92701	.000	6234.3834	6777.6166
	3km/h*5bar	5596.00000 [*]	133.92701	.000	5324.3834	5867.6166
1km/h*3bar	1km/h*2bar	3570.00000 [*]	133.92701	.000	3298.3834	3841.6166
	1km/h*4bar	-2262.00000 [*]	133.92701	.000	-2533.6166	-1990.3834
	1km/h*5bar	-4416.00000 [*]	133.92701	.000	-4687.6166	-4144.3834
	2km/h*2bar	10286.00000 [*]	133.92701	.000	10014.3834	10557.6166
	2km/h*3bar	8340.00000 [*]	133.92701	.000	8068.3834	8611.6166
	2km/h*4bar	7056.00000 [*]	133.92701	.000	6784.3834	7327.6166
	2km/h*5bar	5994.00000 [*]	133.92701	.000	5722.3834	6265.6166
	3km/h*2bar	12250.00000 [*]	133.92701	.000	11978.3834	12521.6166
	3km/h*3bar	10976.00000 [*]	133.92701	.000	10704.3834	11247.6166
	3km/h*4bar	10076.00000 [*]	133.92701	.000	9804.3834	10347.6166
	3km/h*5bar	9166.00000 [*]	133.92701	.000	8894.3834	9437.6166
1km/h*4bar	1km/h*2bar	5832.00000 [*]	133.92701	.000	5560.3834	6103.6166
	1km/h*3bar	2262.00000 [*]	133.92701	.000	1990.3834	2533.6166
	1km/h*5bar	-2154.00000 [*]	133.92701	.000	-2425.6166	-1882.3834
	2km/h*2bar	12548.00000 [*]	133.92701	.000	12276.3834	12819.6166
	2km/h*3bar	10602.00000 [*]	133.92701	.000	10330.3834	10873.6166
	2km/h*4bar	9318.00000 [*]	133.92701	.000	9046.3834	9589.6166
	2km/h*5bar	8256.00000 [*]	133.92701	.000	7984.3834	8527.6166
	3km/h*2bar	14512.00000 [*]	133.92701	.000	14240.3834	14783.6166
	3km/h*3bar	13238.00000 [*]	133.92701	.000	12966.3834	13509.6166
	3km/h*4bar	12338.00000 [*]	133.92701	.000	12066.3834	12609.6166
	3km/h*5bar	11428.00000 [*]	133.92701	.000	11156.3834	11699.6166
1km/h*5bar	1km/h*2bar	7986.00000 [*]	133.92701	.000	7714.3834	8257.6166
	1km/h*3bar	4416.00000 [*]	133.92701	.000	4144.3834	4687.6166
	1km/h*4bar	2154.00000 [*]	133.92701	.000	1882.3834	2425.6166
	2km/h*2bar	14702.00000 [*]	133.92701	.000	14430.3834	14973.6166
	2km/h*3bar	12756.00000 [*]	133.92701	.000	12484.3834	13027.6166
	2km/h*4bar	11472.00000 [*]	133.92701	.000	11200.3834	11743.6166
	2km/h*5bar	10410.00000 [*]	133.92701	.000	10138.3834	10681.6166
	3km/h*2bar	16666.00000 [*]	133.92701	.000	16394.3834	16937.6166
	3km/h*3bar	15392.00000 [*]	133.92701	.000	15120.3834	15663.6166
	3km/h*4bar	14492.00000 [*]	133.92701	.000	14220.3834	14763.6166
	3km/h*5bar	13582.00000 [*]	133.92701	.000	13310.3834	13853.6166

2km/h*2bar	1km/h*2bar	-6716.00000*	133.92701	.000	-6987.6166	-6444.3834
	1km/h*3bar	-10286.00000*	133.92701	.000	-10557.6166	-10014.3834
	1km/h*4bar	-12548.00000*	133.92701	.000	-12819.6166	-12276.3834
	1km/h*5bar	-14702.00000*	133.92701	.000	-14973.6166	-14430.3834
	2km/h*3bar	-1946.00000*	133.92701	.000	-2217.6166	-1674.3834
	2km/h*4bar	-3230.00000*	133.92701	.000	-3501.6166	-2958.3834
	2km/h*5bar	-4292.00000*	133.92701	.000	-4563.6166	-4020.3834
	3km/h*2bar	1964.00000*	133.92701	.000	1692.3834	2235.6166
	3km/h*3bar	690.00000*	133.92701	.000	418.3834	961.6166
	3km/h*4bar	-210.00000	133.92701	.126	-481.6166	61.6166
	3km/h*5bar	-1120.00000*	133.92701	.000	-1391.6166	-848.3834
2km/h*3bar	1km/h*2bar	-4770.00000*	133.92701	.000	-5041.6166	-4498.3834
	1km/h*3bar	-8340.00000*	133.92701	.000	-8611.6166	-8068.3834
	1km/h*4bar	-10602.00000*	133.92701	.000	-10873.6166	-10330.3834
	1km/h*5bar	-12756.00000*	133.92701	.000	-13027.6166	-12484.3834
	2km/h*2bar	1946.00000*	133.92701	.000	1674.3834	2217.6166
	2km/h*4bar	-1284.00000*	133.92701	.000	-1555.6166	-1012.3834
	2km/h*5bar	-2346.00000*	133.92701	.000	-2617.6166	-2074.3834
	3km/h*2bar	3910.00000*	133.92701	.000	3638.3834	4181.6166
	3km/h*3bar	2636.00000*	133.92701	.000	2364.3834	2907.6166
	3km/h*4bar	1736.00000*	133.92701	.000	1464.3834	2007.6166
	3km/h*5bar	826.00000*	133.92701	.000	554.3834	1097.6166
2km/h*4bar	1km/h*2bar	-3486.00000*	133.92701	.000	-3757.6166	-3214.3834
	1km/h*3bar	-7056.00000*	133.92701	.000	-7327.6166	-6784.3834
	1km/h*4bar	-9318.00000*	133.92701	.000	-9589.6166	-9046.3834
	1km/h*5bar	-11472.00000*	133.92701	.000	-11743.6166	-11200.3834
	2km/h*2bar	3230.00000*	133.92701	.000	2958.3834	3501.6166
	2km/h*3bar	1284.00000*	133.92701	.000	1012.3834	1555.6166
	2km/h*5bar	-1062.00000*	133.92701	.000	-1333.6166	-790.3834
	3km/h*2bar	5194.00000*	133.92701	.000	4922.3834	5465.6166
	3km/h*3bar	3920.00000*	133.92701	.000	3648.3834	4191.6166
	3km/h*4bar	3020.00000*	133.92701	.000	2748.3834	3291.6166
	3km/h*5bar	2110.00000*	133.92701	.000	1838.3834	2381.6166
2km/h*5bar	1km/h*2bar	-2424.00000*	133.92701	.000	-2695.6166	-2152.3834
	1km/h*3bar	-5994.00000*	133.92701	.000	-6265.6166	-5722.3834
	1km/h*4bar	-8256.00000*	133.92701	.000	-8527.6166	-7984.3834
	1km/h*5bar	-10410.00000*	133.92701	.000	-10681.6166	-10138.3834
	2km/h*2bar	4292.00000*	133.92701	.000	4020.3834	4563.6166
	2km/h*3bar	2346.00000*	133.92701	.000	2074.3834	2617.6166
	2km/h*4bar	1062.00000*	133.92701	.000	790.3834	1333.6166
	3km/h*2bar	6256.00000*	133.92701	.000	5984.3834	6527.6166
	3km/h*3bar	4982.00000*	133.92701	.000	4710.3834	5253.6166
	3km/h*4bar	4082.00000*	133.92701	.000	3810.3834	4353.6166
	3km/h*5bar	3172.00000*	133.92701	.000	2900.3834	3443.6166

3km/h*2bar	1km/h*2bar	-8680.00000*	133.92701	.000	-8951.6166	-8408.3834
	1km/h*3bar	-12250.00000*	133.92701	.000	-12521.6166	-11978.3834
	1km/h*4bar	-14512.00000*	133.92701	.000	-14783.6166	-14240.3834
	1km/h*5bar	-16666.00000*	133.92701	.000	-16937.6166	-16394.3834
	2km/h*2bar	-1964.00000*	133.92701	.000	-2235.6166	-1692.3834
	2km/h*3bar	-3910.00000*	133.92701	.000	-4181.6166	-3638.3834
	2km/h*4bar	-5194.00000*	133.92701	.000	-5465.6166	-4922.3834
	2km/h*5bar	-6256.00000*	133.92701	.000	-6527.6166	-5984.3834
	3km/h*3bar	-1274.00000*	133.92701	.000	-1545.6166	-1002.3834
	3km/h*4bar	-2174.00000*	133.92701	.000	-2445.6166	-1902.3834
	3km/h*5bar	-3084.00000*	133.92701	.000	-3355.6166	-2812.3834
3km/h*3bar	1km/h*2bar	-7406.00000*	133.92701	.000	-7677.6166	-7134.3834
	1km/h*3bar	-10976.00000*	133.92701	.000	-11247.6166	-10704.3834
	1km/h*4bar	-13238.00000*	133.92701	.000	-13509.6166	-12966.3834
	1km/h*5bar	-15392.00000*	133.92701	.000	-15663.6166	-15120.3834
	2km/h*2bar	-690.00000*	133.92701	.000	-961.6166	-418.3834
	2km/h*3bar	-2636.00000*	133.92701	.000	-2907.6166	-2364.3834
	2km/h*4bar	-3920.00000*	133.92701	.000	-4191.6166	-3648.3834
	2km/h*5bar	-4982.00000*	133.92701	.000	-5253.6166	-4710.3834
	3km/h*2bar	1274.00000*	133.92701	.000	1002.3834	1545.6166
	3km/h*4bar	-900.00000*	133.92701	.000	-1171.6166	-628.3834
	3km/h*5bar	-1810.00000*	133.92701	.000	-2081.6166	-1538.3834
3km/h*4bar	1km/h*2bar	-6506.00000*	133.92701	.000	-6777.6166	-6234.3834
	1km/h*3bar	-10076.00000*	133.92701	.000	-10347.6166	-9804.3834
	1km/h*4bar	-12338.00000*	133.92701	.000	-12609.6166	-12066.3834
	1km/h*5bar	-14492.00000*	133.92701	.000	-14763.6166	-14220.3834
	2km/h*2bar	210.00000	133.92701	.126	-61.6166	481.6166
	2km/h*3bar	-1736.00000*	133.92701	.000	-2007.6166	-1464.3834
	2km/h*4bar	-3020.00000*	133.92701	.000	-3291.6166	-2748.3834
	2km/h*5bar	-4082.00000*	133.92701	.000	-4353.6166	-3810.3834
	3km/h*2bar	2174.00000*	133.92701	.000	1902.3834	2445.6166
	3km/h*3bar	900.00000*	133.92701	.000	628.3834	1171.6166
	3km/h*5bar	-910.00000*	133.92701	.000	-1181.6166	-638.3834
3km/h*5bar	1km/h*2bar	-5596.00000*	133.92701	.000	-5867.6166	-5324.3834
	1km/h*3bar	-9166.00000*	133.92701	.000	-9437.6166	-8894.3834
	1km/h*4bar	-11428.00000*	133.92701	.000	-11699.6166	-11156.3834
	1km/h*5bar	-13582.00000*	133.92701	.000	-13853.6166	-13310.3834
	2km/h*2bar	1120.00000*	133.92701	.000	848.3834	1391.6166
	2km/h*3bar	-826.00000*	133.92701	.000	-1097.6166	-554.3834
	2km/h*4bar	-2110.00000*	133.92701	.000	-2381.6166	-1838.3834
	2km/h*5bar	-3172.00000*	133.92701	.000	-3443.6166	-2900.3834
	3km/h*2bar	3084.00000*	133.92701	.000	2812.3834	3355.6166
	3km/h*3bar	1810.00000*	133.92701	.000	1538.3834	2081.6166
	3km/h*4bar	910.00000*	133.92701	.000	638.3834	1181.6166

Post Hoc Test-Duncan

Application rate (l/ha)

Application rate (mm)			Subset for alpha = 0.05										
	Group	N	1	2	3	4	5	6	7	8	9	10	11
Duncan ^a	3km/h*2bar	4	4110.0										
	3km/h*3bar	4		5384.0									
	2km/h*2bar	4			6074.0								
	3km/h*4bar	4			6284.0								
	3km/h*5bar	4				7194.0							
	2km/h*3bar	4					8020.0						
	2km/h*4bar	4						9304.0					
	2km/h*5bar	4							10366.0				
	1km/h*2bar	4								12790.0			
	1km/h*3bar	4									16360.0		
	1km/h*4bar	4										18622.0	
	1km/h*5bar	4											20776.0
	Sig.		1.000	1.000	.126	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 4.000.

Appendix 5. Pressure and Air velocity simulation in X direction inside wind tunnel. (figure 4.8)

Length [m]	Velocity [m/s]
0	4.00006293
0.085007826	4.187900633
0.170015651	4.199969393
0.255023477	4.189526505
0.340031303	4.18175909
0.425039128	4.176274548
0.510046954	4.171193519
0.59505478	4.165574751
0.680062605	4.159200238
0.765070431	4.15074048
0.850078256	4.109649991
0.935086082	3.862232267
1.020093908	3.181946712
1.105101733	2.384138125
1.190109559	1.760459335
1.275117385	1.385034964
1.36012521	1.197910545
1.445133036	1.111585729
1.530140862	1.077584709
1.615148687	1.066898416
1.700156513	1.063743779
1.785164339	1.06216994
1.870172164	1.060679016
1.95517999	1.05908406
2.040187815	1.057477332
2.125195641	1.055950291
2.210203467	1.05449774
2.295211292	1.05306643
2.380219118	1.051657256
2.465226944	1.050286997
2.550234769	1.048939816

2.635242595	1.047579316
2.720250421	1.046141528
2.805258246	1.044556689
2.890266072	1.042795729
2.975273898	1.040879331
3.060281723	1.038831737
3.145289549	1.036728298
3.230297375	1.035072818
3.3153052	1.032229481

Appendix 6. Ammonia emission (kg NH₃-N ha⁻¹ d⁻¹)

Apply deep Hours	Surface	50mm	100mm
3	12.01	4.82	3.84
6	9.5	2.36	2.01
9	4.2	2.1	1.3
12	3.15	1.98	0.7
15	2.9	1.88	0.6
18	2.35	1.58	0.4
21	2.1	1.3	0.35
24	1.98	1.2	0.3
27	1.88	1.1	0.3
30	1.58	0.99	0.3
33	1.3	0.97	0.3
36	1.2	0.88	0.3
39	1.1	0.7	0.3
42	0.99	0.6	0.3
45	0.97	0.5	0.3
48	0.88	0.5	0.3

Appendix 7. Ammonia emission Statistical analysis (Table 4.10)

surface method					
	Unstandardized Coefficients		Standardize d Coefficients	t	Sig.
	B	Std. Error	Beta		
time	-1.416	.177	-6.336	-8.019	.000
time ** 2	.046	.008	10.828	5.824	.000
time ** 3	.000	.000	-5.369	-4.724	.000
(Constant)	15.383	1.072		14.344	.000
Adjusted R Square R ² = 0.93					

50 mm Subsurface					
	Unstandardized Coefficients		Standardize d Coefficients	t	Sig.
	B	Std. Error	Beta		
time	-.383	.081	-5.110	-4.718	.000
time ** 2	.012	.004	8.463	3.320	.006
time ** 3	.000	.000	-4.283	-2.749	.018
(Constant)	5.090	.492		10.335	.000
Adjusted R Square R ² = 0.87					

100 mm Subsurface					
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
time	-.481	.050	-7.230	-9.625	.000
time ** 2	.016	.002	12.771	7.225	.000
time ** 3	.000	.000	-6.353	-5.880	.000
(Constant)	4.697	.304		15.464	.000
Adjusted R Square $R^2 = 0.94$					

Appendix 8. Anova test of ammonia emission (Table 4.9)

Multiple Comparisons							
Dependent Variable: emission							
	(I) method	(J) method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	surface	50mm	1.53938*	.40341	.000	.7419	2.3369
		100mm	2.26188*	.40341	.000	1.4644	3.0594
	50mm	surface	-1.53938*	.40341	.000	-2.3369	-.7419
		100mm	.72250	.40341	.075	-.0750	1.5200
	100mm	surface	-2.26188*	.40341	.000	-3.0594	-1.4644
		50mm	-.72250	.40341	.075	-1.5200	.0750
*. The mean difference is significant at the 0.05 level.							

emission

Duncan^a

method	N	Subset for alpha = 0.05	
		1	2
100mm	48	.7438	
50mm	48	1.4662	
surface	48		3.0056
Sig.		.075	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

Appendix 9. Application rate (l ha⁻¹) Laboratory test- Material Water- forward speed 1 km h⁻¹ -3.22 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	11583,0	11709,6	10772,6	10750,1	10732,2	10786,2
	300	14552,5	13877,1	13039,7	13378,9	13019,9	12831,5
	400	17398,0	17108,6	16131,9	16872,9	16430,9	15991,5
	500	19887,3	18728,5	18579,7	18263,0	18647,1	20571,4

Appendice 10. Application rate (l ha^{-1}) Laboratory test- Material Water- forward speed 2 km h^{-1} -6.35 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	5881,6	6047,6	5881,6	5282,3	5539,5	6005,2
	300	6679,0	6720,9	7107,3	7215,0	7087,7	6901,3
	400	8611,6	7634,9	8231,2	8173,6	7858,9	8086,3
	500	9131,5	9099,2	9054,3	8475,4	8669,7	8764,2

Appendice 11. Application rate (l ha^{-1}) Laboratory test- Material Water- forward speed 3 km h^{-1} -9.40 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	4974,5	4302,9	3841,9	3687,2	3911,8	3741,7
	300	6064,7	5617,4	5460,6	5457,1	4666,9	4937,4
	400	6890,2	6619,9	7083,0	6370,0	6490,1	6895,7
	500	8035,3	7562,3	7013,7	8172,7	8235,3	7171,5

Appendice 12. Application rate (l ha^{-1}) Laboratory test- Material Liquid Manure - forward speed 1 km h^{-1} -3.22 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	12488,7	11937,9	12831,5	11976,8	12244,9	12256,6
	300	16051,4	16326,5	15804,7	16172,5	16274,9	16121,8
	400	18108,7	18172,6	17457,1	17944,4	18108,7	18367,3
	500	20042,3	20311,4	19290,5	20152,3	20011,1	19933,6

Appendice 13. Application rate (l ha^{-1}) Laboratory test- Material Liquid Manure - forward speed 2 km h^{-1} -6.35 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	6321,1	6617,2	6036,2	6566,5	6380,7	6349,2
	300	8526,0	8030,7	8030,7	8086,3	8045,8	8035,7
	400	9777,3	9623,6	9303,3	9419,2	9667,0	9740,3
	500	10521,4	10410,6	10804,3	9822,1	10285,7	10495,6

Appendice 14. Application rate (l ha^{-1}) Laboratory test- Material Liquid Manure - forward speed 3 km h^{-1} -9.40 Hz

		Repetition					
		1	2	3	4	5	6
Pressure kPa	200	4974,5	4781,0	4346,4	4440,6	4413,3	4482,2
	300	5279,7	5886,4	5606,4	5184,2	5345,2	5312,3
	400	6544,4	6609,7	6940,2	6490,1	6569,4	6544,4
	500	7183,5	6879,2	7002,3	6962,7	7112,3	7171,5

Appendicle 15. Application rate ($l\ ha^{-1}$) Field test- Material liquid manure- forward speed 1km/h- 18 m-64 s. Tank was filled with 20 litter of material, after traveled 18 m decreased (litter) as table

		Repetition			
		1	2	3	4
Pressure kPa	200	12880,00	12760,00	12560,00	12960,00
	300	16400,00	16240,00	16480,00	16320,00
	400	18688,00	18480,00	18288,00	19032,00
	500	20824,00	20520,00	20800,00	20960,00

Appendicle 16. Application rate ($l\ ha^{-1}$) Field test- Material liquid manure- forward speed 2km/h- 18 m-32,37 s. Tank was filled with 20 litter of material, after traveled 18 m decreased (litter) as table

		Repetition			
		1	2	3	4
Pressure kPa	200	5892,86	6018,57	5984,00	6073,57
	300	7857,14	7857,14	8240,00	7700,00
	400	8878,57	9247,86	9160,00	9428,57
	500	10112,14	10214,29	10328,00	10253,57

Appendicle 17. Application rate ($l\ ha^{-1}$) Field test- Material liquid manure- forward speed 3km/h- 18 m-21,7 s. Tank was filled with 20 litter of material, after traveled 18 m decreased (litter) as table

		Repetition			
		1	2	3	4
Pressure kPa	200	3968,25	4206,35	4200,00	3968,25
	300	5055,56	5476,19	5320,00	5555,56
	400	6246,03	6230,16	6560,00	5952,38
	500	7142,86	7182,54	6960,00	7317,46

Appendicle 18. Penetration resistances of the soil channel

Depth (cm)	penetration resistance (Mpa)														
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
0	0.5	0.5	0.4	0.3	0.2	0.4	0.2	0.2	0.4	0.9	0.5	0.3	0.6	0.8	0.3
1	0.7	0.6	0.8	0.5	0.8	0.6	0.3	0.6	0.9	1.1	0.6	0.5	0.9	1.0	1.0
2	0.7	0.6	0.8	0.5	0.8	0.6	0.3	0.6	0.9	1.1	0.6	0.5	0.9	1.0	1.0
3	0.7	0.7	1.0	0.5	0.8	0.9	0.8	1.0	0.9	1.1	0.6	0.6	1.1	1.0	1.0
4	0.8	0.7	1.0	0.5	0.8	1.0	0.8	1.0	0.9	1.1	0.8	0.6	1.1	1.1	1.1
5	0.8	0.7	1.0	0.8	0.9	1.1	1.0	1.0	1.3	1.2	0.8	0.6	1.1	1.1	1.1
6	0.8	0.8	1.1	0.8	0.9	1.1	1.0	1.1	1.3	1.2	0.8	0.6	1.1	1.1	2.1
7	0.8	0.8	1.1	0.8	0.9	1.2	1.0	1.2	1.4	1.2	0.8	0.7	1.1	1.1	2.1
8	0.8	1.1	0.2	0.8	1.0	1.2	1.0	1.2	1.5	1.2	0.7	0.7	1.0	1.1	2.1
9	0.8	1.1	0.2	0.8	1.0	1.2	1.0	0.2	1.5	1.2	0.7	0.7	0.9	1.1	2.1
10	0.8	1.1	0.2	0.8	1.0	1.2	1.0	0.2	1.5	0.2	0.7	0.8	1.0	1.1	2.1
11	0.8	1.1	0.2	0.8	1.0	1.2	1.1	0.2	1.5	0.2	0.7	0.8	1.1	1.1	2.1

12	0.8	1.1	0.2	0.8	1.0	1.2	1.1	0.2	1.4	0.2	0.7	0.8	1.1	1.1	2.1
13	0.8	1.1	0.2	0.8	1.0	1.2	1.0	0.2	1.4	0.2	0.7	0.8	0.8	1.1	2.1
14	0.8	1.1	0.2	0.8	1.0	1.2	1.1	0.2	1.3	0.2	0.7	0.8	0.8	1.1	2.1
15	0.8	1.1	0.2	1.0	1.0	1.2	1.1	0.2	1.3	0.2	0.8	0.8	0.8	1.1	2.1
16	0.8	1.1	0.2	1.1	1.0	1.1	1.1	0.2	1.3	0.2	0.8	0.9	0.8	1.0	2.1
17	0.8	1.1	0.2	1.1	1.1	1.1	1.1	0.2	1.3	0.2	1.0	0.9	0.8	1.0	2.1
18	0.8	1.1	0.2	1.4	1.1	1.1		0.2	1.3	0.2	1.0	0.9	0.8	1.0	2.1
19	0.8	1.1	0.2	1.4	1.3	1.1		0.2	1.3	0.2	1.0	0.9	0.8	1.0	2.1
20	0.8	1.1	0.2	1.4	1.7	1.1		0.2	1.3	0.2	1.0	0.9	0.8	1.1	2.1
21	0.8	1.1	0.2	1.4	1.7	1.1		0.2	1.3	0.2	1.2	0.9	0.8	1.1	2.1
22	0.8	1.1	0.2	1.4	1.7	1.1		0.2	1.3	0.2	1.2	0.8	0.8	1.1	2.1
23	0.8	1.1	0.2	1.4	1.7	1.2		0.2	1.3	0.2	0.9	0.8	0.8	1.2	2.1
24	0.8	1.1	0.2	1.4	1.7	1.2		0.2	1.3	0.2	0.9	0.8	0.8	0.1	2.1
25	0.7	1.1	0.2	1.4	1.7	1.3		0.2	1.3	0.2	0.9	0.8	0.8	0.1	2.1
26	0.7	1.1	0.2	1.4	1.7	1.3		0.2	1.3	0.2	0.9	0.8	0.8	0.1	2.1
27	0.7	1.1	0.2	1.4	1.7	1.3		0.2	1.3	0.2	0.9	0.9	0.8	0.1	2.1
28	0.8	1.1	0.2	1.4	1.7	1.5		0.2	1.3	0.2	0.9	0.9	0.8	0.1	2.1
29	1.1	1.1	0.7	1.4	1.7	1.5		0.2	1.3	0.2	0.9	0.9	0.8	0.1	2.1
30	1.1	1.1	0.7	1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
31	1.1	1.1	3.7	1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
32	1.1	1.2	1.8	1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
33	1.1	1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
34	1.1	1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
35	1.3	1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	2.1
36	2.3	1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	0.7
37		1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	0.7
38		1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	0.7
39		1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	0.7
40		1.2		1.4	1.7	1.5		0.2	1.3	0.2	0.9	1.1	0.8	0.1	0.7