PERFORMANCE EVALUATION OF A GROUND DRIVEN, PUSH TYPE SEED AND FERTILIZER SPREADER

Idiris Farah ABDİ

Supervisor: Prof. Dr. Ahmet ÇELİK

Master Thesis

Department of Agricultural Machinery and Technologies Engineering

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(Yerden Hareketli, İtici Tip Bir Tohum ve Gübre Dağıtma Makinasının Performansının Değerlendirmesi)

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THESIS ACCEPTANCE AND APPROVAL FORM

Idiris Farah ABDİ tarafından hazırlanan "**PERFORMANCE EVALUATION OF A GROUND DRIVEN, PUSH TYPE SEED AND FERTILIZER SPREADER**" başlıklı Yüksek Lisans Tezi 26 / 08 / 2022 tarihinde yapılan tez savunma sınavı sonucunda başarılı bulunarak jürimiz tarafından Tarım Makinaları Ana Bilim Dalı, Tarım Makinaları ve Teknolojileri Mühendisliği Bilim Dalında Doktora tezi olarak kabul edilmiştir.

Jüri Başkanı / Danışman:	Prof. Dr. Ahmet ÇELİK *Atatürk Üniversitesi*	Aslı Islak İmzalıdır
Jüri Üyesi:	Prof. Dr. Yıldıran YILDIRIM *Atatürk Üniversitesi*	Aslı Islak İmzalıdır
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ETHICAL STATEMENT AND PLAGIARISM REPORT FORM

As a Master thesis, we declare that the study titled " PERFORMANCE EVALUATION OF A GROUND DRIVEN, PUSH TYPE SEED AND FERTILIZER SPREADER", presented under the consultancy of Prof. Dr. Ahmet ÇELİK, was written by us in accordance with scientific ethical principles, that the works benefited from are shown in the bibliography, that the Turnitin Program similarity rates determined by the Institute of Science are not exceeded, and that they are at the following rates.

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Idiris Farah ABDİ

ABSTRACT

MASTER THESIS

PERFORMANCE EVALUATION OF A GROUND DRIVEN, PUSH TYPE SEED AND FERTILIZER SPREADER

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Purpose: The objective of this study was to determine the effect of different profile shape of vanes, application rates, and forward speeds on fertilizer and wheat seed distribution uniformity of a manual ground driving push type spreader.

Method: This study was carried out using two different profile shape of vanes (L and C), three different forward speeds (1,25, 1,5, and 1,75 m/s), and three different application rates of fertilizer (13, 20, 26 kg/da), as well as three different application rates of wheat (21,26, 26,58, and 31,91 kg/da) to determine horizontal distribution uniformity of the spreader. The total and average rate of fertilizer and wheat filled in 16 collection trays placed on both sides of the spreader as well as the deviation values of each tray from the average were determined.

Findings: The best uniformity of distribution for the application of fertilizer with overall CV of 104 % obtained with the experiment having forward speed of 1,75 m/s, application rate of 13 kg/da, and using L profile shape of vane. However, the best uniformity of distribution for wheat with overall CV of 90% obtained with the experiment having forward speed of 1,75 m/s, application rate of 26,58 kg/da, and using L profile shape of vane.

Results: The outcomes of this study highlight that 1,75 m/s is the optimal forward speed for both applications of fertilizer and wheat to have a uniform distribution, regardless of application material. Furthermore, the L profile shape of vane is the best option for uniform distribution of both wheat and fertilizer application.

Keywords: Spreader, Profile shape of vane, Spreading disc, Fertilizer, Wheat seed, Distribution uniformity, Coefficient of variation.

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ÖZET

YÜKSEK LİSANS TEZİ

YERDEN HAREKETLİ, İTİCİ TİP BİR TOHUM VE GÜBRE DAĞITMA MAKİNASININ PERFORMANSININ DEĞERLENDİRMESİ

Idiris Farah ABDİ

Danışman: Prof. Dr. Ahmet ÇELİK

Amaç: Küçük ölçekli işletmelerde tahıl tohumu ile kimyasal gübre serpme işlemi genellikle el ile yapılmaktadır. El ile serpmenin neden olduğu sorunlar arasında; üniform olmayan gübre ve tohum dağılımı, istenilenden çok fazla miktarda gübre ve tohum kullanımı sonucu maliyetlerin artması, deneyimli insan gücüne ihtiyaç duyulması, bitki veriminde azalma ve çevre üzerindeki olumsuz etkiler sayılabilir. Öte yandan, traktör ile kullanılan gübre ve tohum serpme makinelerinin temini küçük işletmeler için hem pahalı hem de kullanımları için mevcut alanlar yeterli değildir. Bu nedenle, küçük alanlarda kimyasal gübre ve tohumun üniform olmayan dağılımından kaynaklanan ekonomik ve agronomik problemlerin önüne geçmek büyük önem arz etmektedir. Tarımsal üretim sistemindeki en büyük zorluk, çevresel etkiyi en aza indiren ve aynı zamanda çiftçilere daha iyi gelir sağlayan sürdürülebilir bir üretim garanti etmektir. Doğru normda kullanılan gübre, ürün verimliliği ve kalitesinde önemli düzeyde rol oynar. Tarımdaki temel uygulama sorunlarından biri de, ürün verimliliğini ve gübre uygulama verimliliğini artırmak için tohum ve gübrenin eşit dağılımının optimizasyonudur. İyi ürün üretimini sürdürmek ve ürün kalitesini artırmak için, dünya çapında optimal tarımsal üretim için kimyasal gübrelerin kullanımı esastır. Artan küresel gıda talebini karşılamak için daha fazla tarımsal üretim gerekli olduğundan, yetiştiriciler bu zorluğu karşılamak için, gübre ve özellikle gübre uygulamada farklı yaklaşımlar sergilemektedirler. Ancak gübrelerin düzensiz dağılımından kaynaklanan istenmeyen problemlerin önüne geçebilmek için gübrelerin etkili bir şekilde, homojen olarak uygulanması gerekmektedir. Tarımsal üretim, birim alan başına verimi artırarak, tohum kalitesini iyileştirmek için önerilen gübre oranını tek tip bir dağılımda uygulayarak, tarım teknolojilerini uygulayarak, üretim kayıplarını en aza indirmek çiftçilerin bilgisini geliştirmek suretiyle artırılabilir. Kimyasal gübre kullanımı, toprak besinlerinin devamlılığının sağlanması, verimliliğin artırılması ve ürün kalitesinin artırılması için en önemli faktördür. Gübreleme, bitki gereksinimlerinin sağlanmasında kullanılan en etkili toprak ıslah yöntemlerinden biridir. Ancak yanlış kimyasal gübre uygulaması gelir kayıplarına, ürün kalitesinin düşmesine ve çevresel zararlara neden olmaktadır. Gübre, tarımsal üretim sisteminin en önemli girdilerinden biri ve aynı zamanda önemli bir girdi maliyetidir. Bu nedenle gübre ve tohum doğru oranda ve homojen bir şekilde uygulanmalıdır.

Ekonomik ve çevresel açıdan önemli olan optimum performansı elde etmek için serpme makinelerinin uygun kullanımı konusunda çeşitli çalışmalar yapılmıştır, ancak bu çalışmaların tamamına yakını traktör ile kullanılan gübre ve tohum serpme makinalarına yöneliktir. Bu yüzden küçük ölçekli işletmelerin ihtiyacı dikkate alınarak, el ile kullanılan gübre/tohum serpme makinesinin değerlendirilmesi önemarz etmektedir. Böylece küçük ölçekli tarımsal işletmeler onunla daha verimli ve işlevsel çalışabilirler. Serpme makinesi kullanmak, tohum ve gübre dağılımının homojenliğini arttırmak için temel bir bir yaklaşımdır. Çevre üzerinde en az etki ile optimum üretkenlik için kaynakların ekonomik kullanılmasını sağlar. Gübre üretim maliyetlerinin artması ve çevresel kaygılar ile gübre kullanım verimliliğinin artırılması daha hayati hale gelmiştir. Serpme performansını etkileyen birçok faktör vardır ve bunlar: (a) serpme makinesinin yapısı (dağıtıcı disk şekli, kanatların şekli ve konumu ve deponun şekli ve orifis boyutu); (b) tanecikli parçacıkların özellikleri (boyut ve şekil, yoğunluk, hava direnci katsayısı, nem içeriği seviyesiyle birlikte sürtünme katsayısı); (c) çalışma genişliği; (d) dış etkenler (rüzgar hızı, nem, yüzey düzensizlikleri ve mekanik titreşimler). Dağıtıcı diskler, gübre ve

tohum serpme makinelerinin tarlada üniform gübre ve tohum dağılımını sağlamak için önemli bir parçasıdır. Dağıtıcı diskler genellikle kanatların "L" ve C şekli gibi farklı profil şekilleri ile kullanılmaktadır.

Bu çalışmanın amacı, serpme olarak dağıtılan gübre ve buğday tohumunun dağılım homojenliği üzerinde optimum performansı elde etmek için el ile itmeli tip, yerden hareketli bir serpme makinasının üzerinde çeşitli deneyler yapmaktır. Bu araştırmadan elde edilecek sonuçlar küçük ölçekli işletmelere üniform (homojen) dağılımın etkinliğini sağlamak için yeni ve temel bilgiler sağlaması açısından önemlidir. Bu araştırmanın özel amaçları ise şunlardır: (1) yerden hareketli, itme tipi tohum ve gübre serpme makinesinin performansını çeşitli ilerleme hızlarında değerlendirmek; (2) çeşitli uygulama oranları altında serpme makinesinin performansını değerlendirmek; (3) diskli gübre ve tohum serpme makinelerinde tipik olarak kullanılan iki farklı profil şeklindeki kanatların buğday ve gübre dağılımının homojenliği üzerindeki etkisini belirlemektir. Varyasyon katsayısı (VK), uygulamanın değerinden değişkenliği ve verilerin dağılımını değerlendirmek için bir oran olarak kullanılan verilerin ortalamasına bölünen verilerin standart sapmasının yüzdesidir. Düşük varyasyon katsayıları daha üniform bir dağılım düzenini göstermektedir. Gübre dağılımının VK, eğriltme, minimum ve maksimum değerleri de örtüşen desenlerde belirlenebilir. Eğrilik değerleri, modelin merkez çizgisinin sol tarafındaki parçacıkların yüzdesi ile modelin merkez çizgisinin sağ tarafındaki parçacıkların yüzdesi olarak, minimum ve maksimum değerler ise ortalama oranın yüzdesi olarak ifade edilmektedir.

Yöntem: Bu çalışmada, Rondini Company (Novellara RE, İtalya) tarafından imal edilen ve ticari olarak temin edilebilen, yerden hareketli, itmeli tipte bir gübre serpme makinesi kullanılmıştır. Çalışmada kullanılan itmeli tip, yerden hareketli serpme makinesi; depo, dağıtıcı disk, karıştırıcı, dişli kutusu, çıkış orifisi, besleme kontrol mekanizması, itme kolu ve hareket tekerleklerine sahip, tek diskli tip gübre ve tohum serpme makinesidir. Gübre ve tohumların yerleştirildiği depo huni şeklinde 2 mm kalınlığında sac malzemeden yapılmıştır. Deponun koni şeklindeki yapısı, gübrenin ve tohumun deponun ağız açıklığının dibine sürekli akışını kolaylaştırmaktadır. Gübre ve tohumun boşaltıldığı uygulama oranını belirlemek için depo tabanındaki orifisin büyüklüğü değiştirilmektedir. Orifisten dağıtma diskine akan gübre ve tohum daha sonra diskin yüzeyine sabitlenmiş döner kanatlarla yayılmaktadır. Gübre ve tohumun topaklanmasını önlemek ve akışı kolaylaştırmak için serpme disk miline yatay döner eksenli bir karıştırıcı monte edilmiş ve kullanılmıştır.

Nem içeriği, tohum ve gübrelerin önemli fiziksel özelliklerinden biridir. Üreticilerin, tohum ve gübre serpme kalitesini etkileyen belirli tohum veya gübre türleri için gerekli olan minimum ve maksimum nem içeriğini bilmesi büyük önem arz etmektedir. Gübre üreticilerinin tavsiye ettiği seviyelerde gübre veya tohumlardaki nem seviyeleri aşılmamalıdır. Gübre ve buğdayın nem içeriğini belirlemek için fırında kurutma yöntemi kullanılmıştır. Gübrenin nem içeriği 105 ^{0}C' de 16 saat fırında kurutma yöntemiyle belirlenirken, buğdayın nem içeriği 130 ^{0}C' de 19 saat fırında kurutularak belirlenmiştir. Buğday ve gübrenin nem içeriğinin ölçülmesi için bir fırın (NUVE FN 120 fırın, Nuve Sanayi Malzemeleri, Ankara, Türkiye) kullanılmıştır. Buğday ve gübrenin kütle yoğunluğu 1000 cm^3 hacimli metal bir tepsi kullanılarak belirlenmiştir. Gübre ve buğday ayrı ayrı tepsiye dikkatlice dökülmüş sonra fazla malzeme tepsinin üstünden bıçakla alınmış ve terazi ile ölçülmüştür. Gübre ve buğday danelerinin doğal yığılma açısını belirlemek için, ortak bir yöntem olan huni metodu kullanılmıştır. Gübre ve buğday huniden yatay bir yüzey üzerine yavaş yavaş dökülerek yüzeyde bir koni oluşturularak gübre ile buğdayın zemin ile yaptığı açı ölçülmüştür. Granül haldeki kimyasal gübrelerde parçacık boyutları farklılık gösterir. Serpme makinesinin performansı üzerinde önemli bir etkiye sahip olan parçacık boyutu dağılımını belirlemek önem arz etmektedir. Çalışmada kullanılan gübre partiküllerinin dağılımını belirlemek için delik çapı < 1,40 mm, 1,40 – 1,60 mm, 1,60 – 1,70 mm, 1,70 – 2 mm, 2 – 2,36 mm, 2,36 – 2,50 mm, 2,50– 2,80 mm, 2,80 – 3,35 mm, 3,35 – 3,50 mm, 3,50 – 4 mm ve 4 – 4,75 mm olan elekler kullanılarak elek analizi yapılmıştır. Analiz, titreşim cihazı kullanılarak 10 Hz frekansta ve 5 dakika süreyle her biri 100 gramlık örnekler üzerinde üç tekerrür halinde gerçekleştirilmiştir. Titreşim sonucunda herb bir elek üzerinde kalan gübre miktarları tartılmıştır.

Manuel olarak çalıştırılan dağıtıcının, laboratuvar koşullarındaki performansını değerlendirmek için deneyler yapılmıştır. Deneyler Atatürk Üniversitesi Ziraat Fakültesi Tarım Makinaları ve Teknolojileri Mühendisliği Bölümü laboratuvarında gerçekleştirilmiştir. Dağıtıcı deposu deneyler boyunca aynı seviyede tohum ve gübre içerecek miktarda doldurulmuştur. Deneyler, ASAE S341,3'te önerildiği gibi, kapasitenin %50 ve %75'i seviyesine kadar doldurulan makine deposu ile gerçekleştirilmiştir. Depo kapasitesi dört eşit seviyede bölünerek işaretlenmiştir. Makina deposu kapasitesinin %75' ile doldurularak dağıtma işlemi gerçekleştirilmiştir. Doğru sonuçların alınması için dağıtma makinası, toplama kaplarının bulunduğu hattan 3 m önce harekete başlamış ve 3 m sonra durdurulmuştur.

Makinanın performansını değerlendirmek için deney boyunca aşağıdaki faktörler göz önünde bulundurulmuştur. Operatörlerin yürüme hızı olarak kabul edilen dağıtıcının ilerleme hızı, dağıtıcının deney esnasında 20 m'lik mesafeyi kat etmesi için gereken süreden itibaren ölçülmüştür. Dağıtıcının ilerleme hızını izlemek için dijital ekrana sahip bir hız sensörü kullanılmıştır. Dağıtma makinasının ilerleme hızı, insanların ergonomik uygunluğu dikkate alınarak, üç farklı ilerleme hızı belirlenmiştir. 1,75 m/s ilerleme hızı, sahadaki tipik insan hızını temsil eden optimum ilerleme hızı olarak belirlenmiştir. L ve C olmak üzere iki farklı profil kanat tipine sahip, yerden hareketli itmeli tip kimyasal gübre ve tohum dağıtma makinası, üç farklı ilerleme hızı (1,25; 1,5; 1,75 m/s) ve üç farklı gübre normu (13, 20, 26 kg/da) ile buğday ekim normu (21,26; 26,58; 31,91 kg/da) koşullarında kullanılarak, yatay dağılım düzgünlüğünün belirlenmesine çalışılmıştır. Makinanın geçiş yolunun her iki yanına yerleştirilen tepsilere dolan gübre ve tohumlar tartılarak ortalamalar elde edilmiş ve her tepsinin ortalamadan sapma değerleri belirlenmiştir. Makinanın dağıtım paternini belirlemek için 400 x 400 mm ebatlarında 16 adet tepsi kullanılmıştır. Makine dağıtım genişliğini tam kapsayacak şekilde geçiş yolunun sağına 8 ve soluna da 8 adet tepsi yerleştirilmiştir. Toplama tepsilerinin toplam genişliği, makinanın bir geçişinde (hareket yönüne dik olarak) etkin dağıtım genişliğinin %10'unu aşmayacak şekilde ayarlanmıştır. Dağıtılan tohum ve gübrenin tepsilerden dışarı çıkma olasılığını azaltmak için her tepsi 100 x 100 mm ebadında ve 100 mm yüksekliğinde karton malzeme kullanılarak bölmelere ayrılmıştır.

Bulgular: İlerleme yönüne dik doğrultuda yeleştirilen toplam 16 adet toplama tepsisinden alınan veriler esas alınarak, buğday için 9 ve gübre için de 9 olmak üzere toplam 18 farklı muamele kombinasyonuna göre gerekli analiz ve değerlendirmeler yapılmıştır. İlerleme yönünün sağ ve sol tarafları için etkin dağıtma genişlikleri ile dönüşler için ön görülen kapatma (bindirme) mesafeleri de ayrıca belirlenmiştir. Buğday için maksimum etkin dağıtma genişliği, 1,75 m/s ilerleme hızı ve farklı uygulama normları (21,26, 26,58 ve 31,91 kg/da) için 4,4 m olarak belirlenmiştir. Buğdayın farklı uygulama normları ve ilerleme hızları (1,25, 1,5 ve 1,75 m/s) kombinasyonları için kapatma mesafeleri; 31,91 kg/da uygulama normu ve C tipi kanat profil şekli için sol tarafa dönüş için 0, 8 m ve sağ tarafa dönüş için 1,2 m sağ olarak belirlenirken, L profil kanat için sol tarafa dönüşte 1,6, 1,6 ve 1,2 m ve sağ tarafa dönüşte 1,2, 1,2, 0,8 m kapatma mesafeleri elde edilmiştir. Genel olarak, L profil kanat için sol taraf bindirme genişliği, sağ taraftan daha büyük bulunurken, C profil kanat şekli için kapatma mesafesi sağ taraf sol taraftan daha büyük olduğu için bunun tam tersi olmuştur. Çeşitli gübre uygulama normlarının kapatma mesafeleri de buğdaya benzer şekilde bulunmuştur. L profil kanat şekli için sol tarafta maksimum bindirme genişliği, 13 kg/da uygulama normu ve 1,25 m/s ilerleme hızı için maksimum 2,4 m olarak bulunmuştur. Aynı uygulama normunda (13 kg/da) ve aynı ilerleme hızında (1,25 m/s) aynı kanat şeklinin (L profil şekli) sol tarafı için 0,4 m dağıtma genişliği bulunmuştur. Çeşitli gübre uygulama normlarının sol tarafta binme mesafesi, kanat şeklinin hem L hem, de C profil şeklinin sağ tarafına göre daha büyük bulunmuştur. Farklı ilerleme hızlarında 21,26 kg/da buğday uygulama normunda kanadın L ve C profil şekilleri, benzer dağıtma genişliklerine (3 m) sahip olmuştur. Ancak kanadın C profil şeklinde 31,91 kg/da uygulama normu ve 1,5 m/s ilerleme hızı ile efektif dağıtma genişliği L profil kanat için 4,4 m olarak bulunmuştur. Thaper ve ark. (2022) tarafından yapılan bir çalışmada da benzer sonuçlar elde edilmiştir. Çalışmada, dağıtıcı disk dönme hızı ile ilerleme hızındaki artışın, dağıtıcının etkin serpme genişliğini artırdığı ileri sürülmüştür. Ayrıca, Ziauddill ve Roy (1997) tarafından yürütülen bir çalışmada, disk hızındaki artış ile elde edilen dağıtma genişliklerini; 2,8 m ile 425 rpm, 2,98 ile 470 rpm, 3,05 m ile 515 rpm, 3 ile 560 rpm, 35 m ve 3,75 m ile 696 rpm şeklinde belirlemişlerdir.

Üzerinde durulan faktörlerin gübre dağılım düzgünlüğü üzerindeki etkisi göz önüne alındığında, en yüksek varyasyon katsayısının (CV) %104 olduğu ortaya çıkmıştır. Çalışmada, optimum dağılım düzgünlüğü 1,75 m/s ilerleme hızı, 13 kg/da uygulama normu ve L profilli kanat ile elde edilmiştir. Benzer şekilde, buğdayın üniform dağılımı üzerinde faktörlerin kombinasyonunun etkisi göz önüne alındığında, %90 toplam CV ile en iyi dağılım düzgünlüğü, 1,75 m/s ilerleme hızı, 26,58 kg/da ekim normu ve L profile sahip kanat ile ortaya çıkmıştır. Bu sonuçlar, 1,75 m/s ilerleme hızı ile L profil kanadın dağıtım materyalinden bağımsız olarak, düzgün dağılım için her iki uygulama için de optimum sonuçlar ortaya çıkardığını göstermektedir.

Sonuç: Buğday ve gübre için tek bir uygulama normu için ilerleme hızı göz önüne alındığında, 1,75 m/s'lik ilerleme hızının homojen dağılım düzgünlüğü elde etmek için en uygun ilerleme hızı olduğu belirlenmiştir. Dağıtıcı disk üzerindeki kanat profilinin buğdayın düzgün dağılımı üzerinde önemli bir etkiye sahip olduğu dikkate alındığında, elde edilen veriler kanatların farklı profil şekillerinin homojen dağılım üzerinde çok az etkisi olduğunu gösterse de, C profil kanadın optimum dağılım gösterdiği ortaya çıkmıştır. Aynı şekilde, gübre uygulamasının homojen dağılımına çok az etki eden kanatların L profil şekli de optimum olarak bulunmuştur. Buğdayın düzgün dağılımında önemli bir faktör olarak uygulama normunun önemli etkisi göz önüne alındığında, 26,58 kg/da uygulama normu optimum uygulama normu olarak ortaya çıkmıştır. Aynı şekilde, 13 kg/da gübre uygulama normu en iyi üniform dağılım gösteren norm olmuştur. Yürütülen denemelerde, küçük ölçekli işletmeler için yerden hareketli, itmeli tip gübre serpme makinesinin 1,75 m/s ilerleme hızı ile dağıtıcı diskin üzerinde 4 adet L tipi kanat ile kullanımında yeterli bir performansa sahip olduğu sonucu ortaya çıkmıştır. Birçok araştırmacı tarafından farklı normlarda, farklı hızlarda, farklı kanat profil şekillerinde ve farklı özelliklere sahip serpme makineleri üzerine yapılan çalışmalardan elde edilen sonuçlar ile karşılaştırıldığında, bu çalışmadan elde edilen bulguların benzer bir eğilim gösterdiği anlaşılmaktadır.

Anahtar Kelimeler: Serpme makinası, küçük ölçekli işletmeler, gübre, tohum, dağılım düzgünlüğü, varyasyon katsayısı.

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ACRONMYS AND ABBREVIATIONS

ASAE	: American Society of Association Executives
CAN	: Calcium Ammonium Nitrate
CO2	: Carbon Dioxide
CV	: Coefficient of Variation
da	: Decare
DEM	: Discrete Element Method
DFM	: Deviations from the mean
ERS	: Economic Research Service
FAO	: Food and Agricultural Organization
g	: Gram
HL	: Horizontal Left
HR	: Horizontal Right
ISO	:International Organization for Standardization
kg/da	: Kilogram Per Decares
kg/ha	: Kilogram Per Hectare
km/h	: Kilometer Per Hour
LSV	: Left Side Values
N2O	: Nitrogen Oxide
RSV	: Right Side Values
SD	:Standard Deviation
TS	: Turkish Standards
TSP	: Triple Super Phosphate
U.S.	: United States
USDA	: United States Department of Agriculture
VL	: Vertical Left
VR	: Vertical Right
VRT	: Variable Rate Technology

INTRODUCTION

The world's population is continuously increasing and results in raising the demand for food products which highlights the necessity of supporting agriculture production (Bajželj *et al.* 2014). This growth in population and food demands is expected to be increased by 60% to 110 % in 2050 (Ray *et al.* 2013).

Food consumption per person has increased from an average of 2370 kcal/person/day to 2770 kcal/person/day in the past 35 years (Vasquez *et al.* 2018). Supplying the global demand growth for farm products without disturbing the limited resources of the planet is a critical problem that humans are facing. The three basic approaches for increasing agricultural production are:

- Increasing the agriculture area,
- Improving the crop productivity while protecting the environment using recent technology, and
- Applying the recommended rate of chemical fertilizers in such a uniform distribution way, as utilization of chemical fertilizers was found to increase agricultural production from 30% to 50% (Cordell *et al.* 2009).

The right amount of utilized fertilizer plays an important role in crop productivity and crop quality. One of the main practical problems in agriculture is optimization of uniform distribution of seed and fertilizer to improve crop productivity and fertilizer use efficiency. Applying undesired fertilizer application rate results in nutrient wastes and harms the environment. Over-fertilization results in an increase of CO_2 and N_2O in the soil, which eventually can be released into the atmosphere (Sima *et al.* 2013).

Chemical fertilizers have been used in the world for a past hundred years and cost-effective in crop production (Stewart *et al.* 2005). Crop production has been increased by the contribution of agro-chemicals in millions of hectares (Balmford *et al.* 2005). Nevertheless, a concern about excessive or incorrect, deficiency and undesired application of fertilizers in the farming system still is critical. Fertilizer mining is a main reason for low farm production in some of the developing countries, especially Africa. In other conditions, fertilizers in particular nitrogen and phosphorus usually apply undesirable as there is not a proper management to balance between utilized fertilizers rate and crop's requirements (Noordwijk and Cadisch 2002) which may cause inevitable cost to the farming system (Mosier *et al.* 2002). Therefore, improving agro-chemical usage efficiency is a crucial issue in agriculture.

In Turkey, millions of tons of chemical fertilizers are used for agricultural production each year, either by hand or by machinery. The use of chemical fertilizers is increasing with the development of agriculture in the country. Figure 1 depicts the chemical fertilizers used in Turkey's agricultural production, as million-ton per year from 2010 to 2020 (Anonymous 2020).

In Turkey, the price of the chemical fertilizer has increased over decades, as it plays an important role in agricultural production. The three commonly utilized fertilizers in Turkey are urea, diammonium phosphate, and calcium nitrate which their purchase prices have increased by 5, 4, and 3% respectively from 2010 to 2021. Figure 2 shows Turkey's fertilizer purchased prices from 2010 to 2021 (Anonymous 2021a).

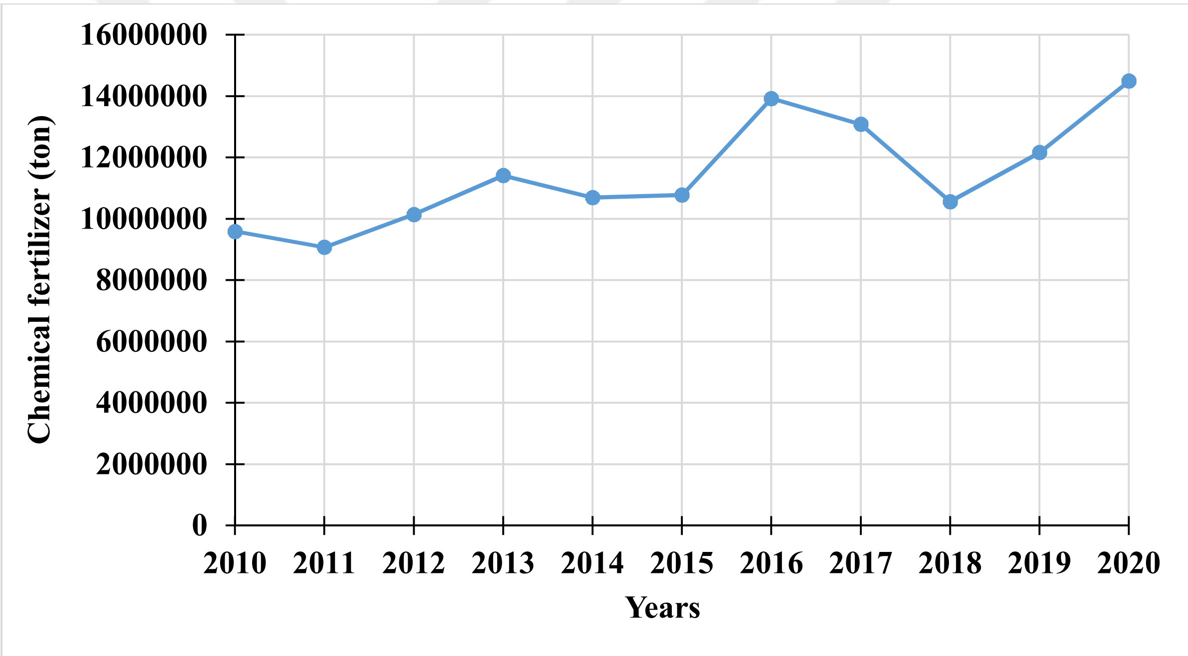


Figure 1. Chemical fertilizer used in Turkey from 2010 to 2020

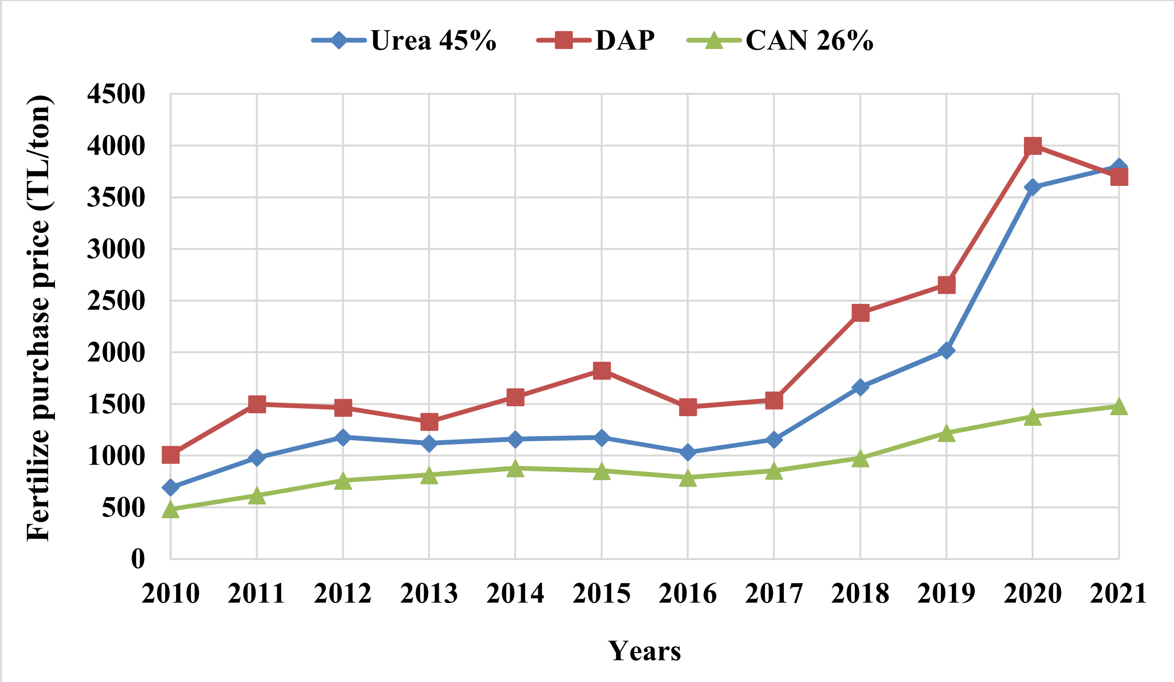


Figure 2. Turkey's fertilizer purchase prices from 2010 to 2021

Undesired usage of fertilizers can cause environmental problems by creating surface run-off and leaching into ground as well as subsurface water bodies. Applying the proper rate of fertilizers for a crop is one of the major issues for producers. Fertilizer rates must be applied in a uniform method and at a recommended rate to meet both achieving the most profitable economic return and advancing environmental conservation. Applying insufficient fertilizers for highly responsive crops, such as potato, wheat, corn results in lower grain yield, quality, and profits. When fertilizers are applied in excess of crop needs, profit is reduced and negative environmental consequences are likely. Ununiformed application of fertilizer to the crop often results in low yields at low fertility areas. It also caused crop damage, lodging of plants and the grain production with high nitrogen contents at high-fertility areas.

In order to maintain good crop production and enhance the crop quality, the use of chemical fertilizers is essential for optimal agricultural cultivation worldwide. Since increasing agricultural production is necessary to cover the growing global food demand, growers are using different approaches to meet this challenge e.g., applying fertilizers and in particular fertilizer. However, fertilizers must be applied in such an efficient way to avoid undesirable problems due to ununiformed fertilizer distribution (Bruulsema *et al.* 2012).

Eraslan *et al.* (2010) stated that increasing agricultural production is must due to the high growing population and changing food preferences of people. Agricultural production can be enhanced by increasing yield per unit area, applying recommended rate of fertilizers in a uniform distribution to improve seeds quality, as well as applying agricultural technologies, minimizing production losses and advancing farmers' knowledge.

The use of chemical fertilizers is the most important factor for sustaining soil nutrients, improving productivity, and increasing the quality of products. Fertilization is one of the most effective reachable soil amendment methods for ensuring plant requirements. However, improper chemical fertilizer application has caused profit losses, crop quality reduction, and environmental harms (Chen *et al.* 2018).

Most of small-scale farmers are still spreading cereal seeds and fertilizers in a traditional way, mainly manually by hand. The challenges caused by this traditional approach include ununiformed fertilizer and seed distribution, increasing costs because of undesired and extra uses of fertilizers and seeds, decreasing agricultural yields, and negative effects on the environment. On the other hand, fertilizer spreaders, which are mounted on tractors are too expensive to purchase as well as challenging to operate in small-scale farms due to limited area for moving the tractors.

Manually fertilizer spreading causes wasting fertilizer in some areas due to lack of a constant forward speed and similar spreading covering width which result in either higher or lower application rate of fertilizer and seed rate. The fertilizer spreaders imply the use of fertilizer and seed at an appropriate rate that can enhance their use efficiency on a uniform distribution pattern as well as reduction of contamination in the soil and uniform population of seeds respectively. The seed and fertilizer spreading system in small-scale farms are based on a traditional method that relies mainly on farmers' manual operation. However, the major disadvantage of traditional spreading methods is non-uniformity in distribution of seed/fertilizers which causes low or high seed/fertilizers rate distribution patterns. Therefore, it results in inadequate use of resources, which causes labor-intensive as well as increasing other input costs. Furthermore, it requires experienced manpower to spread seed and fertilizer uniformly. The controlled spreader can offer uniform distribution for seed and fertilizer at recommended rate than traditional hand spreading (Liu *et al.* 2017).

Dual-disc spinner type spreaders are widely used to spread chemical fertilizers due to its uniformity and capability to adjust the spreading width as well as their cost-efficiency. In these spreaders, rotational speed of the disc plays a key role in spreading width, which varies from 600 to 800 rpm for spreading widths ranging from 18,3 to 30,5 m. However, the spreading uniformity of dual-disc spinner spreaders are affected by many factors such as, spinning disc, and profile shape of vane and orifice size. Particle flow behavior on the spinner discs and effective spreading width are mostly regulated by the profile's shape (Thaper 2014). Manual push type granular fertilizer spreaders are also widely used to distribute granular fertilizers around the small-scale fields, small gardens, and greenhouse nurseries.

Recently, fertilizer spreaders have been considered as necessary and very important by many farmers throughout the world. These spreaders enable farmers to minimize the waste of their fertilizer and seed spreading and ultimately increase their use efficiently (Sima *et al.* 2011).

Similar to the increase in the use of fertilizer spreaders in the world, the use of fertilizer spreaders in Turkey has increased over the years (Figure 3; Anonymous 2021b). Fertilizer spreaders, which have disc type distributors, can be used with three hitch points of tractors, mounted on the tractor, or towed according to their tank volumes.

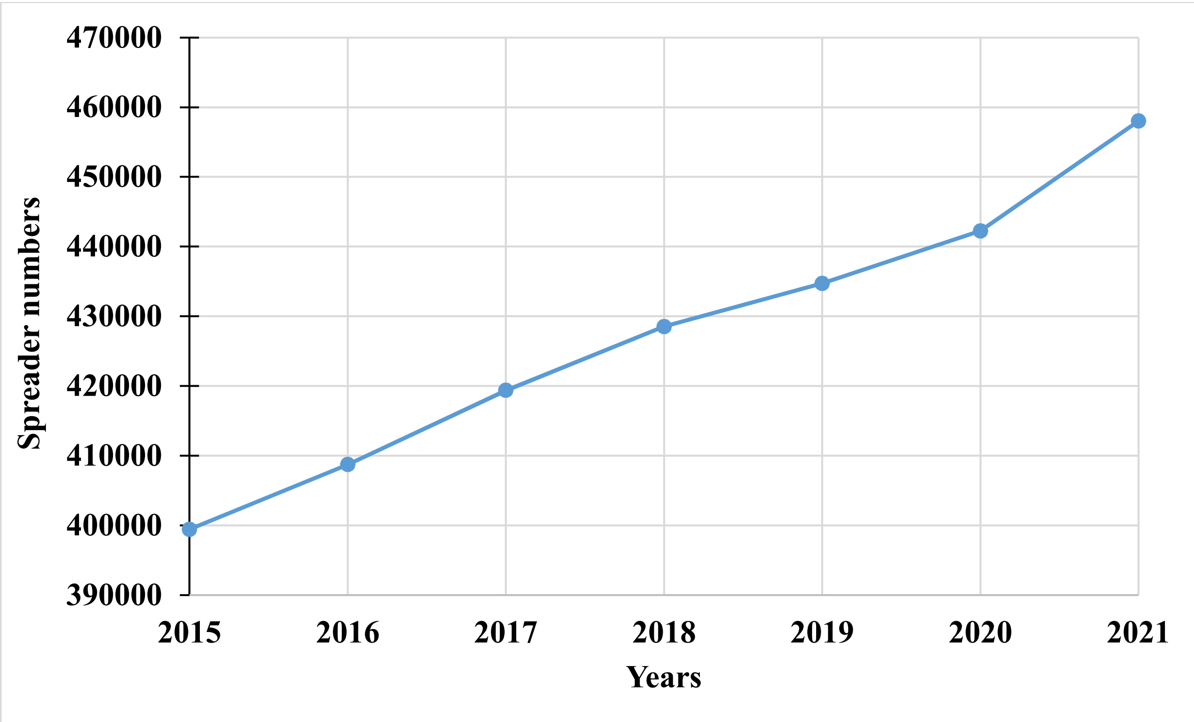


Figure 3. The distribution of fertilizer spreaders used in Turkey from 2015 to 2021.

There are many factors that affects distribution uniformity in spreaders, include: disc diameter, disc numbers, disc surface, the position and number of vanes on the disc, rotational speed of the disc, and the height of the disc from the ground, as well as the physical structures of the fertilizer and seed (Yildirim and Kara 2003). Furthermore, the single disc fertilizer spreader is affected by size and shape of the disc, material drop location, shape and size of feed gate, vanes position, rotational disc velocity, material specifications, and climatic conditions such as wind speed or direction and moisture levels.

Using a spreader is a very useful approach for enhancing the distribution uniformity of seed and fertilizer. It allows the economical utilization of resources for optimum productivity with the least impact on the environment. Increasing fertilizer use efficiency has become more vital with increasing the cost of producing fertilizer and environmental concerns. Furthermore, Reumers *et al.* (2003) stated there are many factors affect the spreader performance which include: (a) structure of the spreader (disc shape, the shape and position of vanes, and shape of the tank and orifice size); (b) properties of granular particles (size and shape, density, air resistance coefficient, friction coefficient with the level of moisture content); (c) working width; (d) external factors (wind velocity, humidity, surface irregularities and mechanical vibrations).

Spreading discs are an important part of fertilizer and seed spreaders for ensuring uniform fertilizer and seed distribution in the field. Spreading discs are generally manufactured with different profile shape of vanes such as “Z” and C shape.

The purpose of this study was to conduct various experiments on manual push-type spreader in order to obtain its optimum performance on fertilizer and wheat seed distribution uniformity. The results of this research were important in terms of providing new and essential information to small-scale farmers in order to ensuring the effectiveness of uniform distribution. Therefore, the specific objectives of this research were to: (1) evaluate the performance of a ground driven, push-type seed and fertilizer spreader under various forward speeds; (2) evaluate the performance of the spreader under various application rates; (3) determine the influence of two different profile shape of vanes, which are typically used in disc type fertilizer and seed spreaders, on uniformity of wheat and fertilizer distribution.

LITERATURE REVIEW

In this section, core information from studies conducted by different researchers on the performance and development of fertilizer and seed spreaders has been evaluated. The section is presented the information according to tractor mounted spreader followed by push-type spreader.

In the past studies it has been stated that the traditional fertilizer and seed spreading method, usually manually spreading, has a major disadvantage of non-uniform distribution and extra utilization of seed/fertilizers rate. This results in waste of limited resources and rising labor-hour and input cost. Furthermore, to spread seed and fertilizer by hand in a uniform distribution, requires skilled workers (Koundal and Kadyan 2021). The purpose of a research conducted by Koundal and Kadyan (2021) was to design and develop a single rotary disc spreader that could be used to easily spread fertilizers in a uniform manner. The most significant advantage of their work was the spreading disc, which played a key role in uniform application distribution. They recommended this kind of the spreader to farmers in order to save time, reduce the amount of unnecessary work to handle large bags of fertilizer as well as reduce fertilizer waste.

Tractor Mounted Spreaders

Hwang and Nam (2021) conducted research aiming to evaluate a centrifugal fertilizer spreader with double outlet opening. The objective of the study was to determine the ideal shutter opening and location that increased distribution uniformity. A simulation model of a centrifugal fertilizer spreader using discrete element method was designed for the spreading pattern. The replication classic was tested using a stationary spreading design which evaluated the behavior of fertilizer particles on the spinner disc. To enhance distribution uniformity, the spreader shape was improved with the tested replication classic. During stationary conditions, the CV of fertilizer distributed to the right side of the spreader was 1,59% higher than the left side with the CV of 34,88% which indicated an ununiformed fertilizer distribution. The amount of fertilizer distributed to the right side significantly reduced when outlet opening position in the direction of spinner rotation was changed.

Khudher *et al.* (2020) conducted research on a centrifugal spreader with the purpose of evaluation of the control disc and modulating disc using different forward speeds of the spreader and disc rotational speed with different rates of fertilizer and barley seed. In the experiment, which was carried out in two stages, fertilizer was used in one and barley seeds were used in the other. The experiments were carried out with the combinations of control and modulating discs, disc rotational speeds (450 and 540 rpm), and application rates (270 and 200 kg/ha). The optimum performance of the spreader was obtained with the forward speed of 12 km/h, disc rotational speed of 450 rpm, and modulating disc for both barley and fertilizer with CV of 5,5%.

Przywara (2020) developed a stationary spreader with the aim of determining the effect of different disc rotational speeds (400 and 600 rpm), vane angles and feed gate positions on fertilizer distribution uniformity. The findings of the study revealed that disc revolution velocity, angle of vane on the disc, and feed gate position has significant effect on distribution uniformity. However, the study was conducted in uncontrolled condition without taking the effects velocity and direction of wind into consideration.

Han *et al.* (2019) evaluated a feeding system of spreaders for wheat distribution. The VICON pendulum spreader was used for wheat spreading. The hopper capacity was 200 kg with 14 m width. The study was conducted on the Giza 168 variety of wheat with moisture content of 12,3% using different forward speeds (4,5, 4,6, and 5,6 km/h), and two different application rates (265 and 277 g/m^2). The results indicated the forward speed had a significant effect on distribution uniformity and the optimum application rate was 277 g/m^2 with the forward speed of 4,5 km/h.

El-Sabrawi *et al.* (2018) improved a variable rate spreader for uniform fertilizer spreading. The spreader was enhanced with a regulator and a sensor for monitoring fertilizer flow rate. The experiment was conducted using three different application rates (200, 300, and 400 kg/ha) and three forward speeds (5, 10, and 15 km/h). To avoid crop damage the CV of less than 15% was considered during the study. The results revealed that the different application rates of 200, 300, and 400 kg/ha had CVs of 8%, 9%, and 8%, respectively. In the study it is recommended the application rate of 200 kg/ha is more optimal for uniform fertilizer spreading.

Gbabo *et al.* (2018) developed and evaluated a fertilizer broadcaster pulled by motorcycle. The spreader consisted of a hopper, mixer, spreading disc, feed control mechanism and flow control. In the study, which revealed that the fertilizer discharge rate and the distribution evenness decreased with the increase in the forward speed, a 15 km/h forward speed was recommended for spreading 250,02 kg/ha of fertilizer on the rice crop.

Kolcu and Değirmencioğlu (2017) conducted research to determine the distribution evenness of a single disc type fertilizer spreader for two different granular fertilizers (urea and triple superphosphate). The main purpose of the study in which the disc rotation speed, blade angle and fertilizer flow rate were taken into account, was to improve the skewing rate and CV for fertilizer distribution from right to left and left to right. As a result of the study, in which all three factors affected the distribution uniformity, mathematical models of optimal conditions for uniform distribution have been developed.

Kömekçi (2017) used a two-disc type fertilizer spreader with different vane heights and vane angles to obtain distribution uniformity of three different fertilizer types (urea, NPK 15-15-15, NPK 20-20-0) and three different application rates. The obtained data were analyzed using mathematical models for assessing the uniform distribution of the spreader. The findings of experiments revealed that the uniform distribution of the spreader was appropriate with the CVs of 6,78, 8,14, and 8,11% for urea, NPK 15-15-15, and NPK 20-20-0 respectively.

Przywara (2015) evaluated the effects of various fertilizer spreaders with three types of fertilizers consisting of urea, ammonium sulfate, and calcium ammonium nitrate to enhance the distribution uniformity of the spreader. The result showed that fertilizer type, profile shape of vane and disc rotational speed had the main effect on performance of the spreader while the disc feed point had a minor effect on the fertilizer distribution uniformity.

Laghari *et al.* (2014) investigated the performance of a tractor mounted rotary fertilizer spreader to improve the evenness of fertilizer distribution at higher field capacity. The spreader was calibrated to spread 250 kg/ha of urea by weighing the rate of fertilizer in the hopper before spreading and after spreading for a specific area with two forward speeds. With the targeted 250 kg/ha fertilizer norm, at a forward speed of 4,23 km/h; 20,82% distribution uniformity (CV), 1,1 l/ha fuel consumption, 2,78 ha/h effective area capacity and 71,28% field efficiency were achieved. Whereas, for forward speed of 8 km/h; the spreader had 21,73% distribution uniformity (CV), 1,64 l/ha fuel consumption, 5,33 ha/h effective field capacity and 73,11% field efficiency were obtained.

Yıldırım and Kara (2012) tried to determine how different blade shape combinations affect the distribution uniformity of triple super phosphate fertilizer at different application rates. The study was conducted with several fertilizer flow rates and a combination of different forward-backward-curved vanes and flat profile shape of vane. The orifice openings of 30, 40 and 50 mm were used for fertilizer calibration rate. The combination of forward curved-5 vane and the straight vane produced a significant fertilizer spreading uniformity at a certain fertilizer application rate. The results revealed that the CV of 30, 40, 50 mm orifice openings were 10,31, 15,49, and 19,92% respectively.

Kweon *et al.* (2009) improved the distribution pattern uniformity in a two-disc fertilizer spreader by using a flat disc with radial straight blades and varying the granular fertilizer flow. They used a sensor to determine fertilizer discharged velocity on the disc and targeted controlling discharge rate using an adjuster to open the outlets. The readings from a sulky disc distributor were used to evaluate implementation of the flow control system. The outcomes revealed the feasibility of distribution uniformity with a CV less than 15%. An optimized mathematical approach including a feed gate regulator unit for a targeted fertilizer rate and swath width, was applied to identify the primary factor adjustments for a particular application distribution management. The findings of the study show that the correlations between outlet opening with discharge amount, disc velocity with granule speed, and disc velocity with desired granular fertilizer covering area were significantly linear (r^2>0,96). They reported that the velocity sensor which was used in the study, was well-suited for monitoring the application uniformity and rate.

Mange *et al.* (2009) evaluated the impact of the vane height on spreading distribution at varied application rates. Two types of fertilizers (triple super phosphate and calcium ammonium nitrate) were applied using a tractor-driven spreader with a 500 mm flat disc. In the study, it was determined that 35 mm vane height and 35 mm orifice diameter were optimum for distribution uniformity. The results indicated that fertilizer types did not have a significant effect on spreading homogeneity.

Kim *et al.* (2008) aimed to test and evaluate the performance of a pneumatic prototype fertilizer spreader they developed in their study. The CV of distribution uniformity in both transverse and longitudinal directions ranged from 11,2 to 13,1% and 2,9 to 15,3%, respectively. The overall distribution uniformity ranged from 81,9% to 97,4% at its working speed range with the response time ranging from 1,5 to 3,0 s. The result indicated that the discharge rates have a significant impact on distribution uniformity and uniformity was decreased with reducing discharge rates.

Tola *et al.* (2008) developed a granular fertilizer rate applicator with a monitoring system. They evaluated a fertilizer rate control system that uses a fertilizer flow sensor to deliver variable rate fertilizer with less error than conventional techniques. The pneumatic system was tested in order to develop a mechanical fertilizer rate adjustment system for managing fertilizer discharging rates automatically. The findings of this research indicated that such automatic implementation of different targeted fertilizer rates, consistent monitoring, and discharged rate management could be easily handled. The overall error of the system was 5% and response ranged from 0,95 to 1,90 s.

Yıldırım (2008) studied the effect of vane shape on distribution uniformity in single-disc rotary fertilizer spreaders. The study was conducted with different vane shapes: straight, composite, forward-curved-5, forward-curved-10, back-curved-5 and back-curved-10 shaped. His result indicated that the shape of the vane had a significant effect on fertilizer spreading uniformity. The best fertilizer uniform distribution he obtained was forward-curved-5 vane shape for both triple superphosphate and calcium ammonium nitrate.

EI-mageed *et al.* (2006) designed and tested a local spreader that can regulate the fertilizer flow rate depending on the forward speed. The study was carried out in two stages, taking into account two different conditions. The initial study was carried out with two different types of fertilizers (powder and granular), two different type of spinners (curved and straight), four different disc rotational speeds (360, 480, 600, and 750 rpm), and two spinners disc having two different numbers of vanes (4 and 6). The second study was conducted with two spinners with different diameters (200 and 300 mm), three blade angles (-10°, 0°, and +10°), and four feeding rates (100, 150, 200, and 250 kg/fed). According to the results obtained, it was revealed that 600 rpm disc rotation speed, 4 blades, 150 kg feed rate and -10° blade angle were the optimum factors for uniform distribution of the spreader.

Yıldırım (2006) tested a rotary disc type fertilizer spreader. The aim of the study was to determine the effects of various orifice sizes and vane numbers on fertilizer distribution uniformity. The research was conducted using different fertilizers (triple superphosphate and calcium ammonium nitrate), with different orifice opening diameters (30, 40, and 50 mm) and different number of vanes on a spreading disc (2, 4, 6, 8, 10, and 12). The result revealed that orifice opening diameter had a significant effect on fertilizer distribution uniformity. The CVs of combinations of different numbers of vane on a spreading disc and orifice opening diameters ranged between 11% and 34% for triple superphosphate, as well as 10% and 34% for calcium ammonium nitrate.

Fulton *et al.* (2005) studied two spinner types and two pneumatic spreaders with different application rates. The CV of the three applicators increased as the application rate increased. The two spined-disc and the pneumatic spreaders chosen because of their acceptable uniformity had a CV of 19% and 27%, respectively. The overall CV value of 20% was considered the optimum level of distribution uniformity.

Fulton *et al.* (2003) evaluated a tractor mounted variable rate granular fertilizer spreader. The study was conducted on three variable rate granular spreaders (two spinner spreaders and one pneumatic). Four different application rates (56, 112, 224 and 336 kg/ha) were considered for testing the study. The application rates were based upon observing at the maximum application rates for murate of potash fertilizer and fertilizer recommendations for wheat, corn, soybeans and alfalfa crops. The result indicated the application rates and speed of the spreader's had significant effect on spreading width. The three applicators performed three different spreading widths of 16, 12, and 18,3 m for different forward speeds of 20,5, 9,2, and 14,5 km/h respectively. The overlap patterns for the two spinner spreaders were more appropriate than the pneumatic one.

Fulton *et al.* (2001) developed a double disc model spinner spreader for optimum variable rate application. The spinner spreader was used at an application rate of 56 kg/ha and 168 kg/ha. The obtained results showed that lower application rates have a significant effect on the uniform distribution.

Sogaard and Kierkegaard (1994) investigated the technical parameters of centrifugal spreaders on fertilizer application uniformity (along the trajectory normal to the machine) with variable speed spinning discs. The dynamics of fertilizer particle spreading were influenced by the spreader's fixed and variable technical specifications, such as the spinning discs' rotation speed and position, the vane angle of the discs, the size of the discharge opening (shutter slide), the spot where each particle falls down onto the spinning disc, the discharge flow rate, the spreader's forward speed, and the working width.

Ziauddill and Roy (1997). Designed and developed a seed and fertilizer spreader for small – scale farmers. The research was conducted on urea fertilizer and wheat seed for different application rates and various speeds of the spreader. The result indicated that an increase in spinner disc speed, increases the effective spreading width (e.g. 425 rpm with 2,8 m, 470 rpm with 2,98, 515 rpm with 3,05 m, 560 rpm with 3,35 m, and 696 rpm with 3,75 m).

Fiala and Oberti (1999) conducted research on a centrifugal fertilizer spreader using three different types of fertilizers (urea, potassium chloride, and compound fertilizer) and three application rates (100, 200, and 300) with the spreader’s forward speed of 6,13 km/h. The study indicated that the change in application rate has a significant impact on distribution uniformity and 100 kg/ha was the optimum rate for fertilizer with errors of ± 10%.

Push-type Spreader

Krishnan *et al.* (2020) developed a disc type spreader with three wheels, two in the front and one in the back, to spread fertilizer uniformly over fallow land. The back wheel facilitated the movement of the machine in moving forward. Fertilizer was discharged from a hopper onto a disc, which was then distributed to the field uniformly.

Birajdar *et al.* (2018) designed and manufactured a simple manually operated fertilizer spreader with 50 cm rear width and 82,5 cm length. In a form of walk-behind spreader which was faster in pushing by farmers for distributing granular fertilizers. The findings showed that the distribution of fertilizers at different application rates were uniform and with respect to their desired width. The study demonstrated that the spreader can apply three different application rates in a uniform pattern.

Narode *et al.* (2015) developed a manual fertilizer spreader to achieve homogeneous fertilizer distribution. In the study, 50% and 80% reductions were obtained in effective field capacity (fertilizing time) and labor cost, respectively, compared to conventional methods.

The coefficient of variation (CV) is a percentage of standard deviation of data divided by mean of the data which is used as a ratio to evaluate variability and dispersion of data from the mean of application's value. Low CVs indicate a more uniform distribution pattern. The CV, skewing, as well as minimum and maximum values of the fertilizer distribution can also be determined in overlapped patterns. The values of skewing are expressed as the percentage of the particles on the left side of the pattern's centerline compared with the percentage particles on the right side of the pattern's centerline. The values of minimum and maximum are expressed as a percentage of the mean rate (Parish 2002).

MATERIALS AND METHODS

The material and methods which were used to conduct this research were described in this chapter. The aim of this chapter was to find out the physical properties of fertilizer and wheat as well as specification of the spreader that directly affect distribution uniformity.

Materıals

The ground driven, push type seed and fertilizer spreader

The type of the spreader used in this study was a manually operated single-disc type fertilizer spreader including hopper, spreading disc, mixer, gear box, orifice, feed control mechanism, hand lever, push handle and wheels (Figure 4).

(a) (b)

Figure 4. Manually operated push type fertilizer spreader. (a) Front view; (b) Side view

The manually operated single-disc seed and fertilizer spreader, which was simple in structure, portable, driven manually and light weight for using was considered in this study. Figure 5 is shown the technical drawing view of the spreader. The technical specifications of the spreader are also given in Table 1.

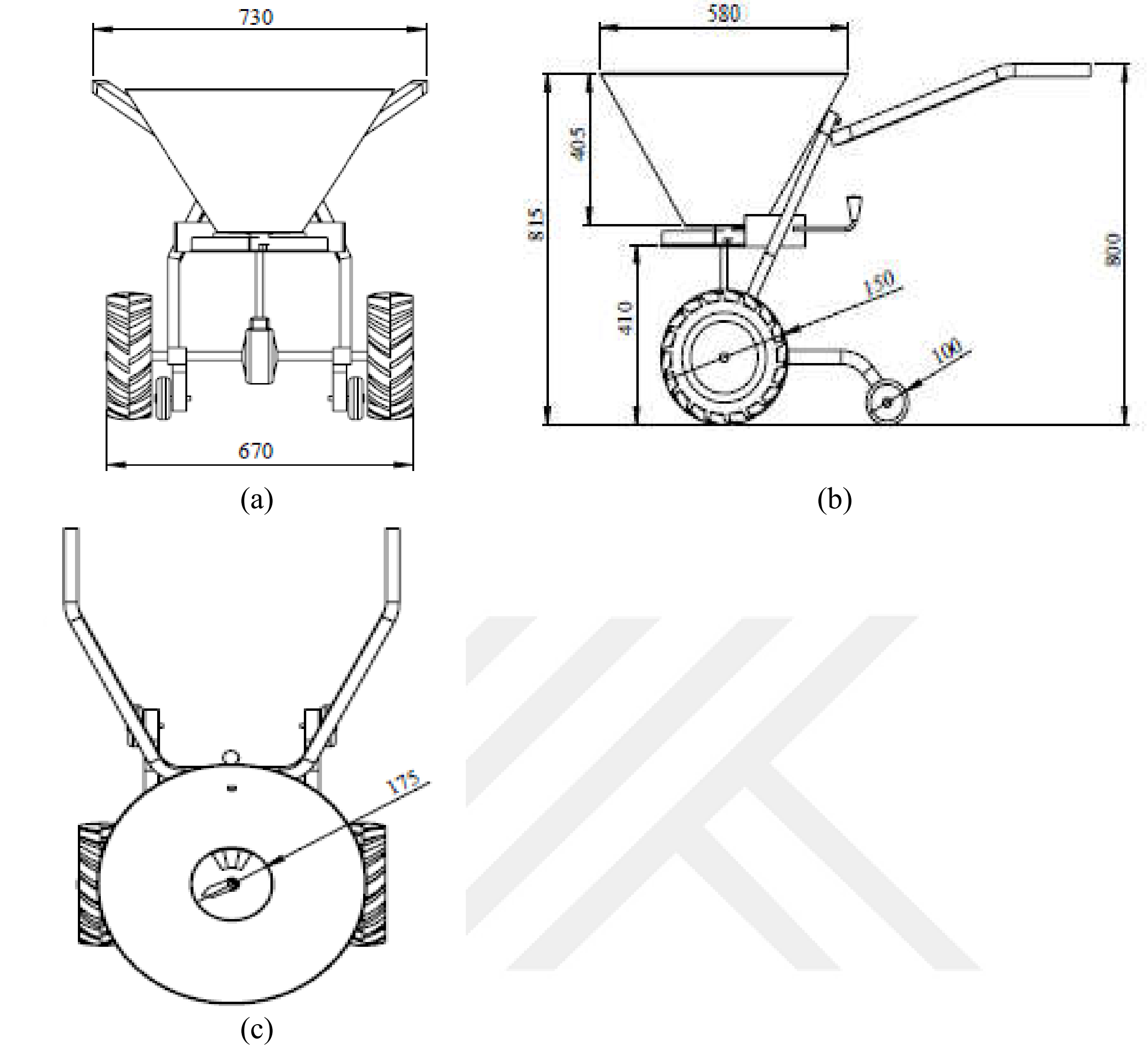


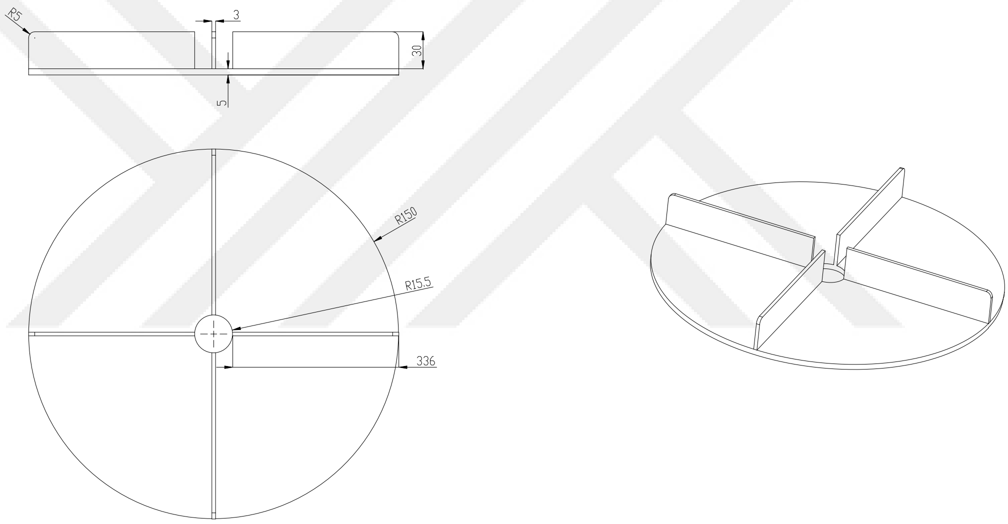
Figure 5. Technical drawing of the spreader with some dimensions. (a) Front side; (b) Left side and (c) Up side views

Table 1. Technical Specification of Manually Operated Spreader

Technical specification	Values
Spreader type	Centrifugal
Overall length (mm)	730
Overall width (mm)	670
Overall height (mm)	815
Total weight (kg)	15
Hopper capacity (liter)	40
Upper diameter of hopper (mm)	580
Bottom diameter of hopper (mm)	175
Spreader disc diameter (mm)	300
Numbers of vane on the disc	4
Number of wheels	4
Diameter of front wheels (mm)	300
Diameter of rear wheels (mm)	100
Wheel/spreader disc transmission rate	1/4
Spreading height above ground level (mm)	410

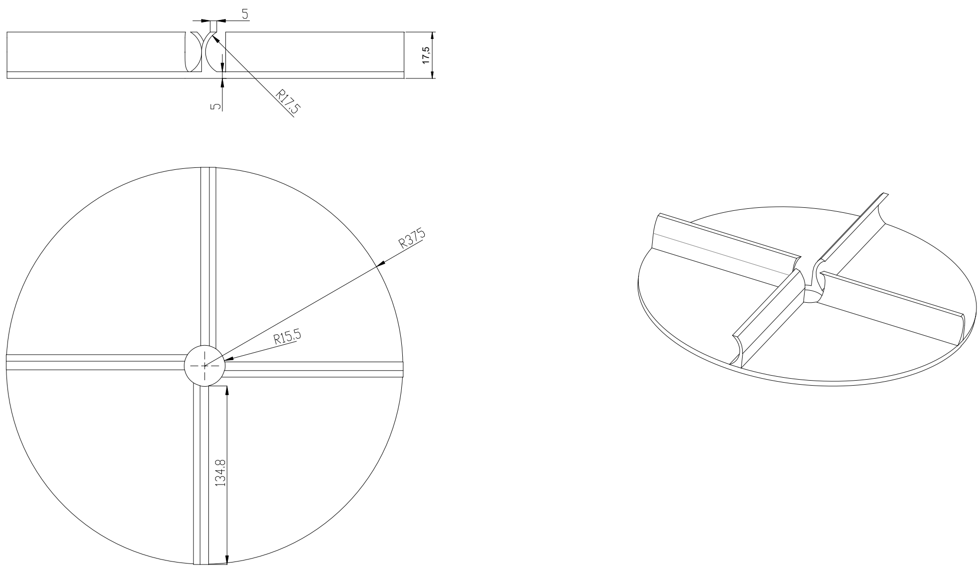
The spreader's hopper, where the fertilizer and seeds were placed, is made of 2 mm thick metal sheet in the shape of a funnel. The cone-shaped structure of the hopper facilitated the continuous flow of fertilizer and seed to the bottom of the hopper's orifice opening. The size of the orifice at the bottom of the hopper was used to determine the application rate at which fertilizer and seed were discharged. Fertilizer and seed flowing from the orifice onto the dispersing disc are then spreaded by rotating vanes fixed on the surface of the disc. With this spreader, the desired fertilizer and seed application rate can be adjusted with the orifice opening.

A mixer with horizontal revolving axis was mounted on the spreading disc shaft and used in order to prevent clumping of fertilizer and seed over the orifice opening and facilitate flow. Since the profile shape of vane and number of vanes on the disc may affect distribution uniformity, L and C profile shape of vanes were used in the experiments as shown in Figure 6 and Figure 7.



(a) (b)

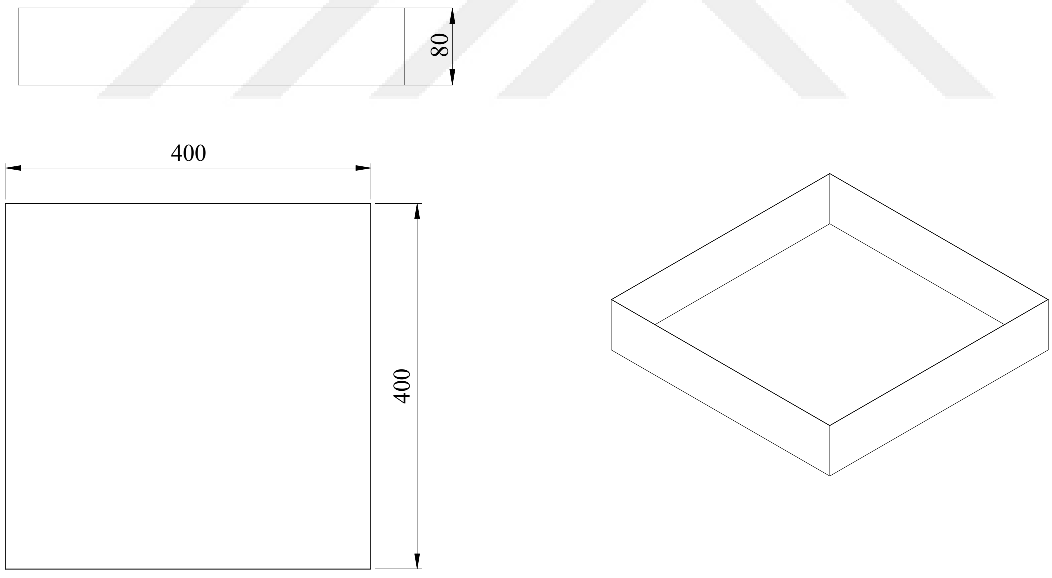
Figure 6. L profile shape of vane on the disc. (a) Front and top views; (b) Isometric view



(a) (b)

Figure 7. C profile shape of vane on the disc. (a) Front and top views; (b) Isometric view

Collection trays placed across the spreading width in fertilizer and wheat spreading experiments and the partitions used in the trays are shown in Figure 8 and Figure 9.



(a) (b)

Figure 8. Collection tray. (a) Front and top views; (b) Isometric view

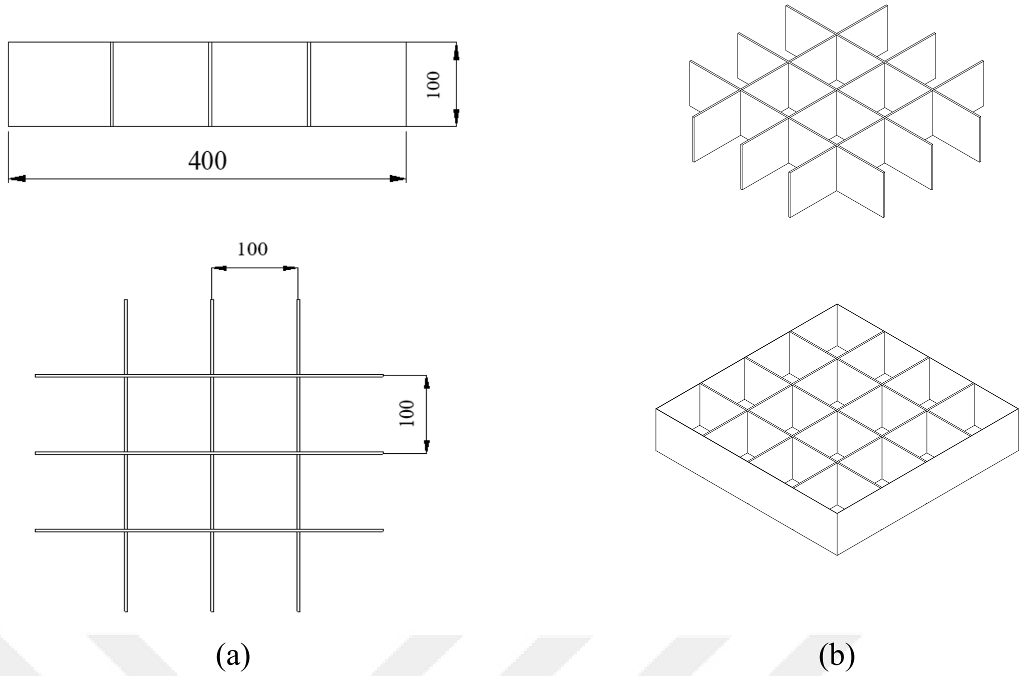


Figure 9. Collection tray compartments. (a) Front and top views; (b) Isometric view

The rotational movement of the wheels was transmitted to the spreader disc at a ratio of 4/1 by changing its direction 90^0 through the gearbox located in the middle of the wheels' axle. A proximity speed sensor (Digital speedometer, Akozonsgv59otdi7-01, Akozon, China) was used to monitor the spreader's forward speed by measuring its wheel rotational speed (Figure 10).

Figure 10. Proximity speed sensor for monitoring the spreader's forward speed

Moisture content is one of the important physical properties of seeds and fertilizers. It is crucial for farmers to know about the minimum and maximum amount of required moisture content in specific types of seeds or fertilizers which affects the quality of spreading the seeds and fertilizers. Not exceed the moisture levels in fertilizers or seeds at the manufacturer recommended levels. Traditionally indirect moisture content analysis was done via gravimetric or evaporation methods (Potter *et al.* 2010). These techniques depicted more practical challenges that made extremely accurate and appropriate determinations of moisture content issues as well as restricted their usage for specific applications. Therefore, measuring the moisture content is crucial for analysis. Different analytical approaches were implemented for this purpose, which make changes in their correctness, cost, and simplicity of their working. To this end, an oven (NUVE FN 120 oven, Nuve Sanayi Malzemeleri, Ankara, Turkey) was used for measuring moisture content of wheat and fertilizer (Figure 11).

Figure 11. Oven used for measurement of wheat and fertilizer moisture content

Physical properties of fertilizer and wheat

In the research, 46% nitrogen fertilizer and Yıldırım variety bread wheat were used as material. Physical properties of the fertilizer and wheat seed, such as bulk density, angle of repose, and moisture content were listed in the Table 2.

Table 2. Physical Properties of Fertilizer and Wheat Used in The Experiments

Physical properties	**Urea fertilizer**	**Wheat**
Bulk density (kg/m^3)	809	803
Moisture content (%)	0,45	12,48
Angle of repose (^{0})	30,96	24

Methods

This experiment was conducted using a commercially available ground-driven, push-type fertilizer spreader manufactured by Rondini Company (Novellara RE, Italy), which its technical specification was given in the material section.

The coefficient of variation was used to assess the seed and fertilizer distribution uniformity of the spreader performance.

Determination of physical properties of wheat and fertilizer

The bulk density of wheat and fertilizer were determined using a metal tray with 1000 cm^3 volume. Fertilizer and wheat were carefully poured into the tray separately, after fulfilling was achieved, excess material was gently removed from the top of tray using a knife and then measured with the scale (Figure 12).

The volume weight of the material was found by subtracting the weight of the empty tray from the total weight of the sample material and the tray weighed using a precision scale. The bulk density of wheat and fertilizer were eventually calculated using the following equation.

$$BD = SW/V \qquad (1)$$

Where:

BD : Bulk density, $g\ cm^{-3}$

SW : Weight of the sample, g, and

V : Volume of metal tray.

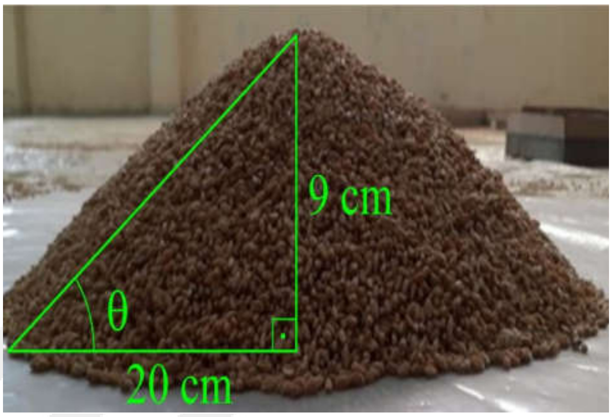
(a) (b)

Figure 12. Bulk density of experiment materials (a) Fertilizer; (b) Wheat

The angle of repose utilized as a standard of the flowability of granules or powders. It is also a rapid technique that provides an indication of the flowability of granular particles. The most frequent technique is to possess the granule freely poured via a funnel, the granular particle forming cone (Ferreira *et al.* 2021).

To determine the repose angle of fertilizer and wheat particles, the funnel approach as a common technique was used to achieve an optimal outcome. Fertilizer and wheat were slowly poured over a horizontal surface from the funnel, forming a cone on the surface (Figure 13) and the formed repose angle of fertilizer and wheat then was measured (Önal 1987).

(a)



(b)

Figure 13. Repose angle of experiment materials (a) Fertilizer; (b) Wheat

Repose angle of applications was determined using the following equation:

$$\theta = \tan^{-1}(2h/d) \quad (2)$$

Where:

θ : Angle of repose, degree,

h : Height of the cone, cm, and

d : Base diameter of the cone, cm.

The oven dry method was used to determine the moisture content of fertilizer and wheat. While the moisture content of fertilizer was determined using the oven drying method at 105 ^{0}C for 16 hours (Önal and Tozan 1984), the moisture content of wheat was determined by drying in the oven at 130 ^{0}C for 19 hours (Ahmed at el. 2015). The following equation was used to determine the moisture content.

$$Wd = \frac{W-d}{d} * 100 \quad (3)$$

Wher;

W : Wet weight of fertilizer and wheat, g and

d : Dry weight of fertilizer and wheat, g.

Particle sizes vary in granular chemical fertilizers. It is important to determine the particle size distribution, which has a significant effect on the spreader's performance. In order to determine the distribution of the fertilizer particles used in the study, sieve analysis was performed using sieves with a hole diameter of <1,40 mm, 1,40 – 1,60 mm, 1,60 – 1,70 mm, 1,70 – 2 mm, 2 – 2,36 mm, 2,36 – 2,50 mm, 2,50- 2,80 mm, 2,80 – 3,35 mm, 3,35 – 3,50 mm, 3,50 – 4 mm and 4 – 4,75 mm. The analysis was carried out in three repetitions of 100 grams each, using the vibration device (Figure 14) at a frequency of 10 Hz and for 5 minutes (Hofstee 1993). As a result of vibration, the remaining fertilizer on the sieves was weighed. The result of sieve analysis is given in Table 3.

The amount of fertilizer (Xn) on each sieve was calculated as the percentage of mass value of the fertilizer via the following equation (Önal 2006).

$$Xn = \frac{\mathbf{Mn}}{\mathbf{Mt}} * \mathbf{100} \tag{4}$$

Where;

mn : is the mass remaining on the sieve

mt : mi+mi+……. +mi

Xn : is the mass percent value of the fertilizer remaining on the n sieve.

Figure 14. Vibrating sieve used for the fertilizer particle size analysis

Table 3. Sieve Analysis of Urea Fertilizer

Sieve size	Fertilizer rate (%)			
	R1	R2	R3	Mean
1,4	0,35	0,01	0,58	0,31
1,40 – 1,60	1,18	0,38	1,32	0,96
1,60 – 1,70	0,09	0,03	0,06	0,06
1,70 – 2	6,82	5,13	8,12	6,69
2 – 2,36	42,45	40,78	39,13	40,79
2,36 – 2,50	4,07	5,31	9,14	6,17
2,50- 2,80	16,81	18,13	12,31	15,75
2,80 – 3,35	17,45	16,63	15,7	16,59
3,35 – 3,50	2,79	2,52	3,34	2,88
3,50 – 4	9,05	10,67	9,74	9,82
4 – 4,75	0,13	0,01	0,01	0,05

Weighted average diameter (WAD) values of fertilizers were calculated by using the results of sieve analysis in the following equation.

$$WAD = \Sigma nidi / \Sigma ni \quad (5)$$

In equation,

ni : Amount of fertilizer remaining in the sieve gap g.

di : Sieve gap mean diameter value, mm.

Working principles of the manually operated spreader

The manually operated spreader performs different spreading pattern shapes such as M-shaped patterns, W-shaped patterns, Triangular patterns and Trapezoidal patterns (Figure 15). Triangular and trapezoidal patterns are best effective since they can offer a uniform distribution when appropriately overlapped. The M-shaped patterns and W-shaped patterns are familiar (Parish 1996).

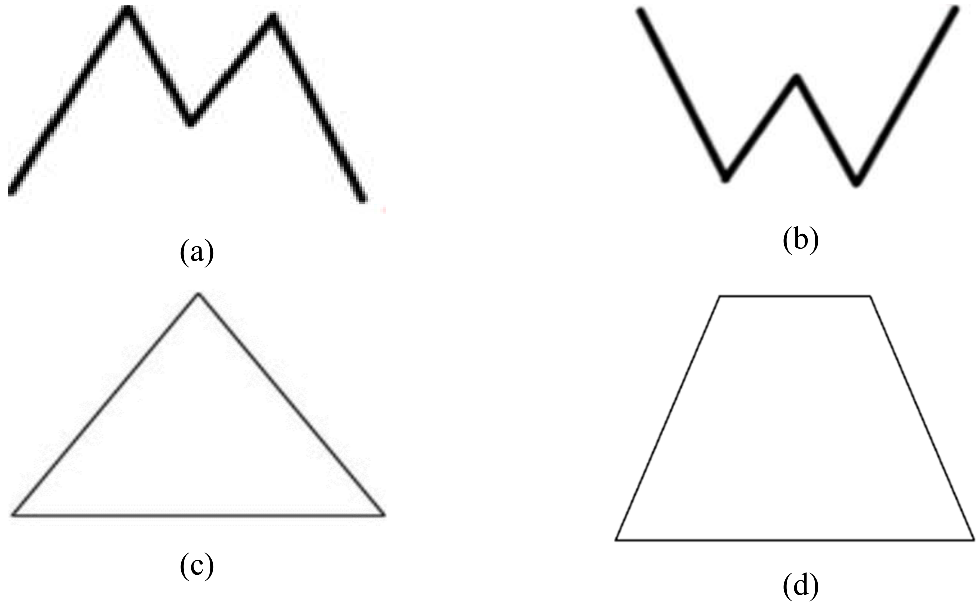


Figure 15. The shape of spreading patterns. (a) M-shaped; (b) W-shaped; (c) Triangular; (d) Trapezoidal pattern

The manually operated spreader was tested for evaluating its performance in the laboratory. The experiments were conducted at the laboratory of Ataturk University Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. The spreader hopper is filled throughout the test. Experiments were conducted with the spreader hopper filled up to the level of 50% and 75% of the capacity as suggested in the ASAE S341.3. Standards (Anonymous 2009). The hopper was divided and marked into four equal splitted capacities. The experiment was carried out using the spreader filled by 75% of capacity of its hopper. For receiving accurate outcomes, the spreader was started and stopped 3 m before and 3 m after the trial area. The following factors were considered throughout the experiment to evaluate the performance of the spreader.

Forward speed of the spreader, which was considered as a walking speed of the operators, was measured from the period needed for the spreader to travel the distance of 20 m on the experiment side. A digital display type proximity speed sensor was used to monitor the spreader's forward speed. Three different spreader's forward speed were considered consequently to evaluate the ergonomic suitability of forward speed of the spreader for humans. Therefore, 1,75 m/s of forward speed was the optimum selected forward speed which represents typical human speed in the field.

Determination of distribution patterns

The spreader’s effective spread width was measured according to the ASAE 341,1 Standards (Anonymous 2009). The effective spread width was determined via 400×400 mm collecting trays placed to the left and right side of the walking aisle which provided enough space for the spreader wheels to pass.

ASAE and TS standards were used to determine spreader's distribution patterns (Anonymous 2009; Anonymous 2021c). Collection trays were used to capture fertilizers and seed during uniformity distribution performance assessment. The Collection trays were considered to be 400 × 400 mm to collect the seed and fertilizer. During spreading, the spreader was started and stopped 3 m before and 3 m after the collection trays' line respectively. There were 16 collection trays that were arranged in a horizontal line, 8 trays on the right side, 8 on the left side. Collection trays were of sufficient size to collect samples, from one pass of the spreader. Width of each collecting tray (measured perpendicular to the direction of travel) was not to exceed 10% of the anticipated effective swath width (Anonymous 2009). To decrease the possibility of particles ricocheting out of the trays, each tray was divided into compartments. The size of each compartment was 100 x 100 mm with 100 mm height. Figure 16 shows the wheels of the spreader passing through the space between the left and right side of the trays. The value of space between left and right side of the trays where the spreader used to be passed was calculated using interpolation techniques as follows:

$$A= \frac{B+C}{2} \tag{6}$$

Where;

A, is the mean weight of fertilizer/wheat in the trays denoted 1 on the left side of the path denoted 0 and the trays denoted 1 on the right side of path denoted 0 where the spreader used to be passed.

B, is the weight of fertilizer/wheat in the trays denoted 1 on the left side of path denoted 0.

C, is the weight of fertilizer/wheat in the trays denoted 1 on the right side of path denoted 0.

Figure 16. Passing between collection trays during experiments

After each pass of the spreader, fertilizer and wheat distributed to the trays were weighed separately with scale and then means as well as the deviations from the mean were determined (Özmerzi 1974).

$$DFM = (k \times 100/\ GT) \times G_1 \qquad (7)$$

Where:

DFM : Deviations from the mean (%)

k : Number of trays were used (pieces)

GT : The amount of fertilizer was collected from all trays (g)

G_1 : The amount of fertilizer was collected from each tray (g)

The coefficient of variation (CV) is a percentage of standard deviation of data divided by mean of the data which was used as a ratio to evaluate variability and dispersion of data from the mean of application's value. Low CVs indicate a more uniform distribution pattern. Distribution graphs were drawn using the obtained data for each treatment combination.

Determination of the spreading width

ASABE Standard (Anonymous 2009) and ISO (International Organization for Standardization) standard 5690-1 (Anonymous 1985) defines applying coefficient of variance (CV) as considered in equation 3,8, 3,9 and 3,10 to demonstrate spreading uniformity. Various adjoining passes were applied to calculate coefficient of variance (CV) measured overlap shapes.

$$X= \Sigma\ Xi/N \qquad (8)$$

$$SD = \{\ [(\Sigma xi - X)^2]/\ (N - 1)\}^{1/2} \qquad (9)$$

$$CV = \text{standard deviation x } 100/\ X \qquad (10)$$

Where,

X = arithmetic mean,

Xi = collected sample mass for every tray position for an overlap swath,

N = number of collection trays.

In order to determine the measured overlap shape for every spreading width, trial masses from measured overlap swaths were collected for every collecting tray. In general, there are two ways by which overlap shape is produced: (1) one-direction application and (2) progressive application (Anonymous 2009). One direction application technique encompasses consecutive adjacent swaths which are finished in the similar direction of travel. The progressive system comprises back and forth traverses among adjacent passes throughout granular application. The effective spreading width is evaluated by considering on the left and right side of the center line where the using rate is one partial at the center line and providing the optimum uniform complete application rate (Anonymous 2009). Coefficient of variance (CV) values could also be applied to evaluate the effective spreading width. The values of the coefficient of variation are calculated for measured overlapped distributed spreading data and the major distribute width related with the lowest CV is regarded as such effective spread width. Graphical view of a single pass creating a simulated overlap distribution pattern is shown in Figure 17 (Anonymous 2009).

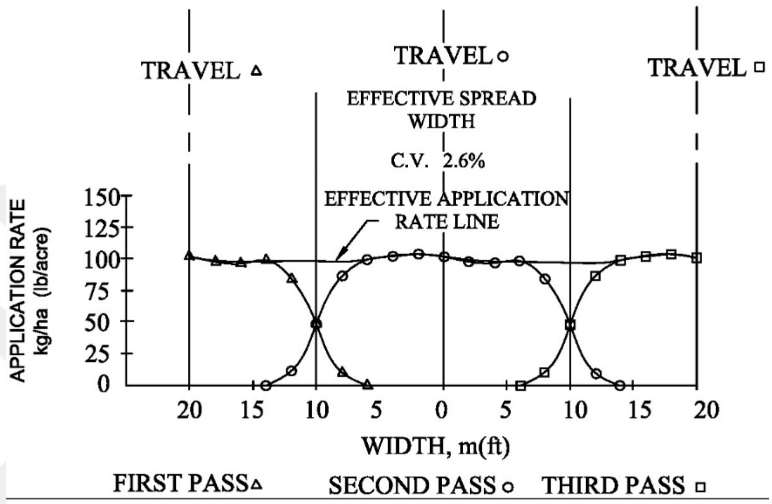


Figure 17. Graphical view of a single pass creating a simulated overlap distribution pattern (Anonymous 2009)

Mass of the granules collected in trays transverse the swath was changed into application rate (kg/da) and was computed using the mean weight of the particles gathered in trays for every crosswise location. The progressive technique (Anonymous 2009) was applied to create simulated overlap shapes. The mean, standard deviation and coefficient variances (CV) were computed for the simulated overlap passes.

The coefficient of the variation (CV) values is calculated at various distribution widths applying the simulated overlap data and then schemed against the various different distribution widths related to the lowest CV or the CV at the highest distribution width crossing the CV = 15%.

RESULTS AND DISCUSSIONS

Performance evaluation of the ground-driven, push type seed and fertilizer spreader were carried out using two types of profile shape vane (L and C profile shape), three forward speeds, and three fertilizer/seed application rates. These parameters were used to assess the performance of the spreader at various levels.

In the experiment, the data of a total number of 16 collecting trays in horizontal line were collected and considered for analyzing of both wheat and fertilizer with different application rates i.e. 21,26, 26,58, 31,91 kg/da for wheat, and 13, 20, 26 kg/da for fertilizer via a L and C profile shape of vanes at different forward speeds i.e. 1,25, 1,5, 1,75 m/s. The distribution patterns of each combination for both wheat and fertilizer were studied on the basis of the experiments.

Distribution Patterns of the L Profile Shape of Vane

Distribution patterns for 21,26 kg/da of wheat and 13 kg/da of fertilizer application rates at a forward speed of 1,25 m/s are given in Figure 18. As it is depicted on Figure 18 for both application of wheat and fertilizer, the deviation from the mean is minimum and close to 0% for the trays number 6, 7, and 8 on the left side as well as the trays number 7 and 8 on the right side of the spreader passage from the center of its path. This could be because of the distance of these collecting trays from the spreader. The deviation from the mean decreases as the trays get away from the spreader. According to this, the deviation from the mean is maximum and close to 220% for the trays number 1 and 2 on the left side as well as the trays number 0, 1, and 2 on the right side for the application of wheat, and for the application of fertilizer it was maximum and close to 380% for tray number 1 on the right side of the spreader passage from the center of its path. The deviation of fertilizer from the mean is two times more than the ones from wheat. This may be due to the physical properties of wheat and fertilizer.

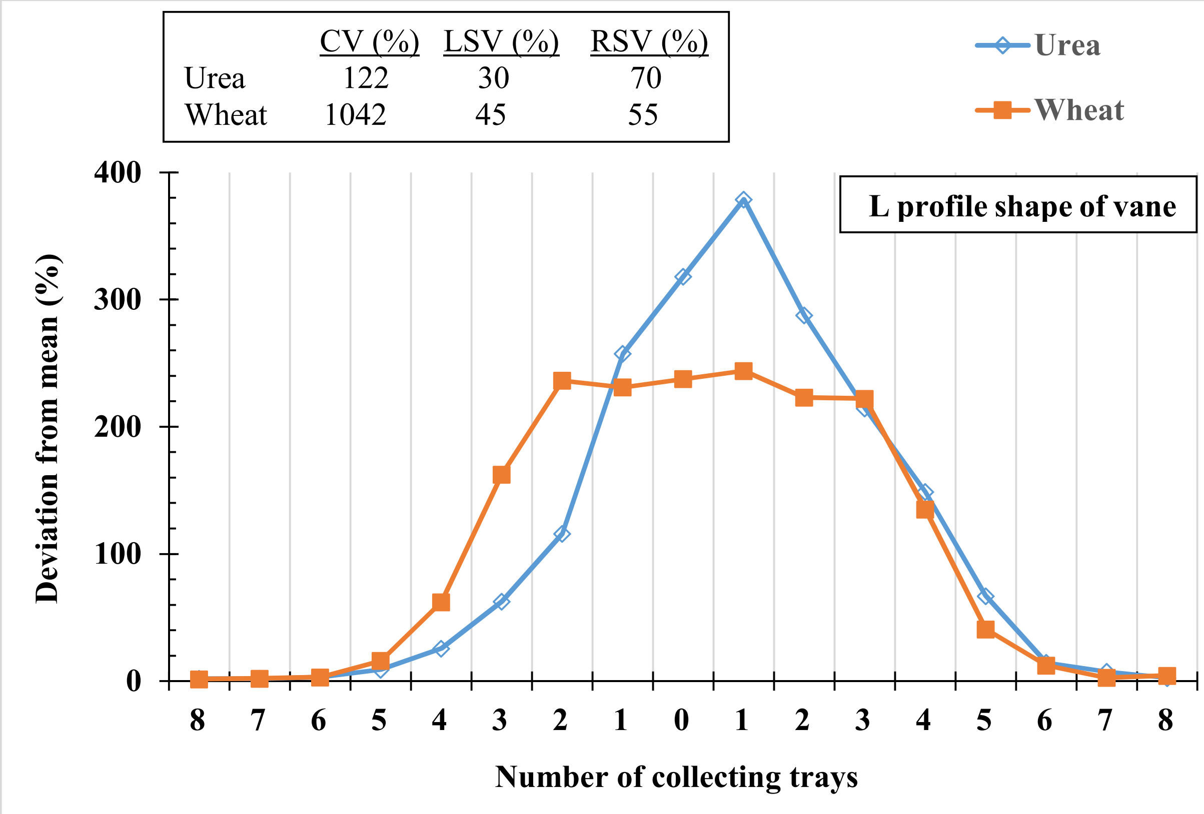


Figure 18. The distribution patterns obtained in the combination of 1,25 m/s forward speed, 21,26 kg/da wheat and 13 kg/da fertilizer application rates

Distribution patterns for 21,26 kg/da of wheat and 13 kg/da of fertilizer application rates at a forward speed of 1,5 m/s are given in Figure 19. As it is depicted on Figure 19 for both wheat and fertilizer, the deviation from the mean for both fertilizer and wheat are minimum and close to 0% for tray numbers 5, 6, 7, and 8 on the left side as well as the trays number 7 and 8 on the right side of the spreader passage from the center of its path. Also, the deviation from the mean is maximum and close to 250% for the trays number 1 on the left side as well as the trays number 0, 1, and 2 on the right side for the application of wheat, and for the application of fertilizer it was maximum and close to 300% for tray number 1 on the right side of the spreader passage from the center of its path. When compared to the previous combination, as forward speed increased from 1,25 to 1,5 m/s, the deviation from the mean on both sides was changed by ±7% for fertilizer. However, for wheat, the deviation from the mean was changed by ±1% on both sides.

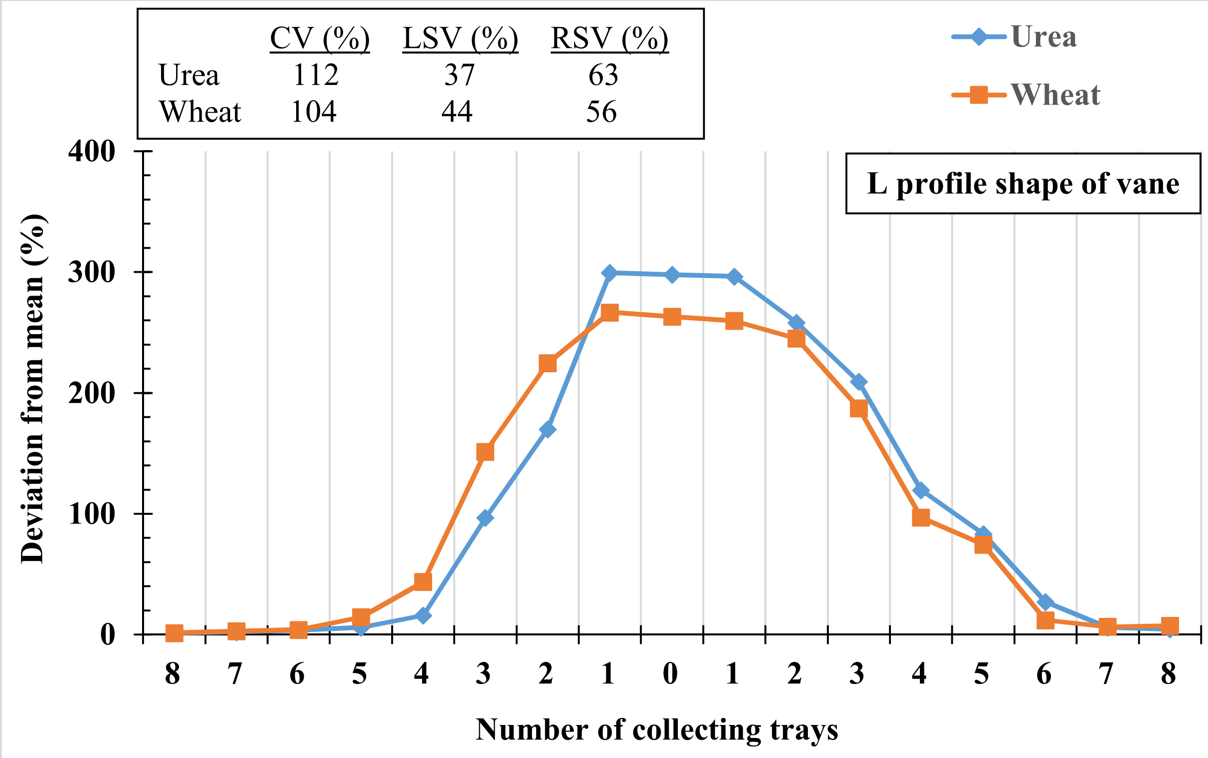


Figure 19. The distribution patterns obtained in the combination of 1,5 m/s forward speed, 21,26 kg/da wheat and 13 kg/da fertilizer application rates

Distribution patterns for 21,26 kg/da of wheat and 13 kg/da of fertilizer application rates at a forward speed of 1,75 m/s are given in Figure 20. As it is depicted on Figure 20 for both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 8 on the right side of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 220% and 300% for the trays near the spreader for wheat and fertilizer respectively. The fertilizer's deviation from mean is higher than the wheat's one. The deviation from the mean for fertilizer on the left side was 37% and for the right side was 63%, while for wheat on the left side was 44% and the right side 56%. Comparison of Figure 19 and Figure 20 revealed that while the spreader forward speed increased from 1,5 to 1,75 m/s, the deviation from the mean was not significantly changed for both sides and the change was +1% for fertilizer. However, for wheat, the deviation from the mean on the left side was increased from 44% to 56% and the right side decreased from 56% to 44%. This indicated that the increase in forward speed results in +12% the deviation from the mean for both sides.

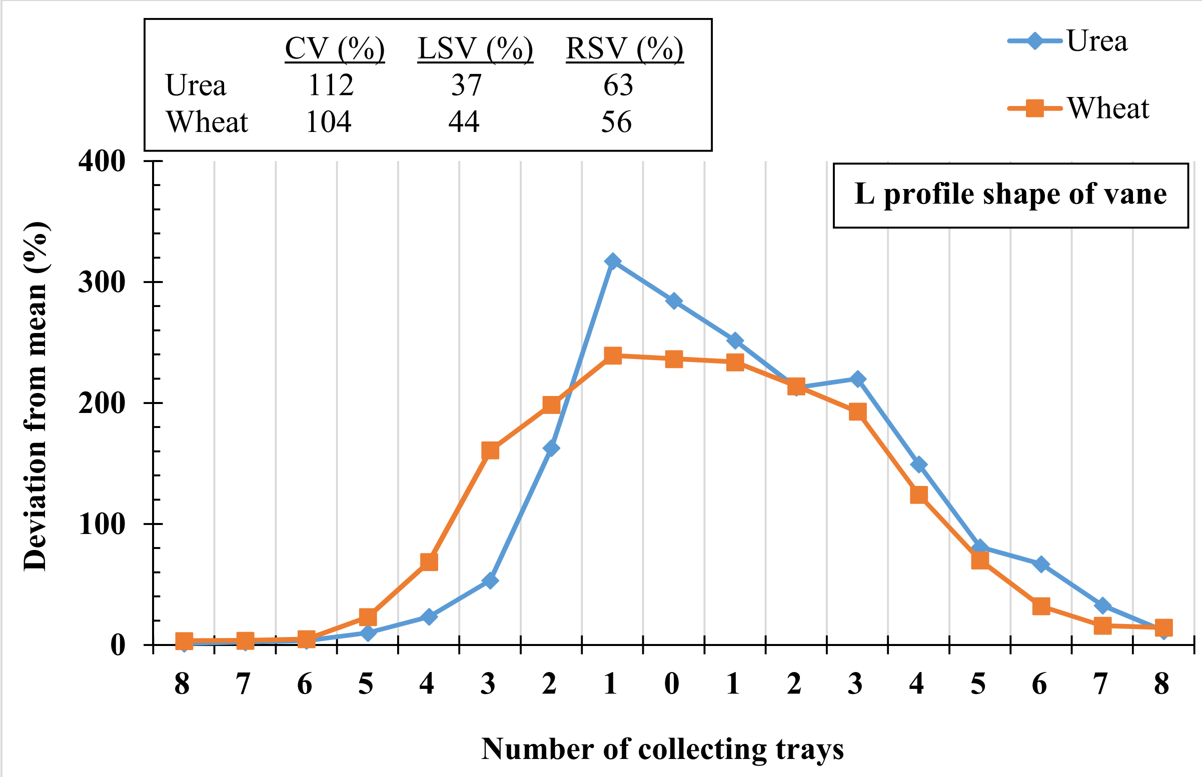


Figure 20. The distribution patterns obtained in the combination of 1,75 m/s forward speed, 21,26 kg/da wheat and 13 kg/da fertilizer application rates

Figure 21 shows the distribution pattern of wheat and fertilizer application rates 26.58 and 20 kg/da respectively, and 1,25 m/s forward speed conditions. As seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. Furthermore, the deviation from the mean is maximum and close to 220% and 350% for the trays near the spreader for wheat and fertilizer respectively. For fertilizer, when the application rate increased from 13 kg/da to 20 kg/da, the deviation from the mean on both the right and left sides is approximately 50%. Although the overall fertilizer distribution was not uniform and had 50% deviation from the mean, the spreader distributed equal distribution to both sides. However, for wheat, when the application rate increased from 21,25 to 26,58 kg/da, the deviation from the mean was 56% for the left side and 44% for the right side. This indicated that the increase in wheat rate results in unequal distribution of application for both sides.

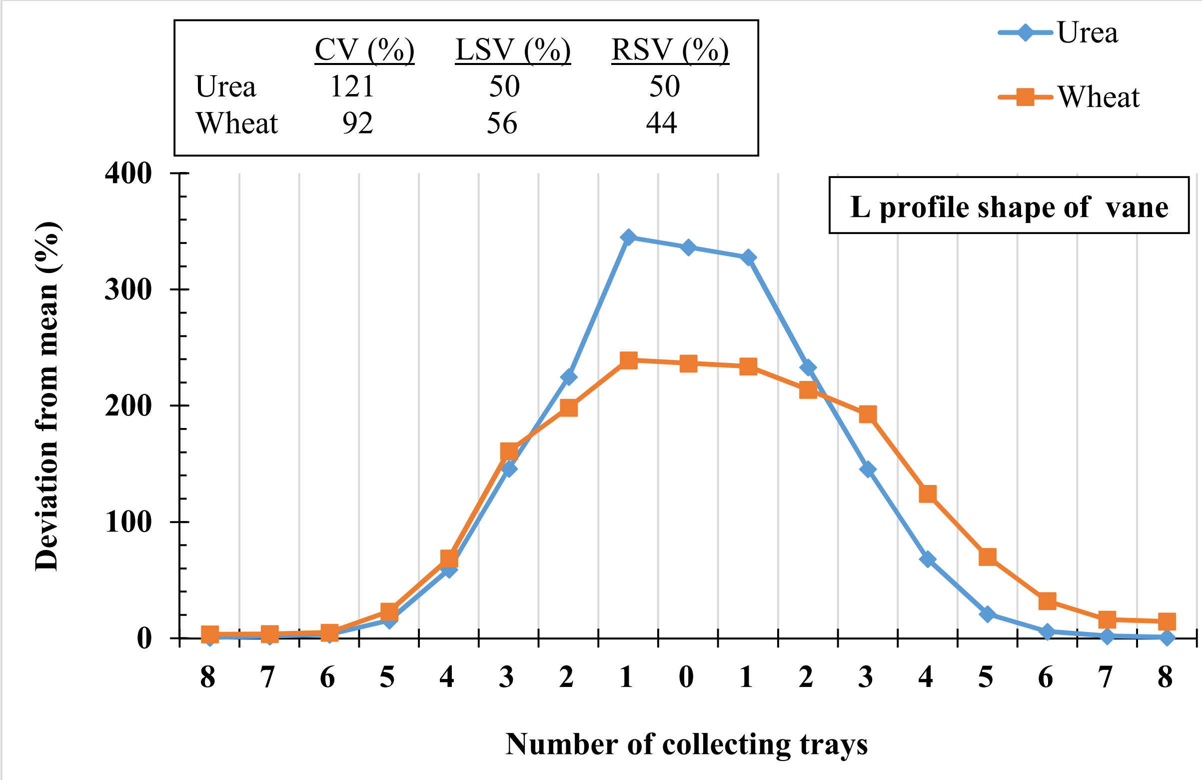


Figure 21. The distribution patterns obtained in the combination of 1,25 m/s forward speed, 26,58 kg/da wheat and 20 kg/da fertilizer application rates

Figure 22 shows the distribution pattern of wheat and fertilizer application rates of 26.58 and 20 kg/da respectively, and 1,5 m/s forward speed conditions. As seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. The deviation from the mean is maximum and close to 260% and 380% for the trays near the spreader for wheat and fertilizer respectively. The deviation from the mean on the left side of the spreader is 58% and on the right side is 42% for fertilizer application and 43% on the left side and 57% on the right side of the spreader for wheat application. Figure 21 and Figure 22 reveal that while the forward speed increased from 1,25 to 1,5 m/s, the deviation from the mean was significantly changed for both sides and the change was ±8% for both the right and left side of the spreader for fertilizer application. However, for wheat, the deviation from the mean was not significantly changed for both sides and the changes were limited with ±2%.

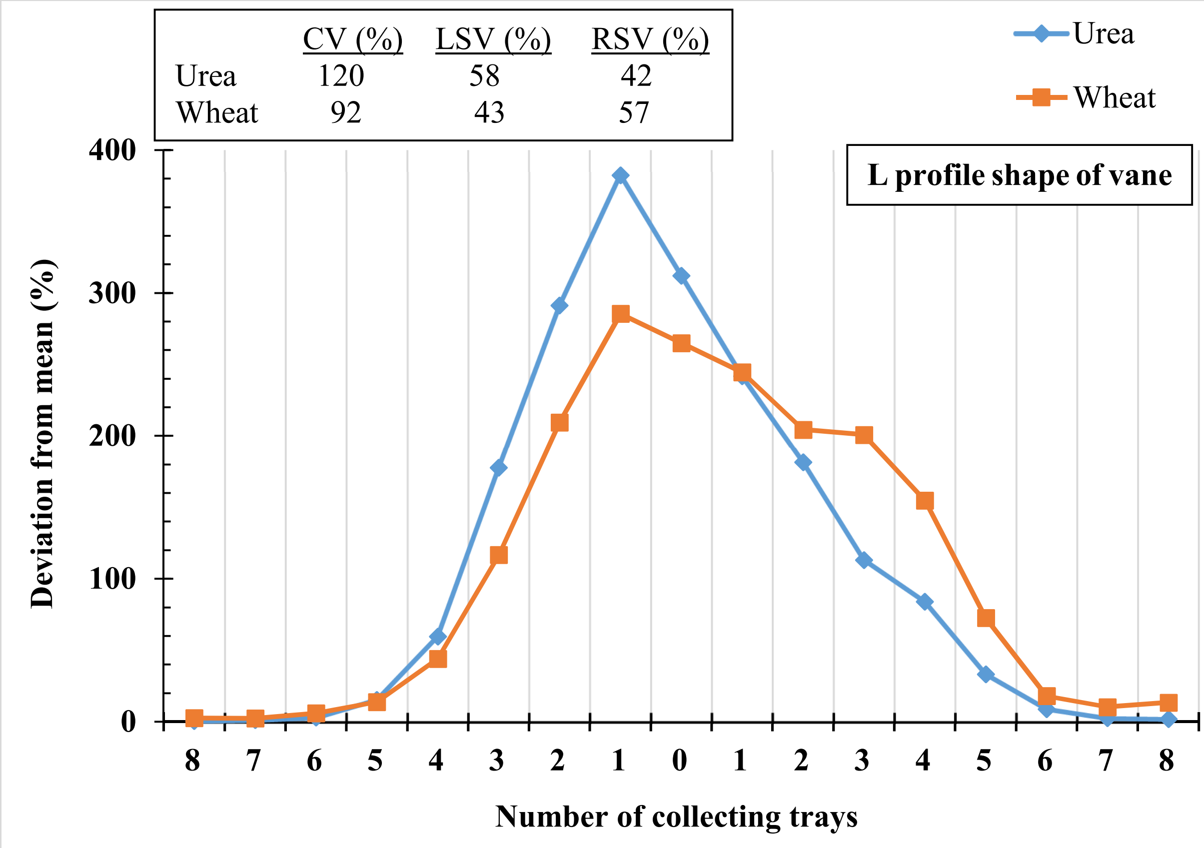


Figure 22. The distribution patterns obtained in the combination of 1,5 m/s forward speed, 26,58 kg/da wheat and 20 kg/da fertilizer application rates

Distribution patterns for 26,58 kg/da of wheat and 20 kg/da of fertilizer application rates at a forward speed of 1,75 m/s are given in Figure 23. As seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray's numbers 6, 7, and 8 on the left side as well as the trays number 7 and 8 on the right side of the spreader passage from the center of its path. Moreover, the deviation from the mean is maximum and close to 220% and 400% for the trays near the spreader for wheat and fertilizer respectively. The fertilizer's deviation from mean is two times more than the wheat's one. The deviation from the mean on the left side of the spreader is 60% and on the right side is 40% for fertilizer application. Whereas, for wheat the deviation from the mean on the left side is 53% and the right side 47%.

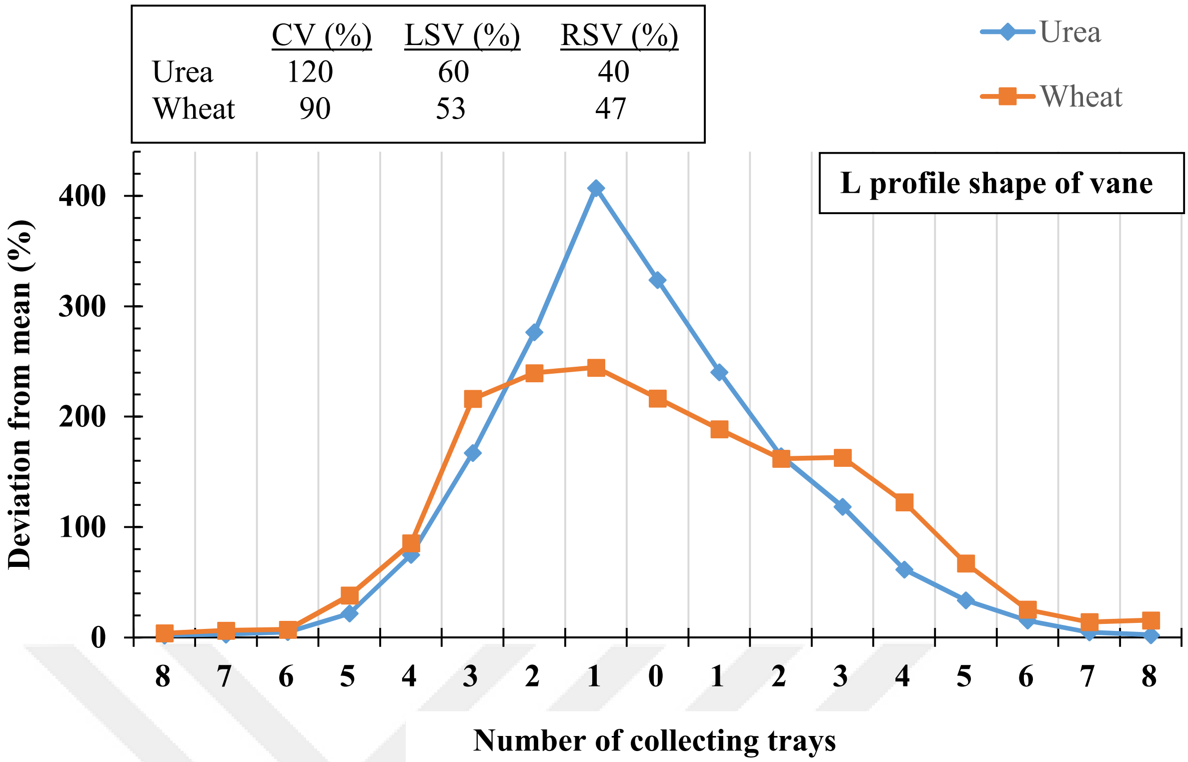


Figure 23. The distribution patterns obtained in the combination of 1,75 m/s forward speed, 26,58 kg/da wheat and 20 kg/da fertilizer application rates

Figure 24 shows the distribution pattern of wheat and fertilizer application rates of 31,91 and 26 kg/da respectively, 1,25 m/s forward speed conditions. As it is shown in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for tray numbers 6, 7, and 8 on the left side as well as the trays number 7 and 8 on the right side of the spreader passage from the center of its path. The deviation from the mean is maximum and close to 240% and 400% for the tarys near the spreader for wheat and fertilizer respectively. The fertilizer's deviation from mean is higher than the wheat's one. The deviation from the mean on the left side and the right side is 59% and 41% respectively for fertilizer. While the left side and right deviation is 47% and 53% respectively for wheat.

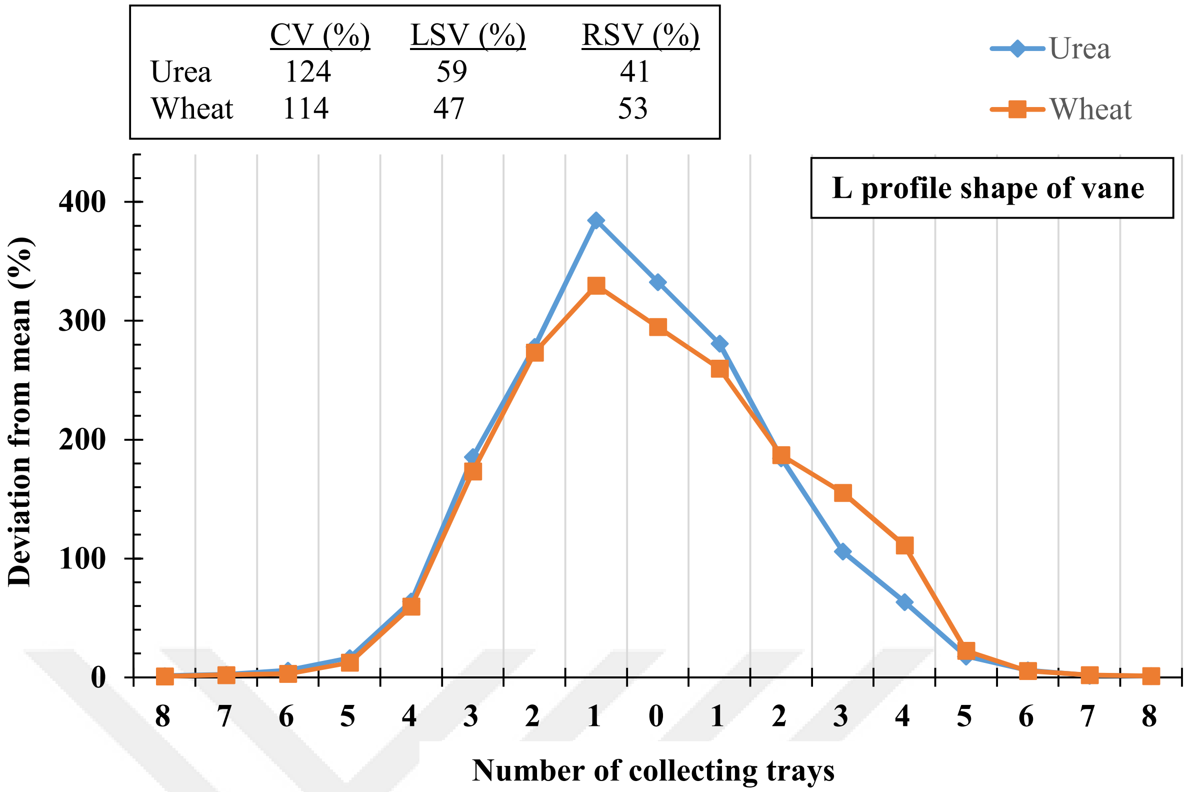


Figure 24. The distribution patterns obtained in the combination of 1,25 m/s forward speed, 31,91 kg/da wheat and 26 kg/da fertilizer application rates

Distribution patterns for 31,91 kg/da of wheat and 26 kg/da of fertilizer application rates at a forward speed of 1,5 m/s and are given in the Figure 25 For both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 5, 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. The deviation from the mean is maximum and close to 280% and 380% for the trays near the spreader for wheat and fertilizer applications respectively. The fertilizer's deviation from mean is higher than the wheat's one. The deviation from the mean on the left side of the spreader is 62% and the right side is 38% for fertilizer application. Whereas, for wheat, the deviation from the mean on the left side of the spreader is 52% and the right side is 48% (Figure 25).

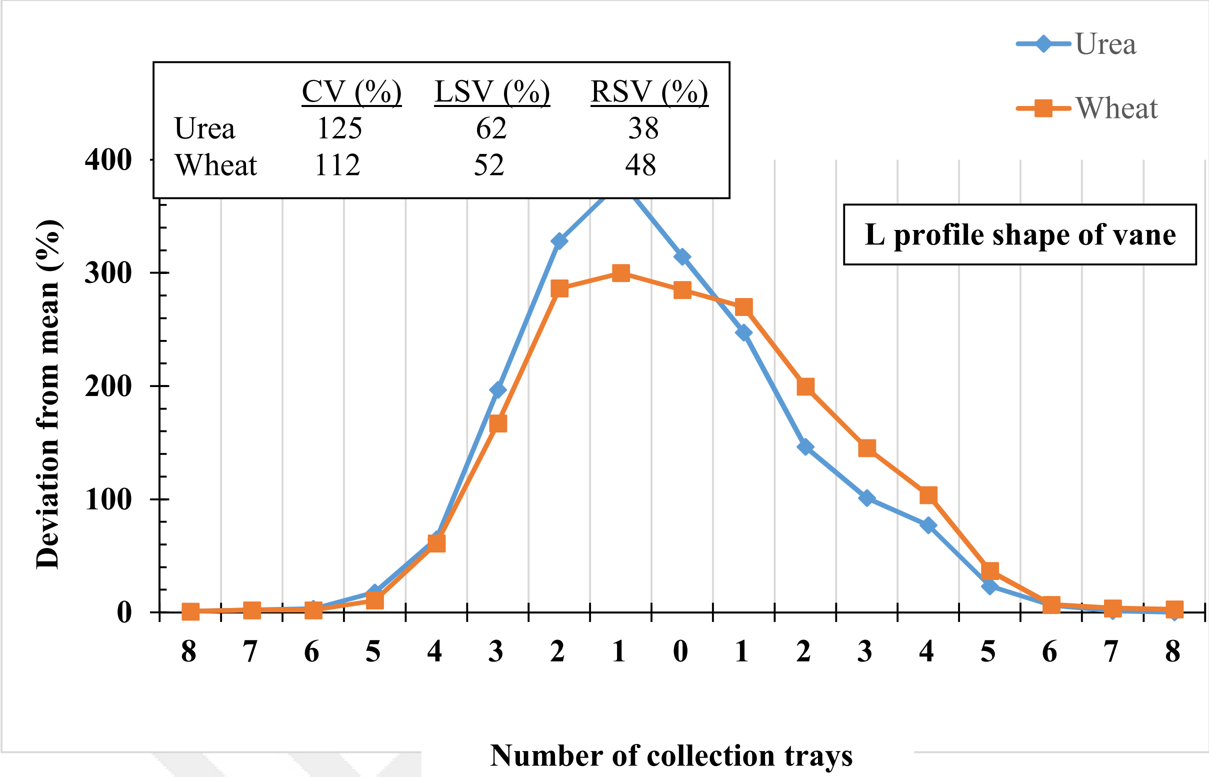


Figure 25. The distribution patterns obtained in the combination of 1,5 m/s forward speed, 31,91 kg/da wheat and 26 kg/da fertilizer application rates

Distribution patterns for 31,91 kg/da of wheat and 26 kg/da of fertilizer application rates at a forward speed of 1,75 m/s are given in Figure 26. For both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 7 and 8 on the right side of the spreader passage from the center of its path. Deviation from the mean is maximum and close to 320% and 400% for the trays near the spreader for wheat and fertilizer respectively. Deviation from the mean in the fertilizer application was higher than in the wheat application. In the combination shown in Figure 25 and Figure 26 similar results relating to deviation of mean obtained for the left and the right side of the spreader.

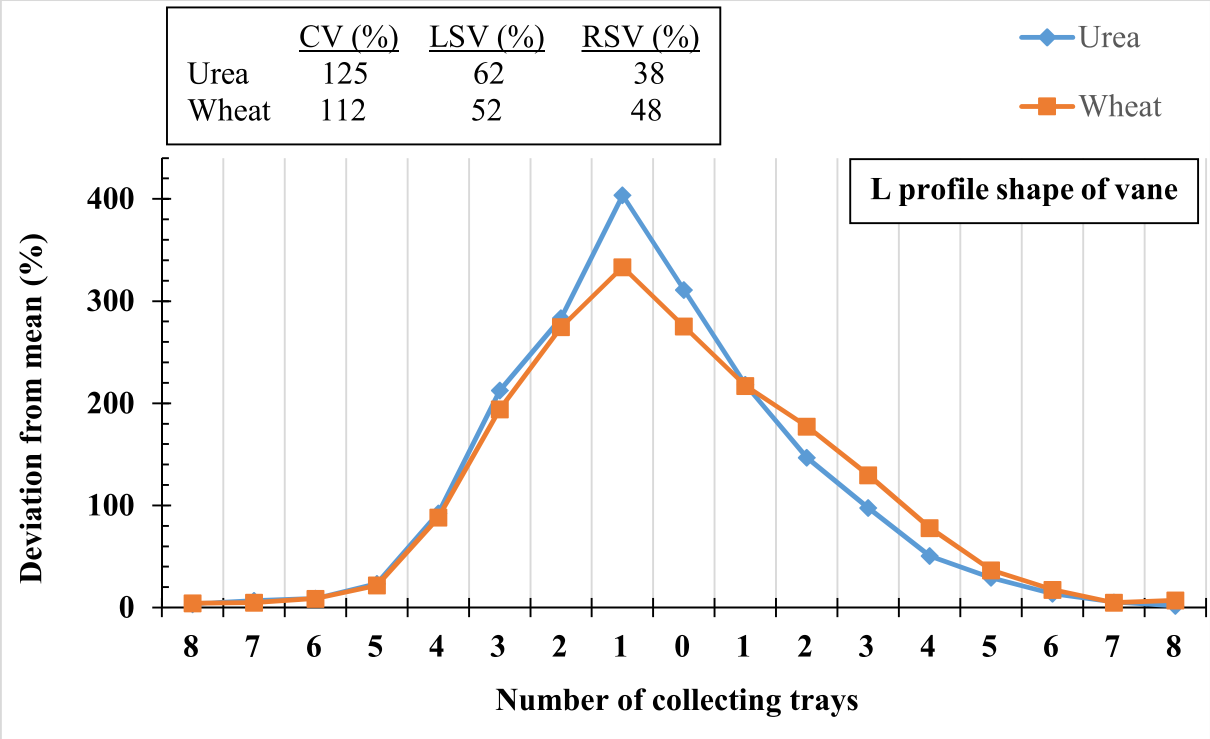


Figure 26. The distribution patterns obtained in the combination of 1,75 m/s forward speed, 31,91 kg/da wheat and 26 kg/da fertilizer application rates

Distribution Patterns of the C Profile Shape of Vane

The distribution patterns for the application rate of 21,26 and 13 kg/da for wheat and fertilizer respectively, with 1,25 m/s forward speed are given in Figure 27. For both wheat and fertilizer, the deviation from the mean is minimum and near to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. The space between the left side and the right side of the trays was allowed to pass through the spreader as explained in the material and method section. Likewise, the deviation from the mean is maximum and close to 280% and 360% for the trays near the spreader for wheat and fertilizer respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. The deviation from the mean on the left side is 27% and the right side is 73% for fertilizer and on the left side is 53% and the right side is 47% for wheat.

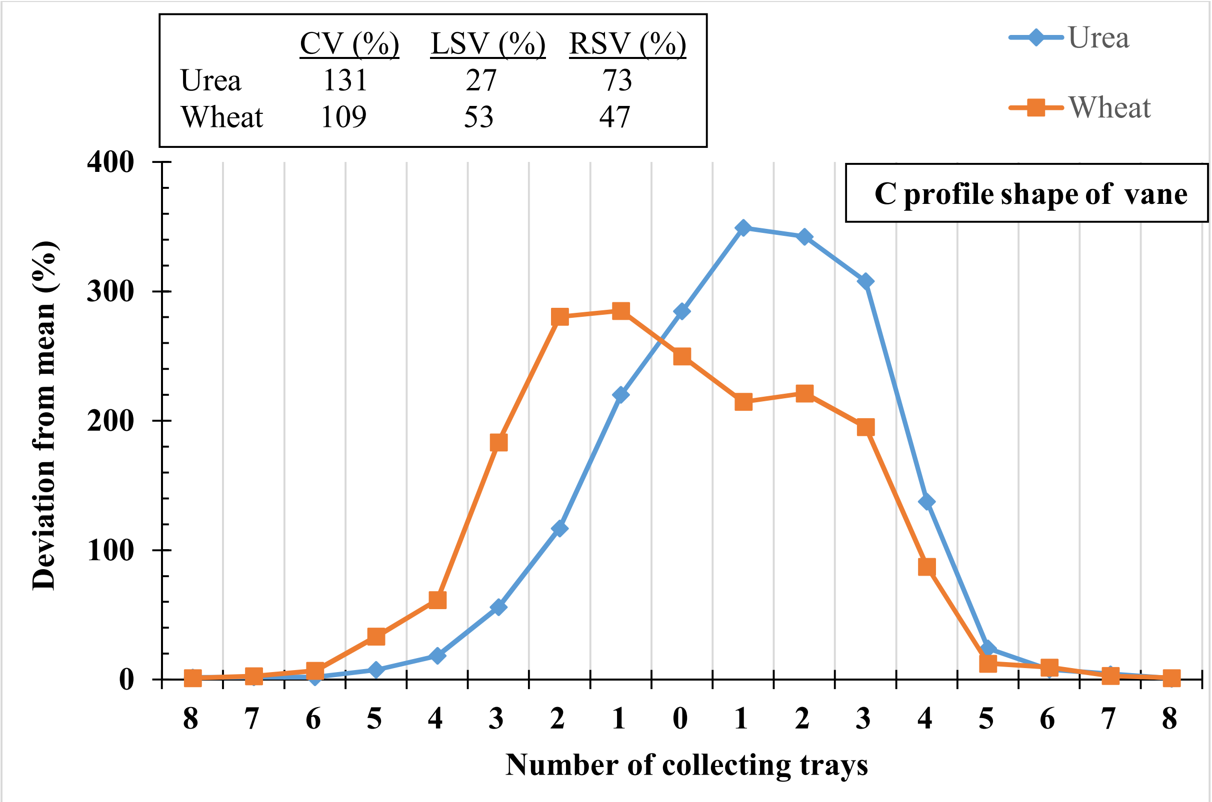


Figure 27. The distribution patterns obtained in the combination of 21,26 kg/da wheat/13 kg/da fertilizer application rates and 1,25 m/s forward speed

The distribution patterns for the application rate of 21,26 and 13 kg/da for wheat and fertilizer respectively, with 1,5 m/s forward speed given in the Figure 28. As it is seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and near to 0% for the trays 6, 7, and 8 on the left side as well as the trays number 5, 6, 7 and 8 on the right side of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 320% and 400% for the trays near the spreader for wheat and fertilizer respectively. The deviation of the wheat distribution values from the mean is less than that of fertilizer. The deviation from the mean on the left side is 32% and the right side is 68% for fertilizer, however on the left side is 31% and the right side is 69% for wheat.

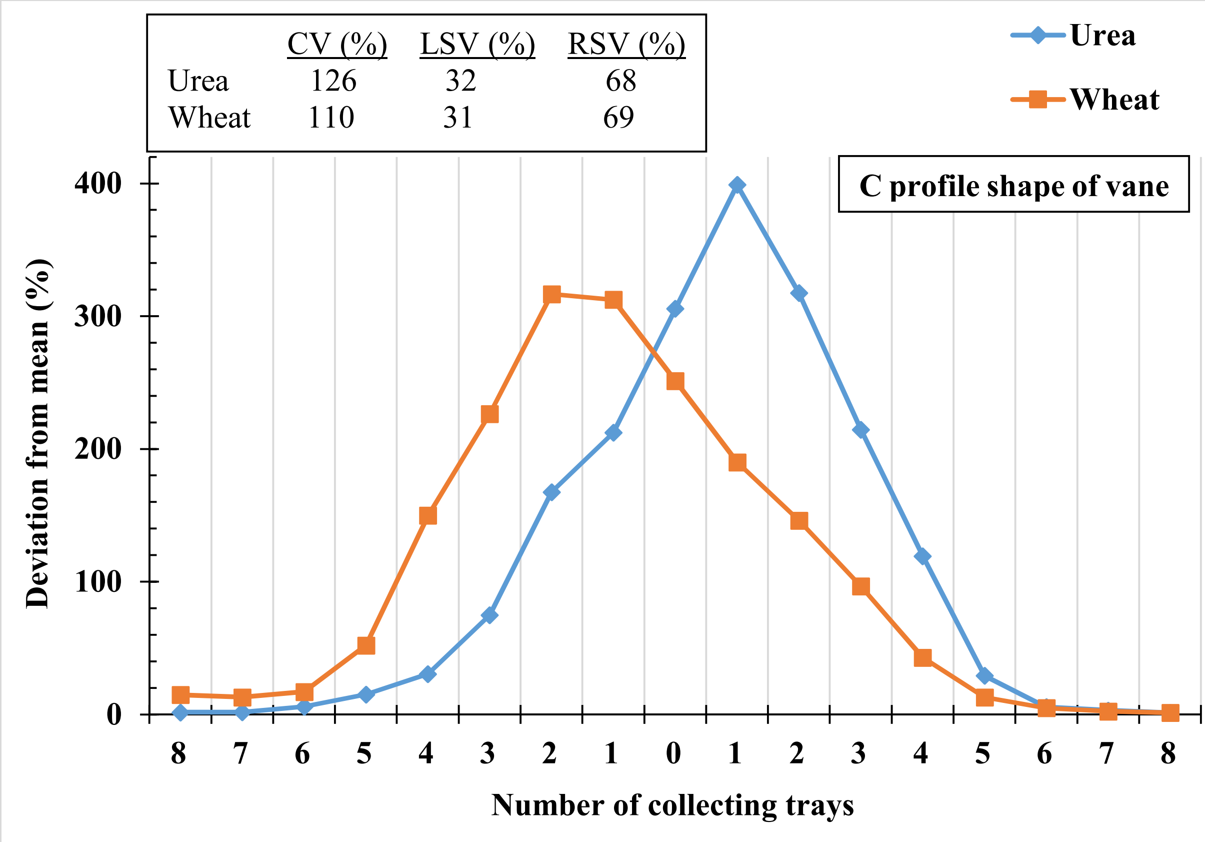


Figure 28. The distribution patterns obtained in the combination of 21,26 kg/da wheat/13 kg/da fertilizer application rates and 1,5 m/s forward speed

The distribution patterns for the application rate of 21,26 and 13 kg/da for wheat and fertilizer respectively, with 1,75 m/s forward speed given in Figure 29. As seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and near to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 260% and 340% for trays near the spreader for wheat and fertilizer respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. The deviation from the mean on the left side is 39% and the right side is 61% for fertilizer, however on the left side is 64% and the right side is 36% for wheat.

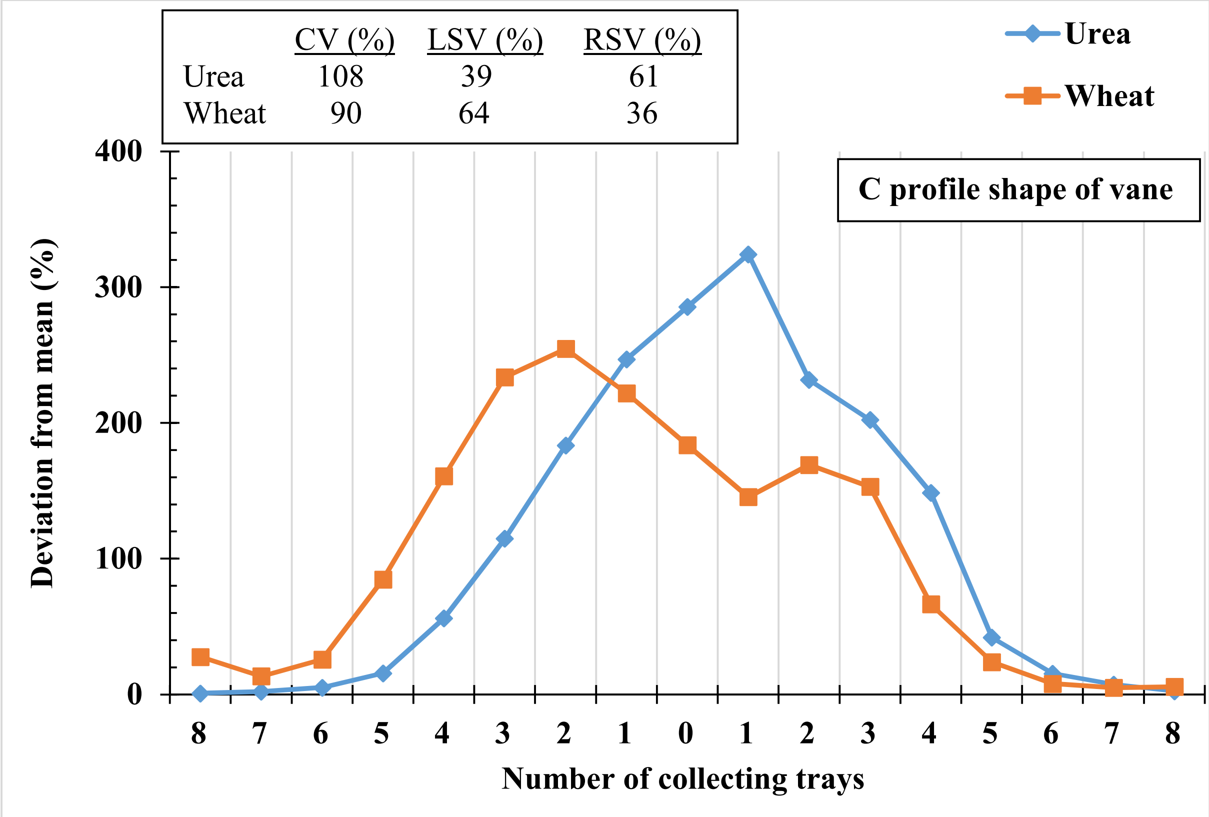


Figure 29. The distribution patterns obtained in the combination of 21,26 kg/da wheat/13 kg/da fertilizer application rates and 1,75 m/s forward speed

The distribution patterns for application rate of 26,58 and 20 kg/da for wheat and fertilizer respectively, with 1,25 m/s forward speed shown in the Figure 30. The deviation from the mean is minimum and near to 0% for the tray numbers 5, 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path (Figure 30). However, the deviation from the mean is maximum and close to 260% and 400% for the trays near the spreader for both wheat and fertilizer respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. In the figure, the deviation of the left side values from the mean for fertilizer is 46% and the right side is 54%, however on the left side is 64% and the right side is 36% for wheat.

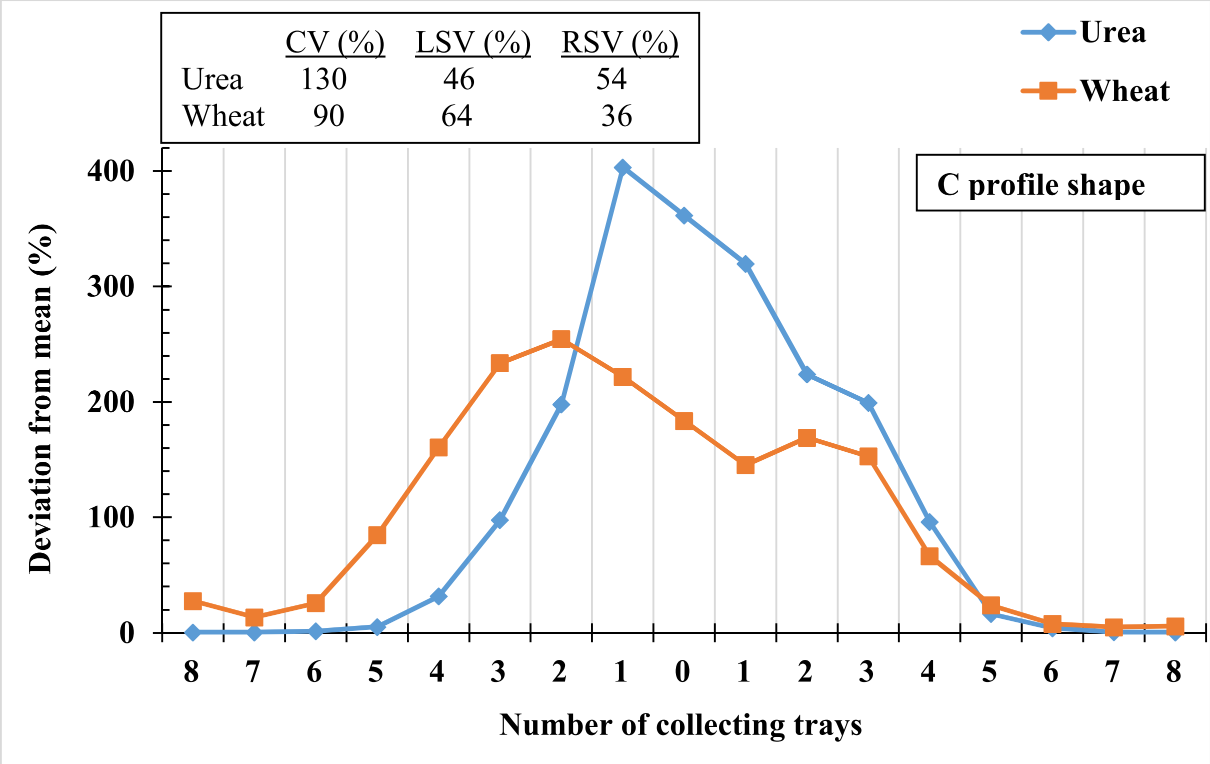


Figure 30. The distribution patterns obtained in the combination of 26,58 kg/da wheat/20 kg/da fertilizer application rates and 1,25 m/s forward speed

Figure 31 shows the distribution patterns for the application rate of 26,58 and 20 kg/da for wheat and fertilizer respectively, with 1,5 m/s forward speed. As it is seen in the figure, for both wheat and fertilizer applications, the deviation from the mean is minimum and near to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 5, 6, 7 and 8 on the right side of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 280% and 400% for the trays near the spreader for wheat and fertilizer respectively. The fertilizer's deviation from mean is higher than the wheat's one. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. Figure 30 and Figure 31 reveal that while the forward speed increased from 1,25 to 1,5 m/s, the deviation from the mean was not significantly changed for both sides and the change was 0% for both the right side and the left side for fertilizer. However, for wheat, the deviation from the mean on the left side was decreased from 64% to 51% and the right side was increased from 36% to 49%. This indicated that the increase in forward speed results in +13% the deviation from the mean for both sides.

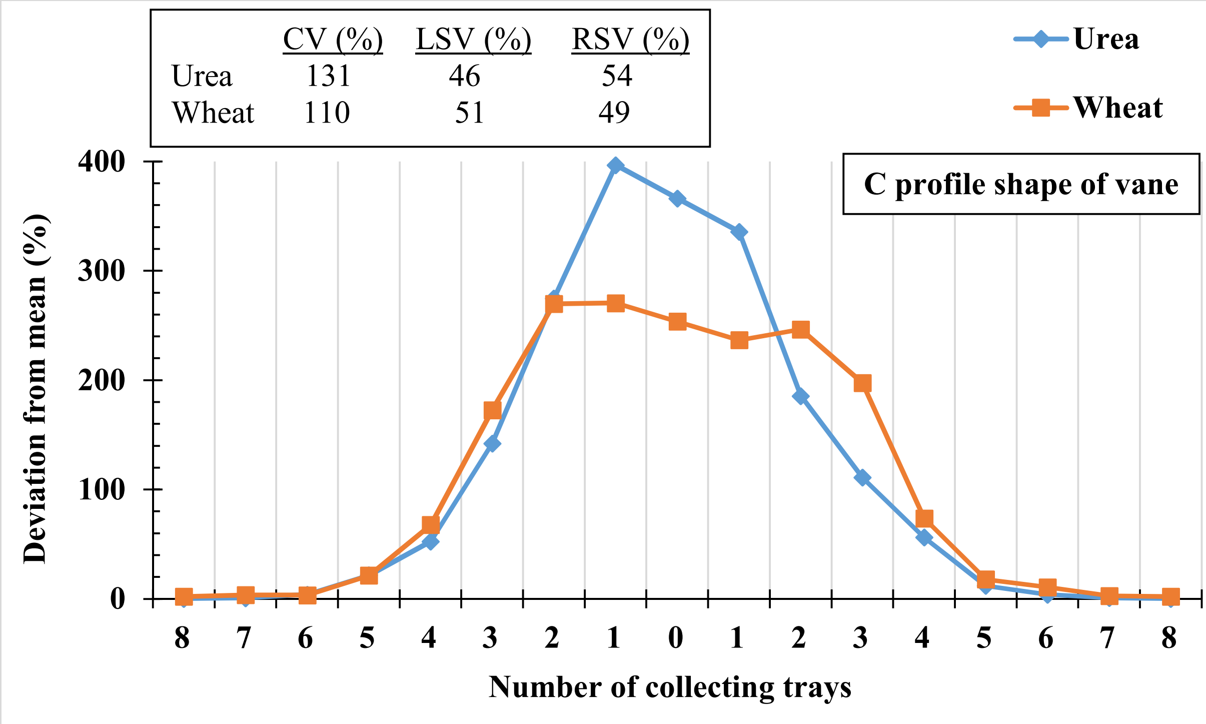


Figure 31. The distribution patterns obtained in the combination of 26,58 kg/da wheat/20 kg/da fertilizer application rates and 1,5 m/s forward speed

The distribution patterns for the application rate of 26,58 and 20 kg/da for wheat and fertilizer respectively, with 1,75 m/s forward speed given in Figure 32. For both wheat and fertilizer applications, the deviation from the mean is minimum and near to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 280% and 380% for the trays near the spreader for wheat and fertilizer applications, respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. The deviation from the mean on the left side is 65% and the right side is 35% for fertilizer, however on the left side is 55% and the right side is 45% for wheat (Figure 32).

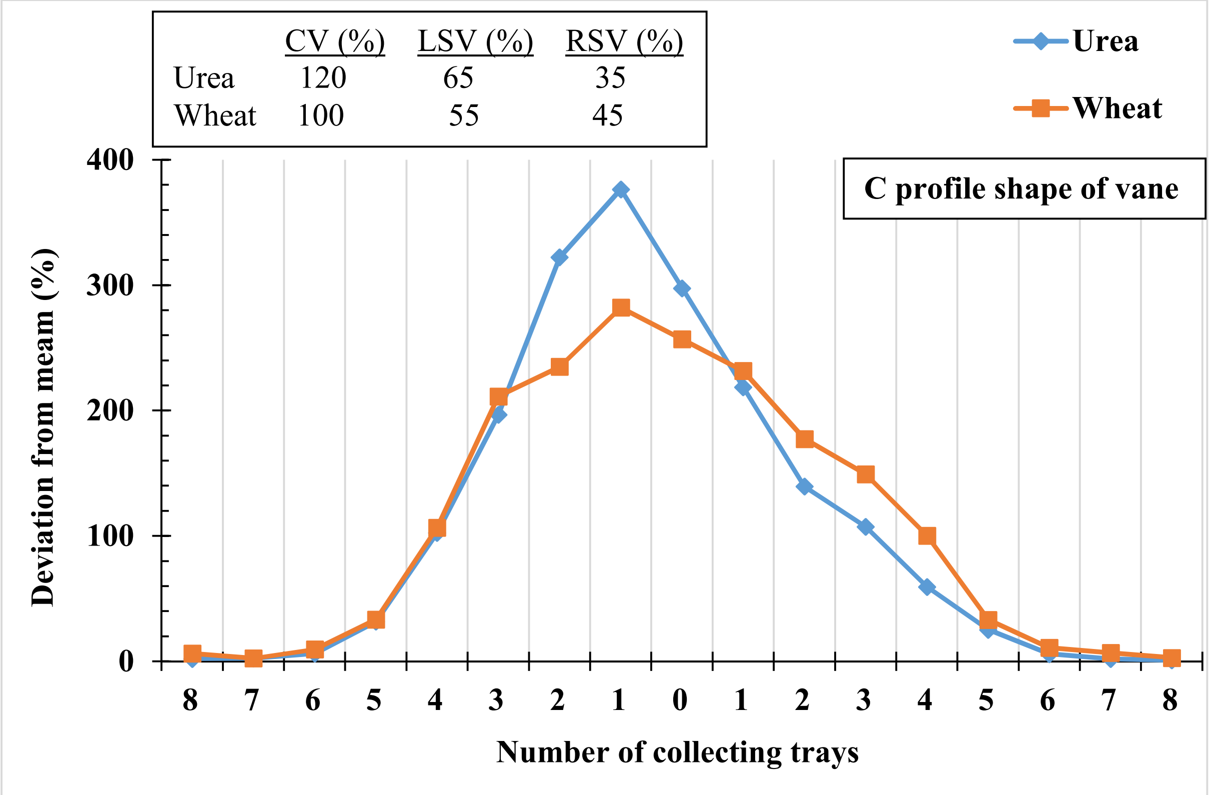


Figure 32. The distribution patterns obtained in the combination of 26,58 kg/da wheat/20 kg/da fertilizer application rates and 1,75 m/s forward speed

Figure 33 shows the distribution patterns for the application rate of 31,91 and 26 kg/da for wheat and fertilizer respectively, with 1,25 m/s forward speed. As it is seen in the figure, the deviation from the mean is minimum and near to 0% for the tray numbers 5, 6, 7, 8 on the left side as well as the trays number 5, 6, 7 and 8 on the right side for fertilizer and 7, 8 on the left side as well as the trays number 6, 7 and 8 on the right side for wheat of the spreader passage from the center of its path. However, the deviation from the mean is maximum and close to 280% and 440% for the trays near the spreader for both wheat and fertilizer applications, respectively. The deviation of the wheat distribution values from the mean is less than that of fertilizer. The deviation from the mean on the left side is 65% and the right side is 35% for fertilizer, however on the left side is 55% and the right side is 45% for wheat (Figure 33). Figure 32 and 33 performed similar results.

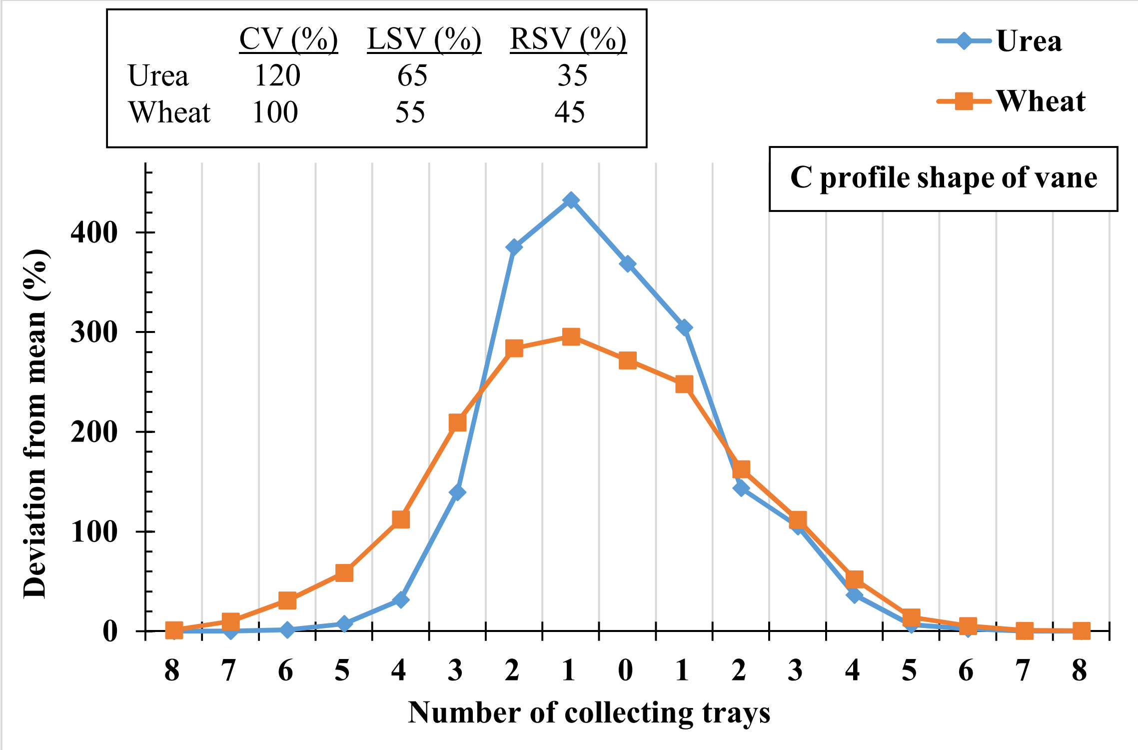


Figure 33. The distribution patterns obtained in the combination of 31,91 kg/da wheat/26 kg/da fertilizer application rates and 1,25 m/s forward speed

The distribution patterns for the application rate of 31,91 and 26 kg/da for wheat and fertilizer respectively, with 1,5 m/s forward speed given in Figure 34. The deviation from the mean is minimum and near to 0% for the tray numbers 5, 6, 7, 8 on the left side as well as the trays number 5, 6, 7 and 8 on the right side for fertilizer and 7, 8 on the left side as well as the trays number 6, 7 and 8 on the right side for wheat of the spreader passage from the center of its path. The deviation from the mean is maximum and close to 260% and 460% for the trays near the spreader for wheat and fertilizer applications, respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. The deviation from the mean on the left side is 37% and the right side is 63% for fertilizer, however on the left side is 44% and the right side is 56% for wheat (Figure 34).

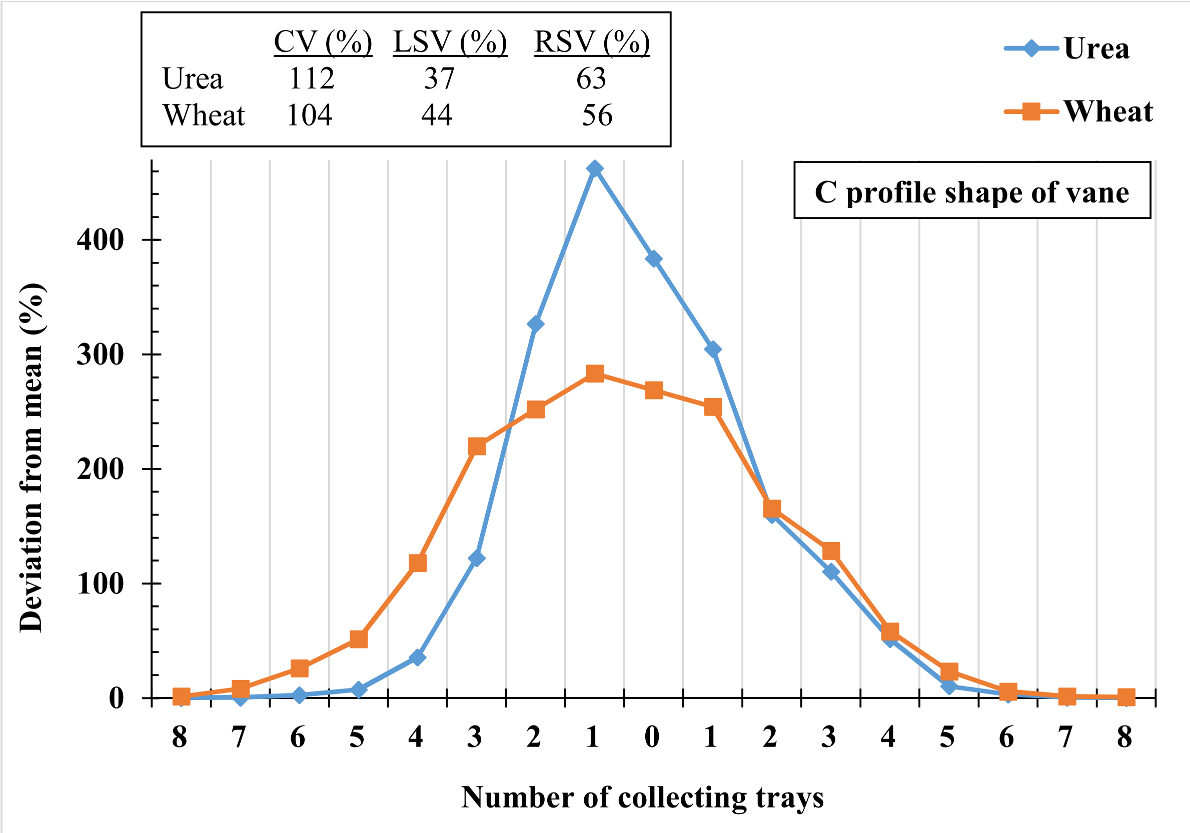


Figure 34. The distribution patterns obtained in the combination of 31,91 kg/da wheat/26 kg/da fertilizer application rates and 1,5 m/s forward speed

The distribution patterns for the application rate of 31,91 and 26 kg/da for wheat and fertilizer applications, respectively, with 1,75 m/s forward speed. For both wheat and fertilizer applications, the deviation from the mean is minimum and close to 0% for the tray numbers 6, 7, and 8 on the left side as well as the trays number 6, 7 and 8 on the right side of the spreader passage from the center of its path. Furthermore, the deviation from the mean is maximum and close to 300% and 480% for the tray near the spreader for wheat and fertilizer applications, respectively. The deviation of the fertilizer distribution values from the mean is higher than that of wheat. The deviation from the mean on the left side is 70% and the right side is 30% for fertilizer, however on the left side is 64% and the right side is 36% for wheat (Figure 35).

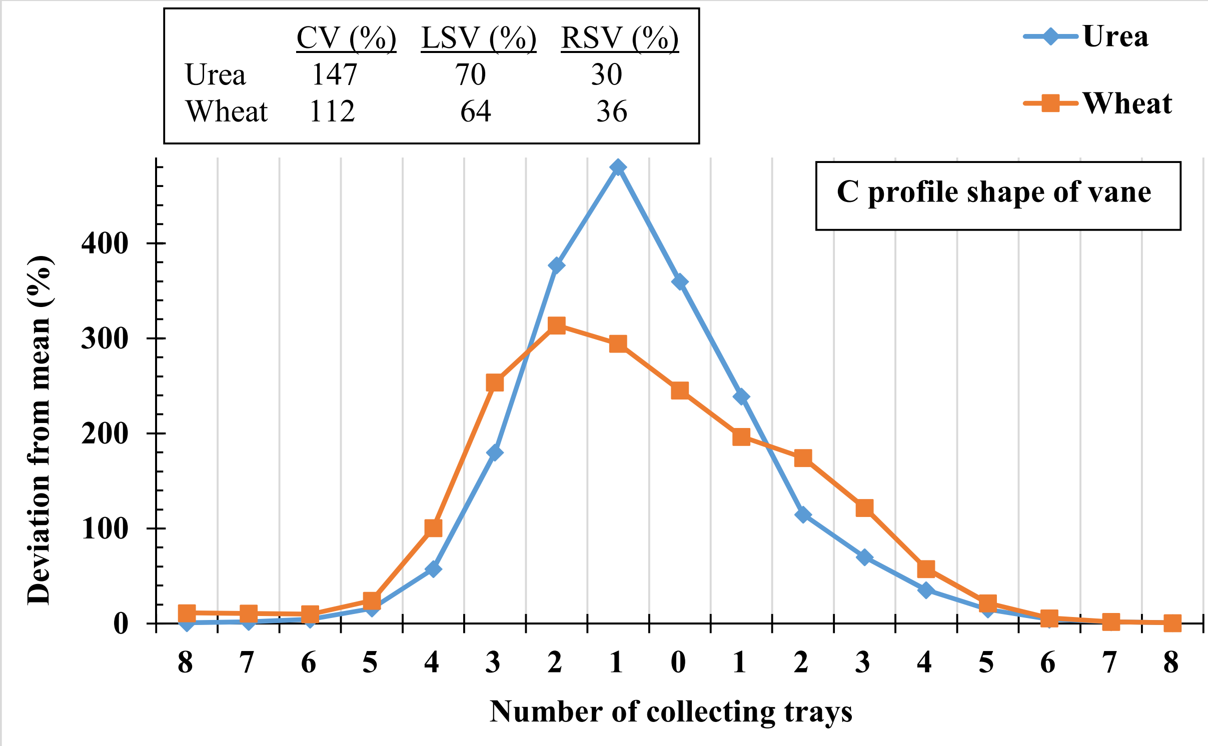


Figure 35. The distribution patterns obtained in the combination of 31,91 kg/da wheat/26 kg/da fertilizer application rates and 1,75 m/s forward speed

The effective spreading width

Swath width and effective spreading width measurement was done by the pattern of the spreading. The distance between outermost seed/fertilizer collected from trays on both sides was measured. Figure 36 is shown for the values of swath width in the X-axis with respect to application rate in the Y-axis. The distribution distance on each side of the forward travel direction of the y-axis (blue line, number 0 on the x-axis), is presented in Figure 36 (the left side 1, 2, 3 and the right side 1, 2, 3, 4). The effective spreading width and overlap distance of the right side and the left side was also determined. The maximum effective spreading width for wheat was measured to be 4,4 m with 1,75 m/s of forward speed and different application rates (21,26, 26,58 and 31,91 kg/da) using C profile shape of vane. However, for fertilizer the maximum effective spreading width was found to be 4 m with 1,75 m/s of forward speed and 20 kg/da of application rate using C profile shape of vane. All the results are presented in Tables of 4, 5, 6, and 7 in this section.

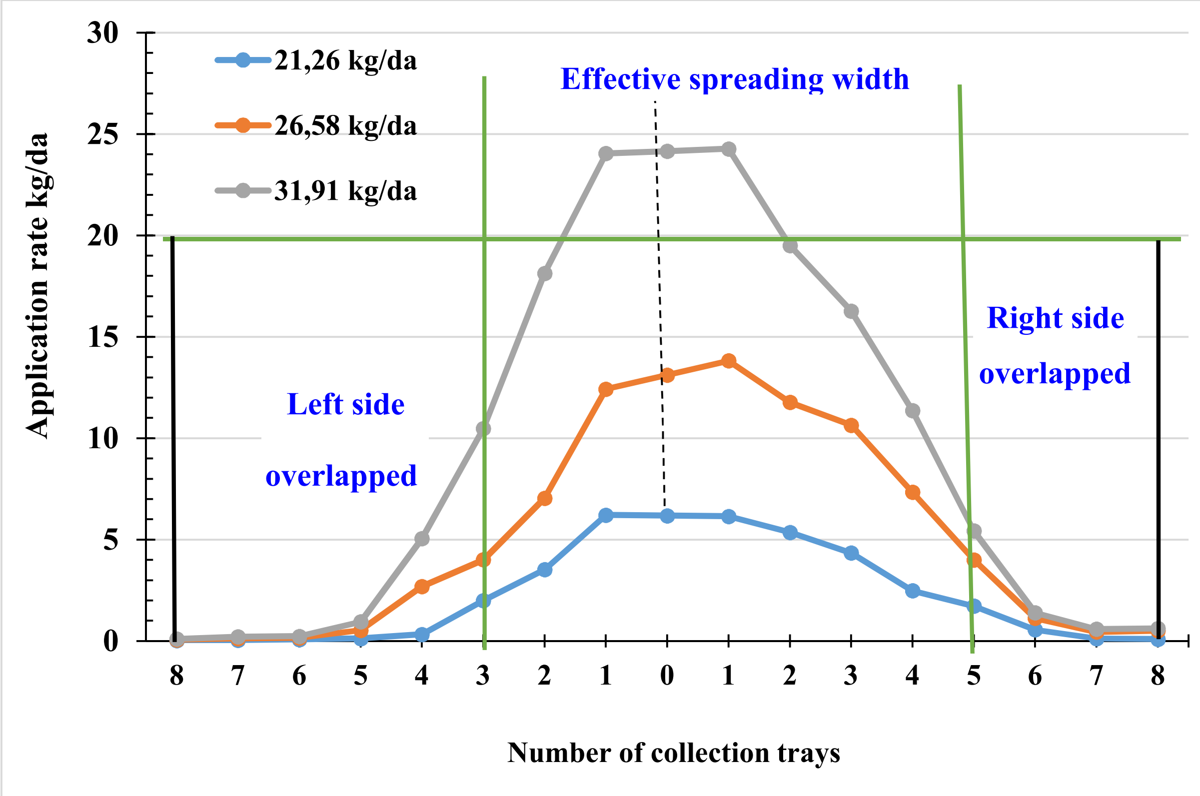


Figure 36. Effective spreading width for 1,5 m/s forward speed and various wheat application rates (21,26, 26,58 and 31,91 kg/da)

The data of L and C profile shape of vane in Table 4 revealed that the application rate of 21,26 kg/da with different forward speeds (1,25, 1,5, and 1,75 m/s), have similar effective spreading widths of 3,6, 3,6, and 4 m, respectively. However, in C profile shape of vane, the effective spreading width at the application rate of 31,91 kg/da, with the 1,5 m/s of forward speed was found to be 4,4 m while in the L profile shape of vane the effective spreading width was found as 4 m. Similar results were found in an experiment done by Thaper *et al.* (2022) which indicated that an increase in spinner disc speed and application rate, increases the effective spreading width of the spreader. Ziauddill and Roy (1997) also indicated that an increase in spinner disc speed, increases the swath width (e.g. 425 rpm with 2,8 m, 470 rpm with 2,98, 515 rpm with 3,05 m, 560 rpm with 3,35 m, and 696 rpm with 3,75 m). Furthermore, Table 4 revealed that there is a minimum of 0,40 m and maximum of 0,80 m difference between the effective spreading width for profile shape of vane in view of spreading width of different application rates with respect to different levels of forward speed.

Table 4. Effective Spreading Width For Various Application Rate of Wheat

Profile shape of vane	Forward speed (m/s)	Width for rate of 21,26 kg/da (m)	Width for rate of 26,58 kg/da (m)	Width for rate of 31,91 kg/da (m)
L profile shape	1,25	3,6	4	3,6
	1,50	3,6	4	4
	1,75	4,4	4,4	4,4
C profile shape	1,25	3,6	4	4
	1,50	3,6	4	4,4
	1,75	4,4	4,4	4,4

The effective spreading width of different fertilizer application rates with different forward speed for L and C profile shape of vane are given in Table 5. The results indicated that an increase in the application rate and forward speed affected the spreading width. The table indicates that the maximum effective spreading width was found for the application rate of 26 kg/da with forward speed of 1,75 m/s for L profile shape of vane and 20 kg/da with forward speed of 1,75 m/s for C profile shape of vane. Similar results were found in the previous studies done by Fulton at el. (2001) and Fulton (2003). Furthermore, the table shows that the minimum effective spreading width of 2,8 m was found for the application rate of 13 kg/da with 1,25 m/s forward speed for the L profile shape of vane. Moreover, Table 5 revealed that there is a minimum of 0,40 m and maximum of 1,2 m difference between the effective spreading width for profile shape of vane in view of spreading width of different application rates with respect to different levels of forward speed.

Table 5. Effective Spreading Width For Various Application Rate of Fertilizer

Profile shape of vane	Forward speed (m/s)	Width for rate of 13 kg/da (m)	Width for rate of 20 kg/da (m)	Width for rate of 26 kg/da (m)
L profile shape	1,25	2,8	3,2	3,2
	1,50	3,2	3,6	3,6
	1,75	3,6	3,6	4
C profile shape	1,25	3,2	3,6	3,2
	1,50	3,6	3,6	3,6
	1,75	3,6	4	3,6

The overlapping width of various application rates of wheat is depicted in Table 6. The overlapping width of application rate of 31,91 kg/da with different forward speeds (1,25, 1,5 and 1,75 m/s), for the C profile shape of vane was found to have similar results of 0,8 m on the left side and 1,2 m on the right side. However, for the L profile shape of vane, the width of 1,6, 1,6 and 1,2 m were obtained for the left side and 1,2, 1,2, 0,8 m of width for the right side. The minimum overlapping which also was constant in different forward speeds was found for the left side in C profile shape of vane with width of 0,8 m while the right side of it had constant overlapping width of 1,2 m. Overally, in the L profile shape of vane, the overlapping width of the left side was found greater than the right side, while in the C profile shape of vane, this was vice versa with the overlapping having the right side greater than the left side.

Table 6. Overlapping Width For Various Application Rate of Wheat

Profile shape of vane	Forward speed (m/s)	Width for rate of 21,26 kg/da (m)		Width for rate of 26,58 kg/da (m)		Width for rate of 31,91 kg/da (m)	
		Left	Right	Left	Right	Left	Right
L profile shape	1,25	1,6	1,2	1,2	0,8	1,6	1,2
	1,50	1,6	1,2	1,6	1,2	1,6	1,2
	1,75	1,2	0,8	1,2	0,8	1,2	0,8
C profile shape	1,25	1,2	1,6	0,8	1,6	0,8	1,2
	1,50	1,2	1,6	1,2	1,2	0,8	1,2
	1,75	0,8	1,2	0,8	1,2	0,8	1,2

The overlapping width of various application rates of fertilizer is shown in Table 7. The maximum overlapping width of spreading was found for the left side of application rate of 13 kg/da for the L profile shape of vane with the maximum of 2,4 m for forward speed of 1,25 m/s while the minimum overlapping of 0,4 m of spreading width was found for the left side of the same application rate (13 kg/da) and the same profile shape of vane (L profile shape of vane) with the same forward speed (1,25 m/s). The overlapping width of various application rates of fertilizer on the left side was found greater than the right side of both the L and C profile shape of vane.

Table 7. Overlapping Width For Various Application Rate of Fertilizer

Profile shape of vane	Forward speed (m/s)	Width for rate of 13 kg/da (m)		Width for rate of 20 kg/da (m)		Width for rate of 26 kg/da (m)	
		Left	Right	Left	Right	Left	Right
L profile shape	1,25	2,4	1,2	1,6	1,6	1,6	1,6
	1,50	2	1,2	1,6	1,2	1,6	1,2
	1,75	2	0,4	1,6	1,2	1,2	1,2
C profile shape	1,25	2	1,2	1,6	1,2	1,6	1,6
	1,50	1,6	1,2	1,6	1,2	1,6	1,2
	1,75	1,6	1,2	1,2	1,2	1,2	1,6

CONCLUSIONS AND RECOMMENDATIONS

Manual distribution of fertilizer/seed has been a challenge due to the issue of application uniformity, time consumption as well as labor intensive to carry large bags of application and wasting fertilizer/seed in some areas due to lack of a constant walk speed. To address this challenge and optimize uniform distribution of fertilizer/seed application and to avoid undesirable losses in energy, time, crop production due to low fertilization and high crop-population and polluted environment because of over-fertilization a manual operated fertilizer/seed spreader can be applied using a proper guideline. This highlights the significance of study on different parameters that affect uniform application distribution i.e. application rate, forward speed, and profile shape of vane of the spreader. Therefore, two profile shape of vanes (L and C profile shape), three forward speeds, and three fertilizer/seed rates were taken into consideration in this study. The findings of this study are presented as a conclusion and recommendation as follows:

The forward speed, application rate and profile shape of vane were studied in this experiment to identify an optimal combination of these factors.

Considering the significance of the forward speed as a key factor on uniform application distribution for wheat and fertilizer, the forward speed of 1,75 m/s was found to be the optimal forward speed for an application uniformity distribution.

Considering the significance effect of profile shape of vane as a key factor effect on uniform application distribution of wheat, though the data showed slight effect of different profile shape of vane on uniform distribution, the C profile shape of vane was revealed to be the optimum one. Likewise, L profile shape of vane with slight effect on uniform distribution of fertilizer application was found to be the optimum one.

Considering the significant effect of the application rate as a key factor on uniform application distribution of wheat, the application rate of 26,58 kg/da was revealed as the optimum uniform application distribution. Likewise, the application rate of 13 kg/da was shown the best uniform distribution for fertilizer application.

Considering the significant effect of combination of all three factors on uniform application distribution of fertilizer, the results revealed the optimum uniform distribution for this application with overall CV of 104% was for the experiment with 1,75 m/s forward speed, 13 kg/da application rate, and L profile shape of vane. Likewise, considering the significance effect of combination of all three factors on uniform application distribution of wheat, the best uniform distribution with overall CV of 90% was for the experiment with 1,75 m/s forward speed, 26,58 kg/da application rate, and L profile shape of vane. These outcomes highlight that 1,75 m/s is the optimum forward speed of either of applications for uniform distribution, regardless of application material. Furthermore, it highlights that the L profile shape of vane is the best option for uniform distribution of either wheat or fertilizer application.

Therefore, the spreader performed the least variations for both fertilizer and wheat in CV, skewing, and minimum values reached the acceptable limits (≤ 20% for CV, ±4% for skewing and ≥ 80% and ≤ 120%) for minimum and maximum values. It highlights that the L profile shape of vane is the best option for uniform distribution of either wheat or fertilizer application. Compared with Yıldırım, (2006) studied the effect of profile shape of vane on distribution uniformity in single-disc rotary fertilizer spreaders. His result indicated that the shape of the profile had a significant effect on fertilizer spreading uniformity. The best fertilizer uniform distribution he obtained was forward-curved-5 vane shape for both triple superphosphate and calcium ammonium nitrate.

Based on the experimental data, the trials demonstrated the effectiveness of the ground driven, push type fertilizer spreader suited small-scale farmers. Many researchers have conducted studies with different flow rates, various speeds, different profile shape of vanes and literature on spreading machines with various basic properties (Yıldırım 2006; Krishnan *et al.* 2020). Comparing the results of this investigation with previous research, the findings of this study is reasonable.

Recommendatıons

1. Users may use a proximity speed sensor to maintain a constant targeted forward speed to improve the distribution uniformity.
2. Users may use the manual push-type spreader at a higher rate of wheat and lower rate of fertilizer to obtain higher uniformity distribution.
3. Studies may be conducted on various wheat varieties and different fertilizers with different physical properties (bulk density and moisture content) in order to identify the optimum uniformity distribution considering the mentioned parameters.

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RESUME

Personal Information	
Name:	Idiris Farah ABDİ
Date of Birth:	
Place of Birth:	
Nationality:	
Address:	
E-mail:	
Education	
High School:	Shabbele Agricultural Secondary School
Degree:	Benadir University, Faculty of Agriculture
Foreign Language Knowledge	
Turkish:	Good
English:	Excellent
Arabic:	Good