Evaluation of the Use of Direct Seeding System Instead of Stubble Burning as a Main Cause of Possible Wildfire

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Abstract In today's world, despite the advent of new technologies and advances in telecommunications to demonstrate the negative impacts of fire, wildfires continue to pose one of the most life-threatening challenges to natural and human ecosystems. Recent records confirm that forest fires can grow and lead to significant blazes during the stubble burning process practiced by farmers. In Turkey, for instance, stubble burning accounts for 184 out of 2,698 registered forest fires. Stubble burning brings with it numerous associated environmental problems. This chapter explores whether the direct seeding (DS) system, an environmentally friendly practice that supports sustainable agriculture in lieu of stubble burning, can serve as a viable alternative. The study includes various applications related to DS in Yozgat, Turkey, situated in Central Anatolia. This region is characterized by a semiarid climate that relies on rainfed agriculture. After implementing DS for three years, farmers witnessed substantial increases in yield, although these improvements may vary depending on various factors. Qualitatively, it is evident that farmer impatience plays a pivotal role in driving the adoption of DS techniques. To mitigate the risk of wildfires caused by stubble burning, there is an urgent need for more comprehensive farmer education

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programs on DS. Widespread adoption of DS could ultimately eliminate the threat posed by stubble burning-induced wildfires.

Keywords Farmers · Fire · Soil management · Soil tillage: stubble

1 Introduction

The challenges our world faces in the twenty-first century include global threats like climate change, accelerated soil degradation, desertification, and the reduction of biodiversity. All of these issues are intricately linked to water and food security for a human population projected to reach 10 billion by 2050. When analyzing the evolution of agriculture and farming, it becomes imperative to address future soil management systems in the context of these challenges (Lal et al., 2007). One of the significant threats to human life in many parts of the world is the occurrence and intensity of wildfires. These fires are becoming increasingly challenging to control due to global climate change and unsustainable land management practices that fail to control urban expansion and rural activities.

It has been demonstrated that one of the primary causes of forest fires is the practice of farmers burning stubble, which refers to the rooted stems left in the field after crop harvesting. Stubble burning has numerous adverse impacts on agriculture, the environment, the economy, and human health (Yakupoğlu et al., 2022). What initially began as an innocuous practice by farmers can result in uncontrolled forest fires due to carelessness and strong winds. Stubble fires are more likely to escalate into wildfires in dry farming areas, particularly in semiarid and arid climates.

In this book chapter, we aim to present a case study of Yozgat province, located in the heart of Turkey, in Central Anatolia, where the annual total precipitation averages 413.6 mm (1991–2020) (TSMS, 2022a, b). Rainfed grain cultivation is prevalent in the region, and it is a common practice for farmers to burn stubble after harvesting, with the majority believing it to be a traditional and acceptable practice (Gursoy, 2012). According to the 2019 data, Turkey experienced a total of 2698 forest fires, with 184 of them attributed to stubble burning (Yakupoğlu et al., 2022). As an illustrative example for our readers, the primary objective of this book chapter is to provide insights into the assessment of rural inhabitants' practices, particularly focusing on the adoption of direct seeding (DS), a conservation tillage (CT) method used to manage stubble without resorting to burning. Additionally, we aim to share knowledge gained from farmer training programs, field days, and the crop production experiences of farmers who have embraced DS in Central Anatolia.

2 Soil Tillage Systems

Before delving into the topic of direct seeding (DS), it is beneficial to provide foundational information about tillage and introduce soil tillage systems. Tillage serves as the initial stage in plant production and is defined as the process of manipulating soil particles to align with the needs of plants, accomplished using machinery or manual activities. Tillage processes encompass cutting, relief, tilting, mixing, shredding, chipping–spinning, and compaction. The primary objective of tillage is to optimize the conditions required by cultivated plants for their development, namely water, air, temperature, and nutrients, and to align them with plant preferences. Proper tillage establishes the desired physical conditions in the rhizosphere, a critical factor in maintaining soil quality and facilitating the balance and movement of air and water (Bayram et al., 2015).

It is important to note that the choice of tillage system can influence various factors that impact soil respiration, including plant residue, soil temperature, water content, pH, redox potential, microorganism species and population, and soil ecology (Kladivko, 2001; Polat, 2020). The disruption of the soil's ability to fulfill essential functions that determine its productivity is often attributed to human-induced effects, particularly tillage (Günal et al., 2015). Soil tillage systems are studied by experts in the field, typically categorized into two groups: (i) traditional tillage (TT) and (ii) conservation tillage (CT) (Aykas et al., 2005). In traditional tillage (TT), the plow serves as the primary tillage tool for seedbed preparation, with soil tilled to a depth of 25–30 cm. Secondary tillage machines are employed at later stages (Kabaş, 2022). In TT, more than 85% of crop residues are buried in the soil, leaving less than 15% on the soil surface. While TT played a pivotal role in the history of agriculture and benefited from mechanization, it is now associated with several recognized disadvantages:

(i) Soil compaction due to excessive field traffic.
(ii) Long-term transformation of lumpy/granular soil structure into a finer grain state.
(iii) Rapid depletion of soil organic matter.
(iv) Increased susceptibility to wind and water erosion.
(v) Gradual reduction in soil moisture levels, making it harder to maintain.
(vi) Potential CO_2 emissions when crop residues are burned.
(vii) Higher fuel costs, often reaching up to 8 L per day, due to elevated energy requirements.
(viii) Longer time requirements (İşler, 2020).

These disadvantages underscore the significance of exploring alternative tillage methods, such as conservation tillage (CT), to address contemporary agricultural challenges. The fundamental tillage system developed to mitigate the drawbacks of traditional tillage (TT) is conservation tillage (CT). As a general guideline, it is recommended to maintain at least 30% of the field surface covered with plant residue in CT (Köller, 2003). CT aims to achieve two primary objectives: (i) retaining preplant or post-harvest crop residues on the field surface or in layers near the surface; (ii) reducing the intensity of soil tillage (Aykas et al., 2005). CT systems, in contrast to TT, primarily involve limiting land preparation activities to shallow depths, preserving and managing crop residues, and preventing soil inversion, thereby reducing soil degradation (Cunningham et al., 2004). Various CT sub-systems exist, including non-inversion tillage, eco-tillage, minimum tillage, mulch tillage, reduced tillage, zone tillage, and direct seeding (DS) (Abdalla et al., 2013). Direct seeding (DS) is sometimes referred to as no-till, zero-tillage, or slot-plant. Alternatively, CT can be categorized into subclasses, including: (i) minimum tillage; (ii) reduced tillage; (iii) mulch tillage; (iv) strip tillage; (v) ridge tillage; and (vi) DS. These different approaches within CT provide flexibility in adapting to various agricultural and environmental conditions.

Minimum tillage is the minimum tillage of the soil that is necessary to meet the crop production and cultivation requirements in the existing soil conditions. Reduced tillage is a system consisting of processes that require less energy than traditional tillage and processes the soil less than conventional tillage. Mulch tillage is a moisture barrier soil tillage system. The basis of this tillage method is to treat the entire soil surface by leaving the plant residues especially on the soil surface or near the surface. Strip tillage is the treatment of < 30% of the soil surface in the form of tapes or strips. Ridge tillage is the system on which the plant will be planted and which creates ridges during maintenance or after harvest and protects them in the same place every year. In this system, the soil is usually left untouched from harvest to planting, except for fertilizer applications. Direct seeding (DS) is the process of sowing seeds directly into previously undisturbed soil. In this system, the soil is left intact from planting to harvest and from harvest to planting (Ozturk, 2014; Gurlek, 2015).

Numerous studies have demonstrated that conservation tillage (CT) offers several advantages over traditional tillage (TT) methods (Filipovic et al., 2006; Kasper et al., 2009; Almeida et al., 2018; Tang et al., 2019; Komissarov & Klik, 2020). These benefits can be summarized as follows:

(i) Reduced soil deformation in CT results in decreased soil moisture loss.
(ii) Undisturbed soil surfaces in CT reduce the chances of weed seed germination.
(iii) Lower soil deformation leads to reduced fuel consumption in CT.
(iv) Plant residues covering the soil surface in CT protect against wind and water erosion.
(v) The upright stubble left in the field during winter in CT prevents snow from being carried away by the wind, which is crucial for providing the necessary chilling for certain grains.

Compared to traditional plow-based tillage, it has been observed that reduced tillage (RT) and direct seeding (DS) methods contribute to increased soil organic matter, improved soil structure, enhanced durability, greater water retention in the soil, and improved biological properties (Barut et al., 2010; Pagliai et al., 2004; Xu & Mermoud, 2001). Furthermore, studies have shown that in general, reduced tillage (RT) and direct seeding (DS) can increase energy efficiency by 25–100% and reduce energy requirements by 15–50% (Yalçın et al., 2003).

These findings highlight the significant benefits of conservation tillage methods for agriculture.

In a study that investigated the impact of different tillage systems on soil and water losses in the Mediterranean climate zone under artificial precipitation (Yakupoğlu et al., 2021), the researchers observed significant differences. In the Kahramanmaras location, it was found that surface runoff and sediment yield from sainfoin and wheat plots under the reduced tillage (RT) system were lower compared to plots using the traditional tillage (TT) system. However, in plots planted with sainfoin in the Tarsus location, the study revealed that the effects of tillage systems on soil and water losses were insignificant.

In this study, the average soil loss from fallow, wheat, and sainfoin plots in the Tarsus location was recorded as 871 g/m^2, 307 g/m^2, and 93.68 g/m^2, respectively. In contrast, for plots in the Kahramanmaras location, the corresponding figures were 29.21, 11.25, and 3.45 g/m^2. These findings underscore the success of the conservation tillage (CT) system in reducing erosion, but they also highlight the influence of soil properties and plant variety on the effectiveness of this system.

3 Direct Seeding as an Alternative to Stubble Burning Which is a Regional Issue

The extensive use of plows, despite their limitations as a resource, led to the deterioration of soil structure due to over-processing. This practice also resulted in increased erosion, reduced soil water retention, and decreased organic matter content due to the intensity of processing. In response to these drawbacks, efforts to develop alternative tillage methods began. Notably, the inclusion of certain herbicides marked a significant milestone in this development process, eventually paving the way for the adoption of direct seeding (DS) into agricultural management in the early 1960s.

Subsequently, with the development and mass production of suitable crop residues for stubble cover, DS gained popularity in the cultivation of second-crop soybeans and corn in the United States, Brazil, Argentina, and England toward the end of the 1960s (Gözübüyük et al., 2012).

The advantages of DS are manifold:

(i) It reduces the risk of erosion.
(ii) DS increases soil infiltration and reduces evaporation, enabling better water retention in the soil.
(iii) The practice improves soil structure by increasing the organic matter content in the topsoil.
(iv) DS promotes biological activity in the soil.
(v) It reduces the need for multiple machinery, tractor power requirements, fuel consumption, and maintenance costs for mechanization.
(vi) DS enhances efficiency, especially in regions with limited humidity.
(vii) It increases available water content.

(viii) DS is well suited for application in light- and medium-textured soils, well-drained soils, volcanic soils, and moist–semi-humid regions.
(ix) It saves time in the planting process.
(x) DS helps regulate temperature around the seeds.
(xi) It reduces field traffic, crucial for mitigating soil compaction, and offers advantages in time-sensitive situations.
(xii) DS reduces greenhouse gas emissions, particularly CO_2.
(xiii) It reduces the preparation time needed for planting, decreasing dependence on weather conditions at planting dates.
(xiv) DS prevents the formation of a soil crust that can impede plant emergence and cause runoff (İşler, 2020).

Numerous studies (Cerda et al., 2020; Favarato et al., 2014; Fernandez et al., 2010; Gohlke et al., 2000; Shakoor et al., 2021; Vincent-Caboud et al., 2017) have highlighted the positive aspects of direct seeding (DS) as listed above. In a study examining the effects of both traditional tillage (TT) and DS methods on soil organic matter content, it was discovered that soil organic matter accumulation on the surface was 130% higher in areas where DS was applied compared to those where TT was used (Feng et al., 2003). Notably, the DS method requires only one pass through the field for sowing, while the TT method typically necessitates at least two or more passes. Fewer passes translate to lower depreciation costs. In terms of fuel consumption, DS can yield an average fuel savings of 31.5 L per hectare per year compared to TT. In the context of annual crop cultivation under Southern European conditions, DS can lead to cost reductions ranging from 40€ to 60€ per hectare for different crops (Çanakcı et al., 2010).

In a pioneering study, it was found that the average soil loss was 1.16 tons per hectare per year in plots plowed at an appropriate moisture level without burning stubble after wheat harvest. In contrast, this value was calculated as 2.73 tons per hectare per year for plots where stubble was burned and then immediately plowed (Avşar & Kanburoğlu, 1996). These studies collectively demonstrate the environmental and economic benefits associated with the adoption of the DS method in agriculture.

As demonstrated by the examples provided above, direct seeding (DS) offers numerous advantages. However, it is essential to acknowledge that DS also comes with certain disadvantages, including:

(i) The need for expensive and diverse equipment, which requires a high initial investment.
(ii) The requirement to use special sowing machines to prevent potential toxic effects resulting from the contact between stubble residues and seeds.
(iii) The necessity to combat emerging weeds since the soil remains uncultivated.
(iv) The need for farmer training, as the direct seeding system involves a new and dynamic approach that demands a high degree of management capability.
(v) Long-term experiences have revealed that farmers encounter various challenges in the direct seeding system, including the use of different techniques in fertilization, spraying, and weed control (Yalçın et al., 2003).

One significant issue to address for the success of DS is the control of voles. Without proper vole control, the pits they create in the field can disrupt the operation of direct seeding machines, leading to significant problems. Another crucial consideration in the direct seeding (DS) system is weed management. Achieving success in DS relies on effective chemical weed control. Additionally, it is important to note that DS may not be suitable for crops that typically require manual hoeing, particularly in arid and semiarid regions. If there are challenges with germination due to excessive stubble accumulation, it may be necessary to disperse the stubble using a rake. Proper crop planning and pattern adjustment are essential to maximize yields in direct seeding, making it a critical aspect of the practice. Crop rotation also holds significant importance within DS systems. Patience is a virtue in the DS system. The primary goal of direct seeding is to preserve the soil for sustainable agriculture and maintain ecological balance. While it may appear costlier in the short term, farmers who prioritize these long-term benefits will ultimately emerge as winners.

4 Direct Seeding Studies in Yozgat City, Turkey

Yozgat city is situated in the heart of Central Anatolia, Turkey. This region, characterized by a semiarid climate, receives an annual total precipitation of 413 mm (1991–2020) and experiences an average annual temperature of 12.6 °C (1991–2020) (TSMS, 2022a, 2022b). The average altitude above sea level in this area is approximately 1200 m. It is predominantly a grain-producing region, with a focus on wheat cultivation. Due to limited water resources and challenging climatic conditions, crops in this region can only be harvested once a year. Despite legal regulations, penalties, and numerous awareness campaigns, farmers often resort to the practice of burning crop stubble (Yakupoğlu et al., 2022).

Stubble burning poses a significant risk of forest fires, particularly in areas near forests. To mitigate this risk, the Yozgat Directorate of Provincial Agriculture and Forestry, under the Republic of Turkey Ministry of Agriculture and Forestry, has organized numerous seminars. These seminars emphasize the importance and benefits of adopting the direct seeding (DS) method and aim to encourage farmers to choose DS over stubble burning. As a motivational incentive, farmers receive a certificate of participation after attending these seminars. Additionally, field meetings are organized, where various activities such as planting, fertilizing, and harvesting are carried out. During these events, leading farmers share their experiences with DS, further encouraging others to adopt this sustainable practice. These initiatives are conducted through collaboration between the aforementioned organizations and the Yozgat Bozok University Faculty of Agriculture.

For visual reference, Fig. 1 provides images from village seminars and field meeting days.

One of the significant challenges in convincing farmers to transition from traditional tillage (TT) to conservation tillage (CT) and to adopt direct seeding (DS) instead of burning stubble is their resistance to innovation. Farmers often prove

Fig. 1 Some pictures showing DS narration and demonstration work in Yozgat, Turkey

Table 1 Comparison of conventional tillage and direct seeding in terms of yield of some plants under rainfed conditions in Yozgat, Turkey

Plant	Regional average yield under conventional tillage system (kg da^{-1} $year^{-1}$)	Direct seeding average yield at the end of the 3rd year (kg da^{-1} $year^{-1}$)
Wheat	300	425
Vetch (hay yield)	275	550
Chickpea	100	142
Lentil	80	160
Triticale	200	238
Barley	300	350

reluctant to change established practices. Conversely, local farmers are keen to see immediate financial returns from DS. However, the expected increase in DS yield depends on various factors, including climatic conditions, soil characteristics, and management practices such as fertilization, irrigation, and herbicide application. It is worth noting that in certain cases, the product yield achieved through the CT method may surpass that obtained through reduced tillage (RT) and DS methods (Videnovic et al., 2011).

Table 1 provides the average yields of fields treated with traditional tillage (TT) and fields treated with direct seeding (DS) over a three-year period for various crops. According to the table, in Central Anatolian conditions where the TT system was applied and rainfed cultivation was practiced, the average wheat yield stood at 300 kg per hectare per year. However, this figure increased to 425 kg per hectare per year with the adoption of DS management. Similar substantial increases in yield are also observed for other crops, such as lentils, where the increase is exactly double. It is important to note that the DS data presented in the table represent yields three years after the initiation of DS. Rapid increases in yield immediately after transitioning to DS are unlikely.

5 Conclusions

While current legislation in Turkey promotes the sustainable management of soil resources, many farmers continue to burn stubble for various reasons. Despite legal regulations that align with the United Nations' Sustainable Development Goals and the Challenge of Land Degradation Neutrality, these practices persist, especially in arid and semiarid regions where rainfed agriculture is prevalent. Stubble fires not only have adverse effects on the physical, chemical, and biological properties of the soil but also carry the potential to escalate into uncontrollable wildfires. Instead of resorting to stubble burning, a more environmentally friendly and sustainable alternative is the adoption of the direct seeding (DS) system. By embracing DS, forest fires triggered by stubble burning can be mitigated. However, achieving increased productivity per unit area through DS hinges on several factors. These include the correct application of fertilization, irrigation, crop rotation, and weed control programs, as well as the selection of the most suitable plant varieties for the region, the use of high-quality seeds, and the implementation of chemical control measures against voles.

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