Die Bodenkultur: Journal of Land Management, Food and Environment
Volume 70, Issue 2, 69–79, 2019. 10.2478/boku-2019-0006
ISSN: 0006-5471 online, https://content.sciendo.com/view/journals/boku/boku-overview.xml

sciendo

Research Article

Influence of tillage depth of a cultivator on the incorporation of crop residues of winter barley in a chernozem soil

Einfluss der Bearbeitungstiefe eines Grubbers auf die Einarbeitung von Wintergerstenrückständen auf einem Tschernosemboden

Franziska Mairhofer[1,3], Norbert Barta[1]*, Pia Euteneuer[2], Julia Schuster[1], Alexander Bauer[1], Andreas Gronauer[1]

[1] Institute of Agricultural Engineering, University of Natural Resources and Life Sciences Vienna, Peter-Jordan-Straße 82, 1190 Wien, Austria
[2] Experimental Farm Groß-Enzersdorf, University of Natural Resources and Life Sciences Vienna, Schloßhofer Straße 31, 2301 Groß-Enzersdorf, Austria
[3] AlpS GmbH, Grabenweg 68, 6020 Innsbruck, Austria

* Corresponding author: norbert.barta@boku.ac.at

Received: 15 April 2018, received in revised form: 16 July 2019, accepted: 18 July 2019

Summary

Although crop residues contribute to erosion control, the influence of the tillage depth (TD) on their incorporation has not been studied extensively. The main objective of this study was to determine the differences in the amount and distribution of incorporated crop residues and surface residue coverage if the TD of a cultivator is varied (0.10, 0.20, or 0.30 m). The experiment was carried out on a chernozem soil with winter barley residues in 2016 in Groß-Enzersdorf (Lower Austria). Individual soil cores, each 0.05 m long, were removed using a special device. No significant differences were observed for the incorporated crop residues up to a depth of 0.35 m between the three TDs. The mean values of the incorporated crop residues at a TD of 0.10, 0.20, or 0.30 m were 11.64, 13.30, and 10.82 t/ha, respectively. The distribution of crop residues in the individual depth segments (DSs) showed a main concentration of more than 90% at a depth of 0.10 m and a significant decrease in deeper layers. This stratification was independent of the TD. Therefore, a shallower TD is sufficient for straw management on a chernozem soil in the production area of Marchfeld, which also enables a reduction in draft and, consequently, fuel consumption and processing costs.

Keywords: reduced tillage, crop residues, residue incorporation, residue distribution, soil cores

Zusammenfassung

Obwohl Ernterückstände einen wesentlichen Beitrag zur Erosionskontrolle leisten, wurde der Einfluss der Bodenbearbeitungstiefe auf die Ernterückstandseinarbeitung noch wenig untersucht. Hauptziel dieser Arbeit war es deshalb, die Unterschiede in Menge und Verteilung der eingearbeiteten Ernterückstände sowie der oberflächlichen Rückstandsbedeckung zu bestimmen, wenn die Bearbeitungstiefe eines Grubbers (0,10, 0,20 bzw. 0,30 m) variiert wird. Das Experiment wurde auf einem Tschernosemboden mit Wintergerstenrückständen im Jahr 2016 in Groß-Enzersdorf (Niederösterreich) durchgeführt. Mithilfe einer eigens angefertigten Entnahmevorrichtung wurden einzelne, je 0,05 m hohe Bohrkerne entnommen, um die eingearbeiteten Ernterückstände zu bestimmen. Bei den eingearbeiteten Ernterückständen wurden bis zu einer Tiefe von 0,35 m keine signifikanten Unterschiede zwischen den drei Bodenbearbeitungstiefen festgestellt. Die Mittelwerte der eingearbeiteten Ernterückstände bei einer Bearbeitungstiefe von 0,10, 0,20 bzw. 0,30 m lagen bei 11,64, 13,30 bzw. 10,82 t/ha. Bei Betrachtung der Ernterückstandsverteilung zeigte sich mit über 90 % eine hauptsächliche Konzentration in den ersten 0,10 m und eine deutliche Abnahme in tieferen Schichten, wobei diese Stratifikation unabhängig von der Bearbeitungstiefe war. Da sich die Ernterückstände auch bei höheren Bearbeitungstiefen nicht tiefer als 0,10 m einarbeiten lassen, kann für Tschernoseme im Produktionsgebiet Marchfeld festgehalten werden, dass beim Strohmanagement eine flachere Bearbeitungstiefe ausreichend ist, wodurch zusätzlich eine Verringerung von Zugkraft, Kraftstoffverbrauch und Bearbeitungskosten ermöglicht wird.

Schlagworte: reduzierte Bodenbearbeitung, Ernterückstände, Ernterückstandseinarbeitung, Ernterückstandsverteilung, Bohrkerne

1. Introduction

Crop residues are major assets on agricultural soils and provide numerous ecosystem services such as reducing runoff and soil erosion as well as improving soil hydraulic capacities, soil water storage, soil organic matter, and soil fertility (Blanco-Canqui and Lal 2010). The problem of erosion and massive soil loss has been a fundamental issue for years; in Germany, for example, 8 t/ha of soil is lost each year (Sommer, 2003). Soil erosion in agriculture can be caused by water, wind, as well as tillage itself (Blanco-Canqui and Lal, 2010). In modern agriculture, with the aim of having sustainable development, erosion reduction is considered to be one of the main elements in achieving this.

Although plowing is still widely used in European agriculture (Lahmar, 2010), reduced and conservation tillage are becoming increasingly important because of the advantage of erosion reduction among other benefits. The ASAE (2005) defines reduced tillage with at least 15% soil coverage and conservation tillage with at least 30% soil coverage remaining in the field. Besides the surface crop residues, also the incorporation of straw or stubble has an influence on soil properties. It results in changes in the physical, chemical, and biological conditions of the soil and also has various effects on pests, diseases, and weeds through interactions with other components (Jordan, 2002). Neugschwandtner et al. (2014) demonstrated that tillage intensity influences nutrient quantity as well as distribution in a chernozem soil in a long-term field experiment in Raasdorf, Lower Austria. With reduced tillage intensity, for example, soil organic carbon content increased significantly in the uppermost soil layers. This is in accordance with the results obtained from another long-term field experiment in Poland by Gadja et al. (2018), which indicate greater values of soil water content and increased soil stability for reduced tillage systems. The soil organic content, enzymatic activity, and microbiological diversity were only increased in the topsoil layer up to a depth of 0.10 m.

As there has been growing awareness of the importance of crop residue management, an examination of their incorporation has become indispensable (Raper, 2002). In addition to the economical and soil-related aspects, straw management must also be taken into account regarding tillage (Köller and Linke, 2001). Although Allmaras et al. (1988) consider the distribution and the placement of crop residues to be important objectives of soil tillage, still little is known about the quality of straw incorporation (Voßhenrich et al., 2003). While there is plenty of information available on the surface crop residues (Allmaras et al., 1988; Staricka et al., 1991; Guérif et al., 2001), the quantity, location, and spatial distribution of incorporated crop residues have been studied less frequently. This lack of data has also been addressed in Raper (2002) and Liu et al. (2010).

Only few studies have investigated the quantity and distribution of incorporated crop residues. The incorporation of residues was studied for oat (Staricka et al., 1991; Allmaras et al., 1996), wheat (Christian and Miller, 1986; Eltom et al., 2015), grain sorghum (Raper, 2002), and winter barley (Ball et al., 1990; Ball and Robertson, 1990). Raper (2002) reported the general assumption that tillage depth (TD) has a significant influence on the incorporation of straw. This is particularly significant in view that every additional centimeter depth that is tilled results in increased draft requirement, wheel slip, fuel consumption, and thus tillage costs (Estler and Knittel, 1996; Brunotte, 2007; Manuwa, 2009; Moitzi et al., 2014; Szalay, 2015). For this reason, an appropriate TD is important for a sustainable and economically as well as ecologically reasonable (reduced) soil tillage. For a good seed placement, crop residues have to be incorporated evenly and sufficiently deep (Köller and Linke, 2001).

In a study by Brunotte (2007), a TD of 0.015–0.020 m per t/ha of straw is indicated. However, Raper (2001) states that the TD of a cultivator does not significantly influence the incorporation of straw. Dölger and Wörz (2006) reported that, with current cultivators, it is not possible to incorporate straw deeper than 0.15 m. According to these authors, TDs of more than 0.18 m are mainly used for loosening soil and less for straw incorporation itself. In addition, many studies, such as those of Allmaras et al. (1988), Ball and Robertson (1990), and Eltom et al. (2015), describe a concentration of crop residues near the soil surface in non-inverting tillage.

In spite of its supposed importance, only a few experiments have dealt with the influence of the TD on the straw incorporation. In some publications, the influence of the TD has been examined, but in the end, only two different soil tillage implements have been compared. So, for example, Akmal et al. (2015) investigated the effect of TD on maize yield, but only compared a plough (deep tillage) with a cultivator (shallow tillage). Hänsel et al. (2009), on the other hand, compared the influence of three cultivator depths (0.05, 0.10, and 0.15 m) only on residue coverage and various soil properties but not straw incorporation. Arvidsson (1998) also investigated the influence of three TDs of a cultivator (0.10, 0.15, and 0.20 m) on bulk density and penetration resistance, and Walther (2009) investigated the effect of three TDs of a cultivator (0.075, 0.125, and 0.175 m) on the residue coverage. When looking at reduced tillage in general and the use of a cultivator in particular, one notices the lack of studies that determine and compare qualitative aspects of straw incorporation, namely, the quantity and spatial distribution of the incorporated crop residues, at different TDs of a cultivator. Therefore, the main objective of this study was to determine differences in the amount and distribution of the incorporated crop residues and the surface residue coverage if the TD of a cultivator was varied.

2. Material and methods

2.1 Field experiment

The experiment was conducted from July 7 to August 8, 2016, at the experimental farm Groß-Enzersdorf of the University of Natural Resources and Life Sciences Vienna. The annual average temperature for the area is 10.6°C with semi-arid climate conditions and an annual precipitation of 538 mm (1980–2009). During the field tests, a total of 62.2 mm of precipitation fell, with 54.6 mm being recorded from June 12 to 14, 2016 (own measurements with the rain sensor Rain Gauge IM523 of the weather station iMetos 3.3 (both Pessl Instruments GmbH, Weiz, Austria; position: latitude, 48.19653; longitude, 16.57015). The soil at the 3.5 ha experimental area is silty loam chernozem (20.2% sand, 59.6% silt, 20.3% clay) with a pH of 7.6 and 2.2–2.3% organic substance. Immediately before tillage, the average gravimetric water content at a depth of 0–0.30 m was 15.6% (measured by weighting of soil samples before and after drying in an oven at 105°C).

The winter barley, *Hordeum vulgare* var. *distichon* (L.) "Caribic", was harvested using an Axial-Flow 2366 combine harvester (Case IH, Racine, Wisconsin, USA; working width 4.8 m with straw chopper) with a grain yield of 7.9 t/ha. After all measurements had been carried out on the untreated area, the soil was tilled with a CVT 6240 tractor (Steyr, St. Valentin, Austria) at a constant target working speed of 8 km/h. Tractor parameters were recorded via the CAN and the ISO bus system using a CAN-logger Series 5102 (RM MICHAELIDES SOFTWARE & ELEKTRONIK GMBH, Fulda, Germany). A Synkro 3030 three-row cultivator (PÖTTINGER Landtechnik GmbH, Grieskirchen, Austria) was equipped with 11 tines standard chisel shares with a tool distance of 0.27 m, leveling discs, and a cage roller. The TD was the performed at depths of 0.10, 0.20, and 0.30 m, corresponding to the area of application according to the operating instructions (Pöttinger, 2007). After cultivating, subsequent tests were carried out on the cultivated area and the samples were processed in the laboratory. For each of the 3 TDs, 15 measuring points were randomly distributed and the tests were carried out. To evaluate the straw distribution before tillage, 15 measuring points were randomly selected from the 45 measuring points. A R10 GNSS antenna in combination with a TSC3 field computer (both Trimble, Sunnyvale, California, USA) using a RTK correction signal (EPOSA, Vienna, Austria) was used to locate the measuring points.

2.2 Determination of the surface residue coverage

Similar to many studies (Winnige et al., 1998; Raper, 2002; López et al., 2003; Hänsel et al., 2009; Walther, 2009; Mitchell et al., 2015), the line transect method was chosen to determine the soil coverage. In these experiments, the line length and number of measuring points were adapted to the 3 m working width of the cultivator. Along the 4.24 m long base of the isosceles triangle, a line with 25 measuring points at 0.10-m intervals was taut. All measuring points that completely cut a minimum 3-mm long straw particle were counted and multiplied by four, resulting in soil coverage factor in percent (%) of the total number of pearls.

As a second method, image analysis was used. Photos (resolution: 6,000 × 4,000 pixels; exposure time: 1/125 to 1/160 s; aperture: f/13 to f/11; focal length: 16 mm; ISO 200 B) were taken using a camera of the model Alpha SLT-A77V (Sony, Minato, Japan) at a distance of 1.5 m above the ground surface with an angle of view of 83° capturing an area of about 1.2 m × 1.8 m.

For the image analysis, a self-written program running in OpenCV 3.3.0 was used. The photos were first transformed from red, green, and blue (RGB) color space into the hue, saturation, and value (HSV) color space. With individual adjustment of the upper and lower thresholds of the three axes, HSV, the changing light conditions were taken into account and only those pixels were depicted, which represented straw. The ratio of straw pixels to the total number of pixels in the photo represented the surface residue coverage in percent (%) to the covered area. By individually adjusting the respective threshold values of color HSV, image analysis was able to achieve a satisfactory differentiation between straw and soil despite the spectral similarity and changing light and moisture conditions.

2.3 Determination of the amount of surface crop residues

As in other studies (Staricka et al., 1991; Arvidsson, 1998; Raper, 2002; López et al., 2003; Mitchell et al., 2015), the surface amount of crop residues was determined by removing them within a defined area. As in the study by Arvidsson (1998), the area had an extension of 0.25 m². After manual collection and air drying, straw and soil residues were separated using a 2 mm sieve and manual sorting. The dry matter of the straw was determined by weighing after drying in an oven for 24 h at 105°C.

2.4 Determination of the incorporated crop residues

The incorporated crop residues were determined using soil cores (as done by Christian and Miller, 1986; Allmaras et al., 1988; Ball and Robertson, 1990; Staricka et al., 1991; Raper, 2002; Duiker and Beegle, 2006; Mitchell et al., 2015). The individual analyzed cores had a length of 0.05 m (cf., Raper, 2002). To avoid partial compaction and thus a distortion of the results by using only one long core, separate 0.05 m long soil cores were used. Core removal was performed with a device that was placed in an excavated profile pit next to the test location. After removing the surface straw, a sharpened 1.5 mm thick ST37 steel plate was driven in horizontally at a specified depth of 0.05 m, guided by the removal device. As a result, the 0.05-m segment was defined in advance and compression during sampling no longer had a falsifying effect on the result. The sampler (ST35 steel tube, 52 mm external diameter, 48 mm internal diameter, 2 mm wall thickness) was carefully hammered from above down to the plate. Before removing, the tube was rotated several times in order to cut off outstanding straw. After removing the core and the surrounding soil, the plate was pulled out and driven in again, but 0.05 m deeper. This process was repeated for all segments. Repeated sharpening of the tube and the plate prevented the straw being pushed into the soil instead of being cut. After air drying of samples, crop residues and soil were sorted using a 2 mm sieve. In addition, remaining small lumps and stones were removed by hand. After drying in an oven for 24 h at 105°C, the dry matter of the straw was determined by weighing.

Before soil tillage, 15 measuring points were analyzed with soil cores up to a depth of 0.35 m in order to determine any crop residues from the pre-crop. After soil tillage, the number of cores was selected depending on the TD, because new straw incorporation was not expected without tillage influence. Ball and Robertson (1990) reported that by loosening the soil, the depth of the working profile was greater than the original TD. Therefore, samples were always collected 0.05 m deeper than that corresponding to the actual TD. So, the 15 measuring points with 0.30 m TD were sampled at a depth up to 0.35 m (i.e., 7 soil cores), the 0.20 m TD up to 0.25 m (5 soil cores) and the 0.10 m TD up to 0.15 m (3 soil cores).

2.5 Statistical analysis and Data evaluation

For the statistical analysis, SPSS Statistics 24 software (IBM, Armonk, New York, USA) was used. Owing to the high variance of the data, outliers were removed from the values of the surface and incorporated crop residues. As outliers, all values that differed by more than two standard deviations from the mean value were defined. Line transect data and image analysis data were analyzed using the Levene test, the one-way analysis of variance, and Tukey's post hoc test. Data on surface and total incorporated residues were analyzed using the Levene test, the one-way analysis of variance, and the Tukey–Kramer post hoc test. In addition, the distribution in the depth segments (DSs) was analyzed using the multivariate variance analysis (MANOVA) with the Pillai–Spur test. Subsequently, univariate analyses and the Games-Howell post hoc test were conducted for each DS. The MANOVA was limited to the top three DS, as these were the only ones for which individual values were collected for all TD.

Data from the CAN and ISO bus were processed with MATLAB R2017a (The Mathworks Inc., Natick, USA) using a program specially written for the application. For the averaging of the process parameters, the turns were geometrically excluded from the calculation.

3. Results and discussion

3.1 Surface residue coverage

Before tillage, soil coverage of 100% was determined. After tillage, no significant differences ($p = 0.136$) could be detected by image analysis, whereas for the line transect method, a significantly higher ($p = 0.001$) soil coverage was observed for the TD of 0.30 m (Table 1). It was observed that soil coverage in these trials was higher with greater TD. In contrast, in the study of Walther (2009), both methods resulted in a higher degree of soil coverage with shallower tillage than with deeper tillage. Hänsel et al. (2009), on the other hand, observed no significant correlation between the TD of a cultivator (0.05, 0.10, and 0.15 m) and the degree of soil coverage. Figure 1 shows the marked differences in results with the two methods: The line transect method resulted in a high degree of coverage with all three TD, while the mean values (MV) of the image analysis were significantly lower for all three TD. In the studies of Walther (2009) and Winnige et al. (1998), the line transect method also resulted in a higher degree of soil coverage compared to image analysis. Pforte (2010) explained this systematic overestimation of the visual method by the fact that if a straw particle is located below a measuring point, the degree of soil cover is always valued equally irrespective of the actual amount of straw present.

3.2 Surface crop residues

Before tillage, surface crop residues had an MV of 10.49 t/ha (standard deviation, $\sigma \pm 2.38$ t/ha) (Table 2). After tillage, there were significant differences ($p < 0.001$) in the amount of surface crop residues among the three TD. With 2.55 t/ha ($\sigma \pm 0.68$ t/ha), at the TD of 0.30 m, significantly more crop residues were present on the surface than for 0.10 m (MV = 0.92 t/ha; $\sigma \pm 0.49$ t/ha) and 0.20 m (MV = 1.39 t/ha; $\sigma \pm 0.54$ t/ha). Although greater TD could be expected to leave less crop residues on the surface, in these experiments, the results (as well as those of the line transect method) showed the inverse effect. This could be due to the changed tool geometry resulting in a greater cutting angle at the surface for deeper tillage and thus a reduced mixing effect. In addition, the reduced speed over ground because of wheel slip and engine power limits at greater TD can also be a reason for a reduced mixing and thus incorporation of harvest residues.

3.3 Incorporated crop residues

Before soil tillage, there was an average of 2.08 t/ha of crop residues in the 0–0.35 m DS (Table 2). After tillage, no significant differences ($p = 0.619$) were observed in the 0–0.35 m DS between the TD in terms of the total incorporated crop residues, although the values showed wide scattering. However, in the experiments of Raper (2002), the two TD of a cultivator (0.076 and 0.152 m) also buried similar amounts of crop residues. In the study of Riley and Ekeberg (1998), also no significant difference was observed in the total organic matter content between three TD of a plough (0.10, 0.20, and 0.30 m). In contrast to plowing, where the depth of incorporation of residues increases with the TD (Eltom et al., 2015), this trend was not observed with reduced tillage.

The following results of the depth distribution of incorporated crop residues, also presented in Figure 2 and Table 2, are given in t/ha contained in one DS (each 0.05 m core and 0.35 m in total). After soil tillage, more than 90% of the crop residues were located in the uppermost two DS, independent of the respective TD; below the depth of 0.10 m, only a small proportion was present (Figure 3). These results are consistent with findings of several studies (Ball and Robertson, 1990; Grube, 2003; Duiker and Beegle, 2006; Dimassi et al., 2014; Eltom et al., 2015; Mitchell et al., 2015). For example, in the long-term experiments on reduced soil tillage of Tebrügge and Düring (1999), 60% of the crop residues were observed at a depth of 0–0.05 m and 30% at 0.05–0.10 m. Also Estler and Knittel (1996) reported that, depending on the type of cultivator, 50–60% of the crop residues were located in the top 0.05 m and 25–30% from 0.05 to 0.01 m. The pre-

Table 1. Mean values (MV) and standard deviations (σ) of the soil coverage by line transect method and image analysis for the three tillage depths, 0.10, 0.20, and 0.30 m, after soil tillage (different letters show significant differences between the values with $p < 0.05$, $n = 15$).
Tabelle 1. Mittelwerte (MV) und Standardabweichungen (σ) der Bodenbedeckungsgrade ermittelt mittels des Linientransektverfahrens sowie der Bildanalyse für die drei Bearbeitungstiefen 0,10 m, 0,20 m und 0,30 m nach der Bodenbearbeitung (unterschiedliche Buchstaben zeigen signifikante Unterschiede zwischen den Werten mit $p < 0,05$, $n = 15$).

	Soil coverage (%) according tillage depth					
	0.10 m		0.20 m		0.30 m	
Method	MV	σ	MV	σ	MV	σ
Line transect	57.60a	7.70	60.53a	10.01	69.87b	7.54
Image analysis	23.80c	5.24	25.07c	7.48	29.27c	9.63

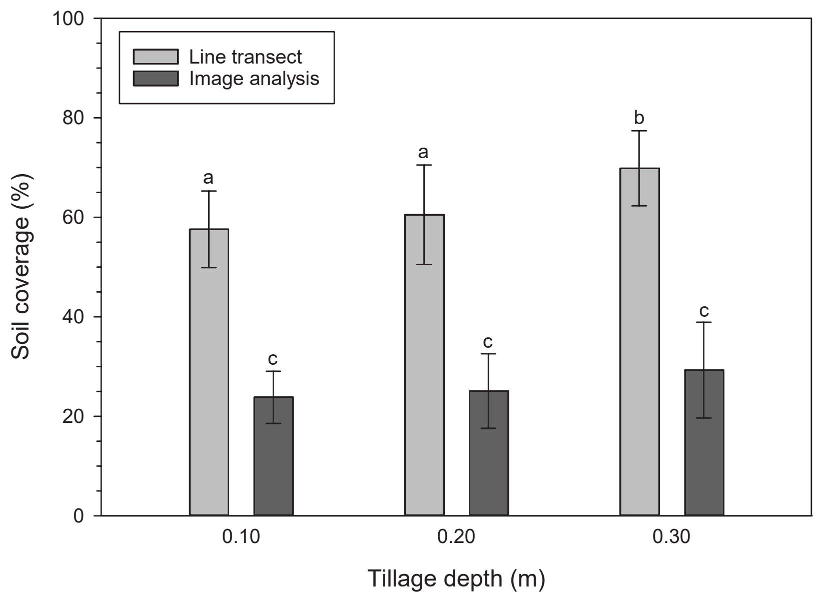

Figure 1. Mean values and standard deviations of the soil coverage by line transect method and image analysis for the three tillage depths, 0.10, 0.20, and 0.30 m, after soil tillage (different letters show significant differences between the values with $p < 0.05$, $n = 15$).
Abbildung 1. Mittelwerte und Standardabweichungen der Bodenbedeckungsgrade ermittelt mittels des Linientransektverfahrens sowie der Bildanalyse für die drei Bearbeitungstiefen 0,10 m, 0,20 m und 0,30 m nach der Bodenbearbeitung (unterschiedliche Buchstaben zeigen signifikante Unterschiede zwischen den Werten mit $p < 0{,}05$, $n = 15$).

dominant incorporation of crop residues into the uppermost 0.10 m of soil and the pronounced stratification over the soil profile seems to be a general occurrence in reduced tillage systems (Dimassi et al., 2014). However, in many studies, only shallow TD of a cultivator was used. Even though deeper tillage was used in this study, at a depth of 0.20 and 0.30 m, incorporation of crop residues was mainly in the near-surface layer and a pronounced stratification of crop residues was noticeable. This was also observed by Schulz et al. (2014) with a TD of 0.18 m. In the study of Christian and Miller (1986), only the practices involving plowing could incorporate significant amounts of straw at a depth of 0.10–0.15 m. When only a cultivator was used, most of the residues were observed in the near-surface layer (0–0.10 m) and 20–30% were observed also on the surface. The results of these experiments and those reported in the literature indicate that, with a cultivator and irrespective of TD, it is not possible to incorporate significant quantities of crop residues deeper than 0.10 m.

The MANOVA showed significant differences ($p < 0.001$) between the three TD for the three uppermost DS in relation to the crop residues incorporated. At a TD of 0.20 m, in the DS of 0.05–0.10 m, there were significantly more crop residues than at the other two TD ($p < 0.001$). No significant differences were observed in the DS of 0–0.05 m and 0.10–0.15 m ($p = 0.081$ and 0.105, respectively).

This indicates that greater mixing was achieved with the TD of 0.20 m, whereas this effect decreased again for the TD of 0.30 m. It seems that the mixing in of crop residues depends on the cutting geometry and the cutting angle at the surface. With an angle of less than 90° between ground surface and tines (seen in the direction of movement), the mixing in of crop residues is limited at a TD of 0.30 m. However, with all three TD, more than 90% of the incorporated crop residues was located in the upper 0.10 m and, in addition, the total amount of incorporated crop residues showed no significant differences.

The tractor data of these experiments (Table 3) showed a linear increase in the horizontal force acting on the rear hitch by increasing the TD. The change in TD from 0.10 to 0.30 m leads to an increase in draft force by a factor of 2.17. This caused a nonlinear enhancement in wheel slip too, resulting in increased fuel consumption by a factor of 2.67 (TD: from 0.10 to 0.30 m). In addition, the area efficiency decreased by 26% (TD from 0.10 to 0.30 m). These two parameters lead ultimately to a significant increase in tillage costs.

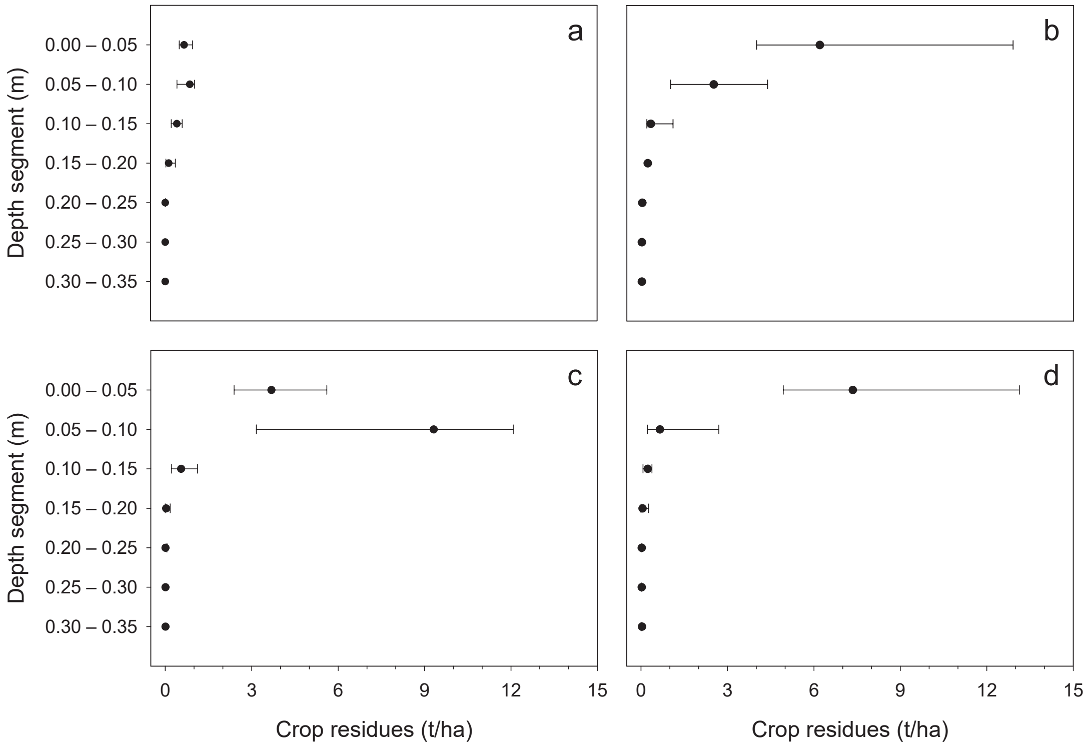

Figure 2. Medians, 25th percentiles and 75th percentiles of crop residues in the different depth segments (a) before (untilled, n = 9) and after soil tillage for the three tillage depths, (b) 0.10 m (n = 13), (c) 0.20 m (n = 11), and (d) 0.30 m (n = 12).
Abbildung 2. Median, 25 und 75 Prozent Perzentile der Ernterückstände in den unterschiedlichen Tiefensegmenten vor (a: untilled, n = 9) und nach dem Grubbern für die drei Bearbeitungstiefen 0,10 m (b: n = 13), 0,20 m (c: n = 11) und 0,30 m (d: n = 12).

Table 2. Mean values (MV) and standard deviations (σ) of surface (n = 15 for untilled and 0.10 m, and n = 14 for 0.20, and 0.30 m) and incorporated crop residues in the different depth segments (DSs) before soil tillage (untilled, n = 9) and after soil tillage for the three tillage depths, 0.10 m (n = 13), 0.20 m (n = 11), and 0.30 m (n = 12) (* represents values not collected directly, but taken from the tests before tillage).
Tabelle 2. Mittelwerte (MV) und Standardabweichungen (σ) der Ernterückstände an der Oberfläche (n = 15 für untilled und 0,10 m sowie n = 14 für 0,20 m und 0,30 m) und in den unterschiedlichen Tiefensegmenten (DS) vor dem Grubbern (untilled, n = 9) und nach dem Grubbern für die drei Bearbeitungstiefen 0,10 m (n = 13), 0,20 m (n = 11) und 0,30 m (n = 12) (* Werte nicht eigens erhoben, sondern von den Vorher-Versuchen übernommen).

	Surface (t/ha) and incorporated crop residues (t/ha per DS)							
	Untilled		Tillage depth					
			0.10 m		0.20 m		0.30 m	
DS (m)	MV	σ	MV	σ	MV	σ	MV	σ
Surface	10.49	2.38	0.92	0.49	1.39	0.54	2.55	0.68
0.00–0.05	0.68	0.30	8.01	4.98	4.49	3.13	8.78	5.45
0.05–0.10	0.76	0.34	2.76	2.03	7.96	4.65	1.59	2.25
0.10–0.15	0.43	0.33	0.67	0.73	0.61	0.42	0.25	0.20
0.15–0.20	0.20	0.20	0.20*	0.20*	0.16	0.34	0.16	0.31
0.20–0.25	0.01	0.01	0.01*	0.01*	0.07	0.21	0.02	0.04
0.25–0.30	0	0	0*	0*	0*	0*	0.01	0.02
0.30–0.35	0	0	0*	0*	0*	0*	0.02	0.02
0.00–0.35	2.08	0.68	11.64	6.39	13.30	4.70	10.82	6.94

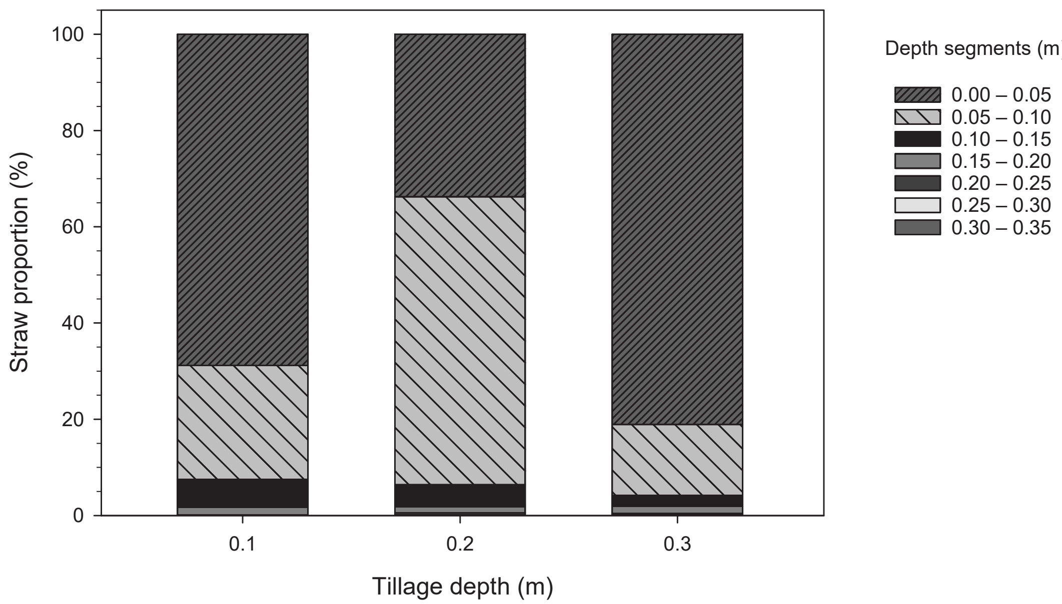

Figure 3. Proportion (%) of the total straw incorporated, which is located in the respective depth segments for the three tillage depths: 0.10, 0.20, and 0.30 m.
Abbildung 3. Anteil (%) des insgesamt eingearbeiteten Strohs, welcher sich in den jeweiligen Tiefensegmenten für die drei Bearbeitungstiefen 0,10, 0,20 und 0,30 m befindet.

4. Conclusions

Regarding the results of the surface crop residues, the line transect method and the amount of surface residues showed a significantly higher degree of soil cover and surface crop residue amounts for the TD of 0.30 m. The image analysis showed also increased surface coverage at a higher TD but demonstrated no significant differences among the three TD in terms of surface residue coverage. These results were contrary to expectations. The significant differences of the other methods could not be proven, on the one hand, with the help of image recognition, which is used for classification into reduced and conservation tillage according to the ASAE (2005) and thus the evaluation of mitigation of soil erosion, and on the other hand, because more crop residues remain on the surface despite a more intensive tillage. No significant differences were observed among the three TD in terms of the total incorporated crop residues. Considering the depth distribution, it was found that more than 90% of the incorporated crop residues were located in the upper

Table 3. Mean values (MV) and standard deviations (σ) of wheel slip, horizontal force acting on the rear hitch, fuel consumption, and area efficiency during tillage for the three tillage depths (TDs): 0.10, 0.20, and 0.30 m.
Tabelle 3. Mittelwerte (MV) und Standardabweichungen (σ) von Radschlupf, Horizontalkraft auf das Heckhubwerk, Kraftstoffverbrauch und Flächenleistung bei der Bodenbearbeitung für die drei Bodenbearbeitungstiefen (TD) 0,10, 0,20 und 0,30 m.

	Wheel slip (%)		**Horizontal force of the hitch (kN)**		**Fuel consumption (l/ha)**	**Area efficiency (ha/h)**
TD (m)	MV	σ	MV	σ	MV	MV
0.10	0.70	0.95	32.22	3.62	9.77	2.38
0.20	6.63	1.68	51.16	4.43	16.02	2.24
0.30	18.64	2.92	69.08	4.39	25.60	1.76

0.10 m, irrespective of the TD. When using a cultivator, it does not seem possible to incorporate significant amounts of straw deeper than 0.10 m. At a TD of up to 0.20 m, the mixing of soil and crop residues is improved, whereas with a greater TD, the mixing in effect seems to decrease. Thus, it can be concluded that for the chernozem soil in the production area of Marchfeld, using a cultivator with chisel shares and a target working speed of 8 km/h, in terms of straw management alone, a TD greater than 0.20 m is not necessary, as the soil structure and texture do not require a deeper loosening. Consistently shallower soil tillage would also enable a reduction in draft and fuel consumption and, thus, tillage costs. As the influence of tool geometry is suspected, further studies are considered necessary to investigate this.

Acknowledgment

We would like to thank the K1-Center alpS GmbH for its support in this project. Pöttinger Landtechnik GmbH and Steyr Traktoren GmbH are thanked for providing the equipment for the field trials.

References

Akmal, M., Shah, A., Zaman, R., Afzal, M. and N. ul Amin (2015): Carryover response of tillage depth, legume residue and nitrogen-rates on maize yield and yield contributing traits. International Journal of Agriculture and Biology 17, 961–968.

Allmaras, R.R., Copeland, S.M., Copeland, P.J. and M. Oussible (1996): Spatial relations between oat residue and ceramic spheres when incorporated sequentially by tillage. Soil Science Society of America Journal 60, 1209–1216.

Allmaras, R.R., Pikul Jr., J.L., Kraft, J.M. and D.E. Wilkins (1988): Method for measuring incorporated crop residue and associated soil properties. Soil Science Society of America Journal 52, 1128–1133.

Arvidsson, J. (1998): Effects of cultivation depth in reduced tillage on soil physical properties, crop yield and plant pathogens. European Journal of Agronomy 9, 79–85.

ASAE (2005): Terminology and Definitions for Soil Tillage and Soil-Tool Relationships. American Society of Agricultural Engineers, St. Joseph, MI, USA.

Ball, B.C., Bickerton, D.C. and E.A.G. Robertson (1990): Straw incorporation and tillage for winter barley: Soil structural effects. Soil & Tillage Research 15, 309–327.

Ball, B.C. and E.A.G. Robertson (1990): Straw incorporation and tillage methods: Straw decomposition, denitrification and growth and yield of winter barley. Journal of Agricultural Engineering Research 46, 223–243.

Blanco-Canqui, H. and R. Lal (2010): Principles of Soil Conservation and Management. Springer, Dordrecht.

Brunotte, J. (2007): Konservierende Bodenbearbeitung als Beitrag zur Minderung von Bodenschadverdichtungen, Bodenerosion, Run off und Mykotoxinbildung im Getreide. Landbauforschung Völkenrode Sonderheft 305. Bundesforschungsanstalt für Landwirtschaft (FAL), Braunschweig.

Christian, D.G. and D.P. Miller (1986): Straw incorporation by different tillage systems and the effect on growth and yield of winter oats. Soil & Tillage Research 8, 239–252.

Dimassi, B., Mary, B., Wylleman, R., Labreuche, J., Couture, D., Piraux, F. and J. Cohan (2014): Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years. Agriculture, Ecosystems & Environment 188, 134–146.

Dölger, D. and M. Wörz (2006): Drei Schritte zur optimalen Tiefe. DLG-Mitteilungen 12, 42–47.

Duiker, S.W. and D.B. Beegle (2006): Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil & Tillage Research 88, 30–41.

Eltom, A., Ding, W., Ding, Q., Tagar, A., Talha, Z. and Gamareldawla (2015): Field investigation of a trashboard, tillage depth and low speed effect on the displacement and burial of straw. CATENA 133, 385–393.

Estler, M. and H. Knittel (1996): Praktische Bodenbearbeitung: Grundlagen, Gerätetechnik, Verfahren, Bewertung. DLG-Verlag, Frankfurt am Main.

Gajda, A.M.,Czyz, E.A., Dexter, A.R., Furtak, K.M., Grządziel, J. and J. Stanek-Tarkowska (2018): Effects of different soil management practices on soil properties and microbial diversity. International Agrophysics 32, 81–91.

Grube, J. (2003): Beurteilung von konservierenden Bodenbearbeitungssystemen zur Bewirtschaftung peripherer Ackerbaustandorte – unter Berücksichtigung verfahrenstechnischer, ökonomischer, ökologischer sowie pflanzenbaulicher und bodenphysikalischer Parameter. Cuvillier, Göttingen.

Guérif, J., Richard, G., Dürr, C., Machet, J.M., Recous, S. and J. Roger-Estrade (2001): A review of tillage effects on crop residue management, seedbed conditions and seedling establishment. Soil & Tillage Research 61, 13–32.

Hänsel, M., Müller, E. and U. Becherer (2009): Erosionsminderung in der Landwirtschaft - Maßnahmen zur Erosionsminderung im konventionellen und ökologischen Landbau unter Einbeziehung der teilschlagspezifischen Bodenbearbeitung. Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Dresden.

Jordan, V.W.L. and J.A. Hutcheon (2002): Influence of cultivation practices on arable crop diseases. In: El Titi, A. (Ed.): Soil Tillage in Agroecosystems. CRC Press, Boca Raton, FL, USA, pp. 187–206.

Köller, K. and C. Linke (2001): Erfolgreicher Ackerbau ohne Pflug. DLG-Verlag, Frankfurt am Main.

Lahmar, R. (2010): Adoption of conservation agriculture in Europe. Land Use Policy 27, 4–10.

Liu, J., Chen, Y. and R.L. Kushwaha (2010): Effect of tillage speed and straw length on soil and straw movement by a sweep. Soil & Tillage Research 109, 9–17.

López, M.V., Moret, D., Gracia, R. and J.L. Arrúe (2003): Tillage effects on barley residue cover during fallow in semiarid Aragon. Soil & Tillage Research 72, 53–64.

Manuwa, S.I. (2009): Performance evaluation of tillage tines operating under different depths in a sandy clay loam soil. Soil & Tillage Research 103, 399–405.

Mitchell, J., Shrestha, A., Horwath, W., Southard, R., Madden, N., Veenstra, J. and D. Munk (2015): Tillage and Cover Cropping Affect Crop Yields and Soil Carbon in the San Joaquin Valley, California. Agronomy Journal 107, 588–596.

Moitzi, G., Wagentristl, H., Refenner, K., Weingartmann, H., Piringer, G., Boxberger, J. and A. Gronauer (2014): Effects of working depth and wheel slip on fuel consumption of selected tillage implements. Agricultural Engineering International: CIGR Journal 16, 182–190.

Neugschwandtner, R.W., Liebhard, P., Kaul, H.-P. and H. Wagentristl (2014): Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. Plant, Soil and Environment 60, 57–62.

Pforte, F. (2010): Entwicklung eines Online-Messverfahrens zur Bestimmung des Bodenbedeckungsgrades bei der Stoppelbearbeitung zu Mulchsaatverfahren. Dissertation, Universität Kassel, Witzenhausen.

Pöttinger (2007): Betriebsanleitung SYNCRO 3003. https://www.poettinger.at/landtechnik/download/betriebsanleitungen/9762.DE.80I.1.pdf. Accessed on 9 July 2019.

Raper, R.L. (2002): The influence of implement type, tillage depth, and tillage timing on residue burial. Transactions of the American Society of Agricultural Engineers 45, 1281–1286.

Raper, R.L. (2001): The influence of implement type and tillage depth on residue burial. In: Ascough II, J.C. and D.C. Flanagan (Eds.): Soil erosion research for the 21st century. Proceedings of the International Symposium, 3–5 January 2001, Honolulu, USA, American Society of Agricultural and Biological Engineers, St. Joseph, pp. 517–520.

Riley, H. and E. Ekeberg (1998): Effects of depth and time of ploughing on yields of spring cereals and potatoes and on soil properties of a morainic loam soil. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science 48, 193–200.

Szalay, T., Moitzi, G., Liebhard, P. and H. Weingartmann (2015): Einfluss unterschiedlicher Bodenbearbeitungssysteme auf Kraftstoffverbrauch und Arbeitszeitbedarf für den Winterweizenanbau im semiariden Produktionsbetrieb. Die Bodenkultur 66, 39–48.

Schulz, F., Brock, C., Schmidt, H., Franz, K. and G. Leithold (2014): Development of soil organic matter stocks under different farm types and tillage systems in the Organic Arable Farming Experiment Gladbacherhof. Archives of Agronomy and Soil Science 60, 313–326.

Sommer, C. (2003): Techniken und Verfahren zur ressourcenschonenden Bodennutzung - Rückblick und Perspektiven. Landbauforschung Völkenrode, Sonderheft 256, 101–109.

Staricka, J.A., Allmaras, R.R. and W.W. Nelson (1991): Spatial variation of crop residue incorporated by tillage. Soil Science Society of America Journal 55, 1668–1674.

Tebrügge, F. and R.-A. Düring (1999): Reducing tillage intensity — a review of results from a long-term study in Germany. Soil & Tillage Research 53, 15–28.

Voßhenrich, H.-H., Brunotte, J. and B. Ortmeier (2003): Methoden zur Bewertung der Strohverteilung und Einarbeitung. Landtechnik 58, 92–93.

Walther, S. (2009): Variable Bodenbearbeitungsintensität: ein Beitrag zum nachhaltigen Bodenschutz. Kovač, Hamburg.

Winnige, B., Corzelius, U. and M. Frielinghaus (1998): Indikation der aktuellen Erosionsgefährdung mit Hilfe der Bodenbedeckung. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 88, 569–572.