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Plant remains distribution quality of different combine harvesters in connection with conservation tillage technologies

Z. Kviz*, F. Kumhala and J. Masek

Czech University of Life Sciences in Prague, Faculty of Engennering, Department of Agricultural Machines, Kamycka 129, Prague 6 – Suchdol, 165 21, Prague, Czech Republic; *Correspondence: kviz@tf.czu.cz

Abstract. Conservation tillage technologies are nowadays a part of modern agriculture. These technologies are used in plant production all around the world. Typical feature for these shallow soil tillage technologies is that all plant residues are left on the soil surface or in the treated (tilled) upper soil layer. The plant residues can significantly influence the next plant germination and growth, especially when they are unevenly placed on the field surface. Today's modern combine harvesters are able to crush and distribute all plant remains quite evenly with satisfactory results but all their mechanisms have to be properly set and sometimes some small improvements have to be done. This paper describes and evaluates the husk and straw distribution quality – the distribution pattern, on two very commonly used combine harvesters – CASE IH and JOHN DEERE. The measurement was carried out on serially manufactured machines without any change on them and with a small improvement on distribution mechanisms. The measurement of husk and straw distribution pattern was carried out on CASE IH combine harvester with an axial threshing system and on John Deere with a conventional tangential threshing system. Thereby it was possible to compare two completely different systems of threshing process and to observe a possible influence on straw and husk distribution quality (distribution pattern).
The most important outcome of the measurement of straw and husk distributors' work quality on combine harvesters is that cross irregularity of husk and straw distribution depends on instantaneous material feedrate through the harvester.

Key words: straw crushing, combine harvesters, conservation tillage, plant remains, distribution pattern.

INTRODUCTION

Soil conserving tillage technologies, where ploughing by a mouldboard plough is replaced by tillers and shallow soil loosening, are used in agricultural practice as an alternative soil treatment. Besides the advantages of the application of this kind of soil cultivation, there are some problems and risks arising, which are not significant when ploughing is applied. It is typical for shallow soil tillage that all plant residues are left on the soil surface, or in the treated (tilled) upper soil layer. These plant residues can play an important role for the next plant cultivation and its yield. Based on the research of Johnson (1988), it can be said that all possible negative effects (effects on next plant seed germination, shedding growth, rodents spreading) can be eliminated or at least minimized as early as when the preceding crop is harvested (short stubble, small plant particles – maximum length of crushed straw particles up to 5 cm and regularity of plant residues left on the field surface after combine harvester passage). Furthermore, the negative effects can be minimized by appropriate technology and application time and, last but not least, by tools used for shallow tillage, seedbed preparation and seeding.

Sow et al., 1997 evaluated the influence of tillage and residue management practices on grain sorghum (*Sorghum bicolor* (L.) Moench), namely rooting depth and also changes in soil water content and cone index. Conservation tillage systems even increased sorghum grain yields by around 15% compared to conventional tillage system with ploughing. Root length in the 40 to 60 cm depth on reduced tillage plots was by 30 to 85% greater compared to the conventional tillage. Malhi at al., 2006 found out that different tillage and straw treatments had generally no significant effect on crop yield during the first three years observed. But after that time, reduced tillage plots produced 55, 32 and 20% greater canola seed, straw and chaff respectively than conventional tillage. There is also research evaluating different combinations of soil tillage and straw management including straw burning and their influence on next crop yield (Heege & Voßhenrich, 2000).

Placement of straw remains into the seeding layer, which is very often to happen when using only shallow tillage without ploughing, has an adverse effect and reduces plant germination up to 68% compared with 80% germination ratio when straw incorporating by a plough (Prochazkova & Dovrtel, 2000).

There is also research evaluating different combinations of soil tillage and straw management including straw burning and their influence on next crop yield (Heege & Voßhenrich, 2000). The best results were achieved exactly for straw burning technology and the worst for straw chopping and its shallow incorporation into soil.

From the previous crop harvest point of view, it has been revealed that cross irregularity of husk and straw distribution is a very significant point for the start of next crop planting. According to many authors, the basic precondition for good tillage and further crop growth is well performed harvest of preceding crop – short stubble, well chopped straw and evenly distributed plant remains on the field surface (Raoufat & Mahmoodieh, 2005; Bahrani, 2007).

The main subject of this article is the observation of the husk and straw distribution pattern by axial and tangential combine harvesters in real operation. Furthermore, the effect of this plant residues' irregular on-surface placement after harvest on residues placement in soil profile after treatment by a shovel tiller.

MATERIALS AND METHODS

Soil conservation technology is a soil tillage system with certain benefits but also with specific prerequisites. One of the specific conditions is the quality of chopping and distribution of plant remains after preceding crop harvest. Good plant remains management means that the crushing mechanisms of combine harvesters have to ensure that 90% of plant remains particles must be shorter than 80 mm and the crushed straw and other organic remains (husk weed seeds, grain losses etc.) have to be evenly distributed along the working width of the machine Johnson (1988).

Plant remains distribution quality was observed after a passage of the combine harvester observed type. The observed area was 6 m wide strip behind the combine harvester passage with crop residues chopped and distributed on a field surface. This sampling area was at minimum 20 m from the point where the combine harvester started the passage in order to ensure that the combine harvester was completely full with the harvested material. The sampling area – 6 m long strip corresponded with machine's working width and was divided into twelve 0.5 m wide intervals. Then, all plant residues were collected from 0.1 m^2 area, which was considered as an 'interval sample'. Grain losses were separated from each sample and their placement across combine harvester working width was evaluated.

The measurement of husk and straw distribution pattern was carried out on CASE IH 2188 combine harvester with an axial threshing system and on John Deere 2266 with a conventional tangential threshing system. Thereby, it was possible to compare two completely different systems of threshing process and to observe a possible influence on straw and husk distribution quality (distribution pattern).

The following experimental arrangements and machines were evaluated:

Combine harvester John Deere 2266 was equipped with the engine power of 199 kW; header 5.90 m in width; threshing drum 660 mm in diameter and 1,670 mm in width; the total concave area 1.08 m^2; the total straw walker´s area 7.67 m^2; the total sieves area 5.083 m^2; the machine was equipped with a standard straw chopper and a twin vane-disc straw distributor mounted. (JD genuine equipment).

Combine harvester Case IH 2188 was of 196 kW engine power; 5.90 m header in width; rotor placed longitudinally; rotor 762 mm in diameter and 2,970 mm in length; the total cleaning area 5.12 m^2; a standard straw chopper and a two disc straw distributor mounted.

Combine harvester Case IH 2188 with 196 kW engine power; 5.90 m header in width; rotor placed longitudinally; rotor 762 mm in diameter and 2,970 mm in length; the total cleaning area 5.12 m^2; a standard straw chopper and two disc straw distributor mounted – with a specific improvement.

The straw distributor improvement consisted in elongation of husk distributing disc shafts by 20 cm. Due to this, the rotation surface of discs was lower, and therefore more small straw particles and husks, coming from sieves, could fall down onto both discs and could be distributed with more even pattern.

The number of repetitions of each measured variant was six at minimum. It means that we had 12 interval samples from one combine harvester passage with six or more repetitions.

Our experiments were realised during the standard harvesting season 2012 under ordinary field conditions on farms in the Czech Republic. The samples were being taken under normal operational conditions and therefore represent common machine setting, travelling speed and harvested plant state suitable for optimal harvest.

Measurement conditions:

- oil rape harvest – combine harvester setting according to the manufacturer's recommendations, working speed 6–8 km h^{-1}, grain moisture 7%, straw moisture 12%, yield 3.0 t ha^{-1}, 57 plants per 1 m^2;
- winter wheat harvest – combine harvester setting according to the manufacturer's recommendations, working speed 5–9 km h^{-1}, grain moisture 15%, straw moisture 17%, yield 5.2 t ha^{-1}, 590 plants per 1 m^2.

For plant residues' distribution quality evaluation, the Christiansen's coefficient was used. This coefficient determines a percentage deviation of each measurement and then an average value of these deviations from all measurements' arithmetic mean. When these deviations are small the value of Christiansen's coefficient is close to the value 1 (alternatively 100% if counting in percent) and vice versa.

This evaluation criterion was chosen because it perfectly and logically shows the variation size of the plant remains distribution values throughout the combine harvester header working width. The range of the Christiansen´s coefficient is within confined interval <0; > or <0; 100% > as opposed to other statistical variables possible to use for the distribution quality evaluation. And also this coefficient is used for the uniformity of liquid spreading and other liquid distribution characteristics evaluation on sprayers and sprinklers, which is very close to the distribution pattern of plant remains behind the combine harvesters. Coefficient of Christiansen´s is calculated using the following formula (1):

$$C_u = \left[1 - \left(\sum_{i=1}^{n} \left| i_{si} - i_m \right| / n \cdot i_m\right)\right] \quad (1)$$

where: i_{si} – weight of an interval sample (g); C_u range <0;1>; i_m – arithmetic mean of i_{si} values (g); n – number of samples.

For every measurement the Christiansen's coefficient was counted separately for husk and for straw remains. It was assumed that the distribution quality of crop remains would depend also on their immediate amount, so the Christiansen's coefficient was calculated in dependence on the total weight of the sample from the area across the combine working width.

These values were processed separately for oil rape and winter wheat, each time for straw and husk and for all three kinds of evaluated combine harvesters. Graphical evaluation of our measurement was carried out by means of MS Excel charts.

Shallow tillage after harvest was performed by a shovel tiller after harvest on the examined plot. Number of plants germinated from grain losses was determined by manual counting.

Also plant residues placement evaluation after shallow tillage was carried out at the same places as grain losses were observed and by manual collecting of plant particles from the area of 0.1 m^2. The evaluation of crop residues placement after shallow tillage consisted of two measurement – firstly collection and weighing of crop residues remained on the field surface, and secondly collection and weighing of crop residues within the treated soil profile.

RESULTS AND DISCUSSION

Distribution regularity evaluation – In all cases and variants it was found out that the irregularity of crop residues' distribution was always increasing with the increasing feed rate of combine harvester (mass going through the harvester). This fact was proved both for straw (Fig. 1) and for husk (Fig. 2) by winter wheat and oil rape harvest as well. The more material was harvested the worse Christiansen's coefficient was calculated.

There is a total weight of plant residues from one combine harvester passage (the sum of all interval samples) on the X-axis and there are Christiansen's coefficient values on the Y-axis. The presented charts are for winter wheat only.

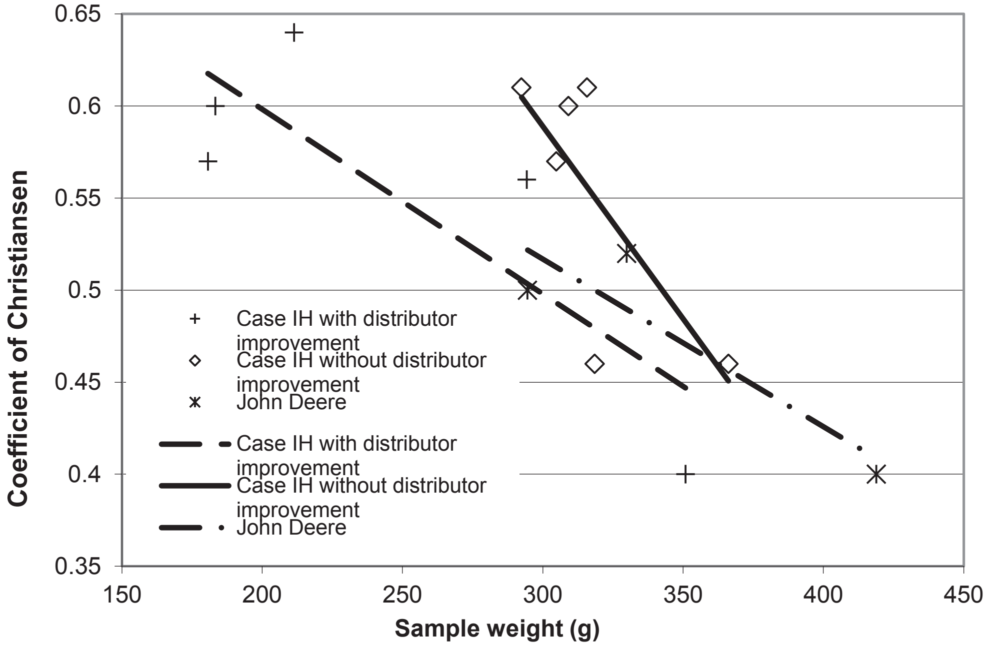

Figure 1. Straw distribution uniformity during winter wheat harvest.

The cleaning sieves on axial combine harvesters (CASE IH) gather more small plant particles in comparison with conventional tangential harvesters (John Deere). These particles flow from a threshing mechanism where material stays a certain time in the space between the threshing drum and the concave during threshing. When evaluating the axial threshing system, harvested material stays longer in the threshing space and the straw is therefore much more treated and broken up than by using a tangential threshing system. This fact was observed mainly during the oil rape harvest where the straw, very easy to break off, was not crushed so much in tangential threshing system as opposed to axial system. This resulted in better husk distribution on tangential combine harvester with mounted straw distributor because there were not so many small particles on the sieves going into the distributor.

However, there was the opposite situation in distribution of oil rape straw. Because a great amount of oil rape straw is going into a chopper, the distribution plate was overloaded and then the distribution quality was declining and was worse than on axial combine harvester.

For better plant remains distribution, a constructional change was proposed. The improvement on axial combine harvesters consists in elongation of husk and straw distributor shaft by 20 cm. This had a very significant effect on husk and straw distribution quality during the winter wheat harvest. This change could be highly recommended. During the oil rape harvest the effect on distribution quality was not very significant.

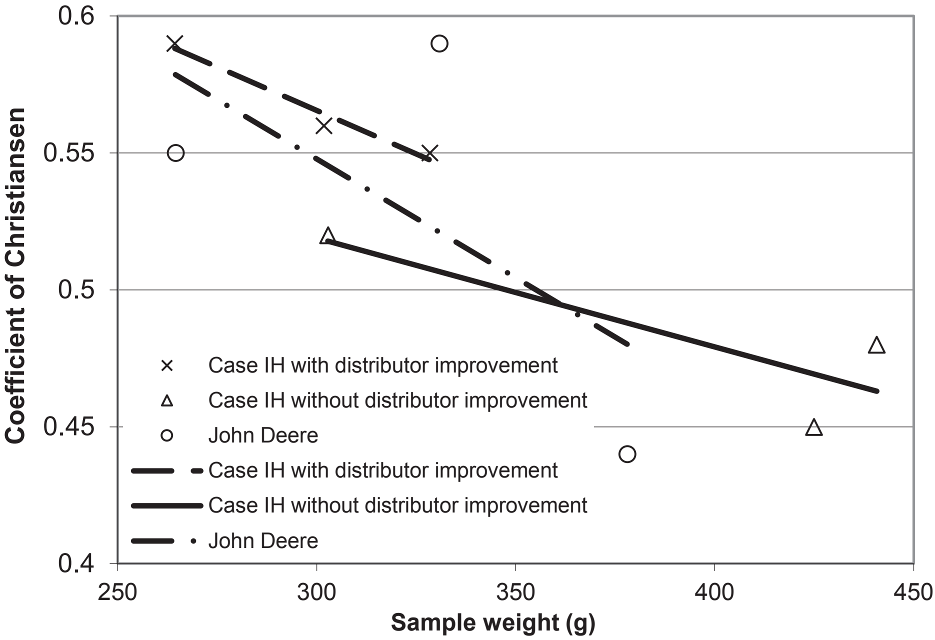

Figure 2. Husk distribution uniformity during winter wheat harvest.

Plant residues' distribution after shallow tillage evaluation – It can be seen on charts (Figs 3, 4 and 5) that there are some noticeable differences in plant residues placement after shallow tillage between different types of combine harvesters and also between standard design of the straw distributor and improved version.

Two variants are compared on charts (Figs 3–4), namely John Deere with the serial straw distributor mounted, and CASE IH without any straw distributor change/improvement. It means, regarding the regularity of straw distribution, the best and the worst measured variant. It follows from the charts that the overall regularity of the plant residues distribution after harvest had no influence on on-field-surface part of plant remains. This on-surface part of residues, consisted of straw and bigger particles and was a minor one. The vast majority of plant residues were incorporated into soil profile during tillage at a shallow depth.

This under-soil part of plant remains consisted mainly of husk and small straw particles. It turned out that the overall quality of husk and straw distribution corresponded with the amount of crop residues under the soil surface in the treated profile (irregular distribution) whilst the on-surface crop residues were always very balanced. Consequently, this fact can deteriorate conditions for the next plants germination and their growth.

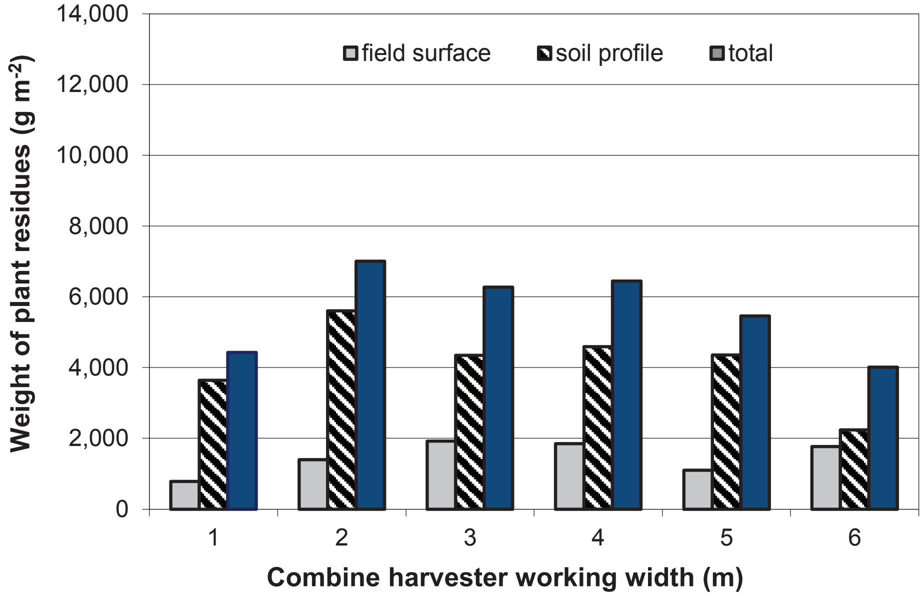

Figure 3. Plant residues distribution after shallow tillage (combine harvester John Deere).

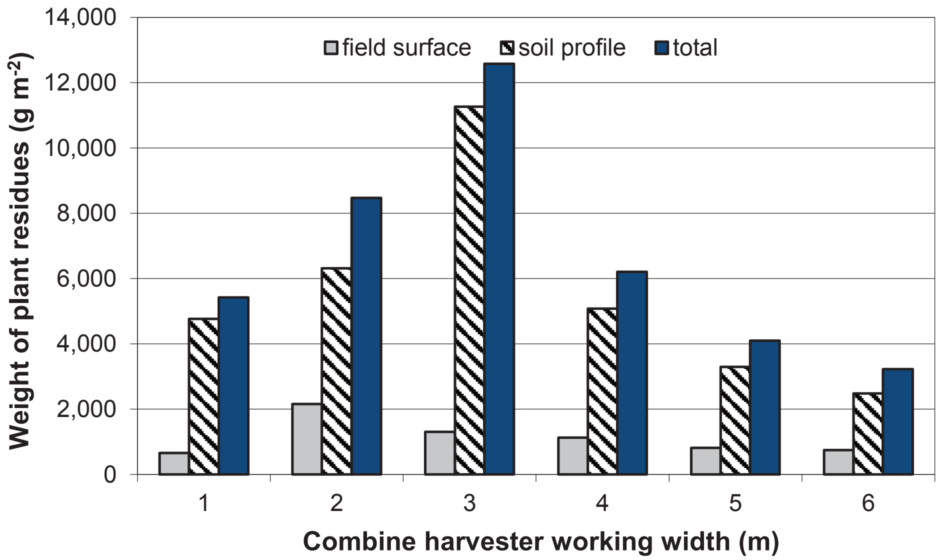

Figure 4. Plant residues distribution after shallow tillage (combine harvester Case IH without straw distributor improvement).

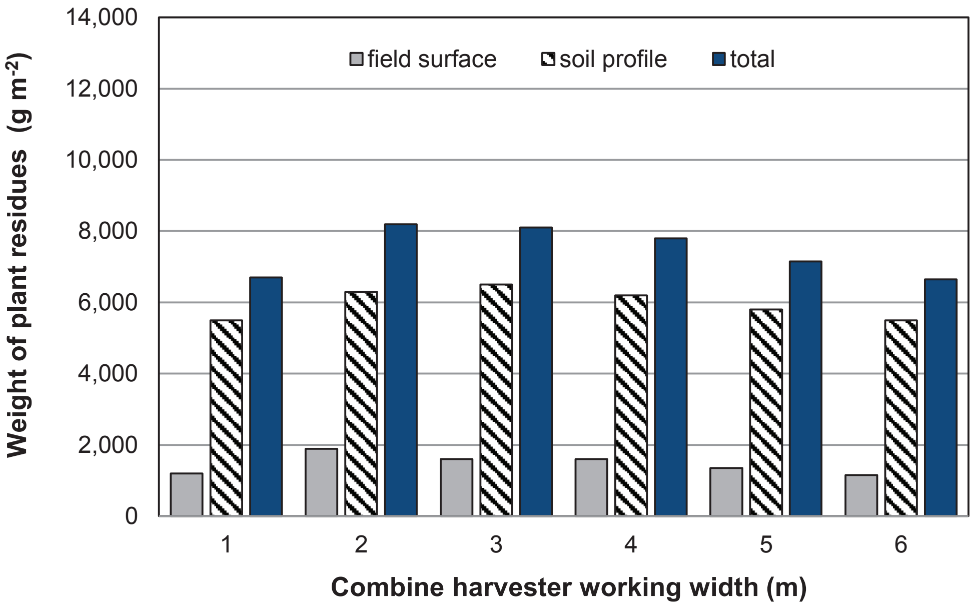

Figure 5. Plant residues distribution after shallow tillage (combine harvester Case IH with straw distributor improvement).

CONCLUSIONS

The most important outcome of the measurement of combine harvesters husk distributors' work quality is that cross irregularity of husk and straw distribution depends on instantaneous material feedrate through the harvester. The more material, the worse regularity of husk and straw distribution. From a practical point of view it can be recommended to pay adequate attention to this problem especially when applying conservation tillage and when the preceding crop had a high yield and high amount of crop residues. Generally it is beneficial from that point of view to have optional possibility of settings for distributor deflection blades and for the angle of husk spreader as well. It is becoming necessary to set not only threshing and cleaning mechanisms on combine harvesters but also husk and straw distribution mechanisms.

The advantage of our change of distributor shaft on Case IH for better distribution quality was proved.

Axial combine harvesters, thanks to their technological process of threshing, break up straw more intensively then tangential combine harvesters. Straw crushers on tangential combine harvesters are therefore more loaded and need more attention from the crushing quality point of view. On the contrary, on axial combine harvesters most material goes on cleaning sieves and more attention should be paid to this small particles distribution.

The placement of all plant residues after tillage was almost even on field surface. Most small particles were mixed into soil when tilled and the placement of these particles corresponded with irregular distribution of all harvested plants' residues before tillage. To sum up this part of our research, the plant remains, mixed into soil after tillage, were placed as irregularly as they were before tillage. The plant remains left on the soil surface were placed more evenly, but the separation of small and big particles took place. The long and big particles stayed on the field surface and the majority of small ones were mixed into soil.

The mentioned irregularity of small plant remains in treated soil profile and so their great concentration at the particular place could affect next plant germination and growth.

This problem presented here is becoming very important nowadays because more and more farmers use conservation tillage systems on their fields and that is why it is necessary to pay proper attention to do the best from this point of view.

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