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Straw Yield and Quality: An Extra Motivation for the Introduction of Triticale in Mixed Farming Systems**

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Straw is a valuable by-product from cereal production. It is used for agricultural purposes as feed and bedding material for livestock. Additionally, cereal straw is a resource for the production of sustainable biomaterials and bio-energy. To meet the demands of these sectors substantial amounts of straw, with specific properties (e.g. water-holding capacity), are necessary. Since wheat breeding has mainly focused on grain yield rather than on straw yield other cereal species, such as triticale, can be of interest. Therefore, in this research the straw yield and water-holding capacity of four winter wheat and four winter triticale varieties were studied during two growing seasons. For both wheat and triticale there were differences in dry matter yield and percentage dry matter between growing seasons. Furthermore, depending on the growing season, there were significant differences in straw yield between the different wheat and triticale varieties. However, during both growing seasons, the straw yield obtained from the triticale varieties was significantly higher compared to the straw yield obtained from the wheat varieties. Concerning the water-holding capacity, it was concluded that the water absorption potential of triticale straw was higher compared to the water absorption potential of wheat straw. However, only in 2014 a significant difference between wheat and triticale was noted. So, it can be concluded that, besides the known advantages of triticale (performance on marginal soils, disease resistance, low fertilizer input, etc.), this crop has the potential to deliver high yields of high quality straw.

Keywords: straw, triticale, water-holding capacity, wheat

Introduction

Winter small cereals, including wheat and triticale, are mainly grown for their grains. However, the production of high quality straw is, especially on mixed farms, equally important. Traditionally straw is used as forage or as bedding material in animal production. It has a high absorbing power and is not expensive compared to other bedding materials, this makes straw an ideal bedding material for litter housing systems. However, last years the use of straw in animal production has decreased. This is primarily due to the

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high labour requirements of a litter based animal housing system compared to a liquid manure system. In the review of Tuyttens (2005) the importance of straw for pig and cattle welfare is discussed. Straw bedding improves the physical comfort of the floor, and, unless temperatures are high, straw enables pigs to somewhat control their microclimate thereby increasing thermal comfort. The importance of straw for the welfare of cattle mainly concerns floor-comfort. However, it appears that the provisioning of (high quality) synthetic lying mats, perhaps in combination with soft walking floors, may provide floor-comfort equal to that of straw. However, these alternatives are more expensive. Because of the high investments cost and the current critical economic situation in agriculture, there is a renewed interest in the use of straw in animal production. In case straw is used as bedding material the potential to absorb moisture from urine is extremely important. If a bedding material absorbs more water or urine, a lesser amount will be needed which can save labour and costs (Pearson et al. 1999). Furthermore, a dry adequately bedded stall maintains cow cleanliness and inhibits microbial growth. Research has shown that the water-holding capacity of straw is determined by physical and chemical straw properties and by the harvest and preservation techniques that are used (Deininger et al. 2000). The results of Deininger et al. (2000) showed that rectangular big balers have an enormous conditioning effect on the straw thanks to the high pressures in these machines. This high pressure flattens the round stems of the straw and destroys partially the structure of the stems. This conditioning effect increased the water-holding capacity of straw in rectangular bales compared to straw in round bales produced by round balers.

Furthermore, straw may be fed as part of the roughage component of a cattle diet. Since straw is characterized by a high fibre content and low crude protein and energy content, it is an excellent forage in situations where dietary energy or protein dilution is desired (Shaver and Hoffman 2010).

Straw incorporation in the soil improves soil properties and soil fertility. It can replenish the soil organic matter by enhancing carbon inputs, which has a positive effect on the accumulation of nutrients and it improves the nutrient utilization efficiency. It has also been reported that straw incorporation increases the soil nitrogen, phosphorous and potassium levels and improves the activity levels of soil enzymes and microbial biomass communities (Lou et al. 2011; Wei et al. 2015).

Additionally, straw is used as mulch in gardens and by small fruit growers. Straw mulch keeps soil temperatures more uniform, it prevents the soil from drying out and can decrease the number of weeds (Sinkevičienė et al. 2009).

Finally, recently, there is a growing interest in the use of straw for the production of sustainable biomaterials and bio-energy. In Denmark for example, 30% of the total straw production is used in the production process of bio-energy (Sun 2010; Larsen et al. 2012). Therefore, the production of high quality straw can provide an additional income for farmers.

Whether straw is used in animal production or for industrial purposes, it is of interest to increase the straw yield. It is known that the straw yield potential is determined by genetic differences, different varieties of cereals will have different straw yields (Donaldson et al. 2001; Engel et al. 2003). Of course grain yield remains the primary goal of cereal production and selecting for a higher straw yield should not bring along negative consequences to the grain yield, susceptibility to lodging and diseases (Townsend et al. 2017). Furthermore, straw yield is affected by many environmental factors, such as water availability, fertilization, sowing density, seeding date and the adequate crop protection.

Triticale (× *Triticosecale* Wittmack) is the intergeneric hybrid between the female parent wheat (*Triticum* ssp.) and the male parent rye (*Secale* ssp.) having the qualities of both parents. Experiments in the past, conducted by University College Ghent (Derycke and Haesaert 2014, 2015), showed that triticale has a high yielding potential not only on sandy soils, but also on heavier soil types. In less optimal growing conditions, triticale performed clearly better than wheat and barley, while on heavy soils triticale performed equally well compared to both wheat and barley. Furthermore, the uptake of nutrients by triticale is more efficient compared to nutrient uptake of wheat and other cereals, triticale is thus suited to cultivate on marginal lands. The grain protein content of triticale is, in general, similar compared to the grain protein content of wheat, which makes it a valuable alternative grain for inclusion in feed. In the study of Alijošius et al. (2016) wherein triticale, wheat and rye were compared, the highest protein content was found in the triticale variety SW Talentro (12.51%), however, in average the wheat varieties were characterized by a slightly higher protein content compared to the triticale varieties (11.13% compared to 10.79%). Furthermore, the nutritive value of triticale protein has been shown to be greater than wheat protein, thanks to the higher concentrations of the limiting amino acids lysine and threonine. However, it should be pointed out that much variation exists between triticale varieties (Stallknecht et al. 1996; Myer and Lozano del Rio 2004). Furthermore, compared to the old varieties, the new triticale varieties are more resistant to pre-harvest sprouting and less susceptible to lodging (Estrada-Campuzanoa et al. 2012).

Despite the numerous positive aspects of triticale, the response from farmers remains low. The assumption that triticale straw has a lower water-holding capacity compared to wheat straw is a frequently used argument. However, there is no scientific literature and data supporting this assumption. Therefore, during 2013–2014 and 2014–2015 in Bottelare (Belgium) a field experiment with four winter wheat and four winter triticale varieties was set up with the focus on straw yield and water-holding capacity of straw.

Materials and Methods

Field trial

The experimental field trial was conducted in Bottelare (50.96° NB, 3.75° EL, Belgium) during two consecutive growing seasons, 2013–2014 and 2014–2015. During both growing seasons the straw yield and water-holding capacity of four winter triticale varieties (Borodine (Serasem), Joyce (Sem-Partners), Remiko (Danko) and Vuka (Saatzucht Hege)) and four winter wheat varieties (Elixer (Limagrain) and Henrik (Wiersum Plant Breeding)) (long straw type) and Sahara (Limagrain) and Sokal (Sogroup) (short straw type)) were evaluated. These varieties are all currently grown on farms. The trial was laid out according to a randomized complete block design with four replications with a plot size of 15 m^2.

For the cultivation of both wheat and triticale conventional crop husbandry practices were adopted. The wheat and triticale varieties were sown on the same field on 26 November 2013 and 25 October 2014 with a seeding density of 350 kernels/m^2. The nitrogen fertilizer rates were based on the field-specific advice of the Soil Service of Belgium (the N-index system, www.bdb.be). The fungicide treatments per variety were based on an average Epipré-advice. On 9 April 2014 and 23 May 2014 the triticale varieties were treated with, respectively, Venture 1.5 l ha^{-1} (epoxyconazool + boscalid: 100.5 g + 349.5 g ha^{-1}) and Evora Xpro 1.25 l ha^{-1} (bixafen + prothioconazool + tebuconazool: 93.75 g + 125 g + 125 g ha^{-1}). The same treatments were applied to the triticale varieties in the following growing season, respectively, on 17 April 2015 and 21 May 2015. On 30 April 2014 and 23 May 2015 the wheat varieties were treated with, respectively, Granovo 1.7 l ha^{-1} (boscalid + epoxyconazool: 238 g + 85 g ha^{-1}) and Ceriax 1.75 l ha^{-1} (72.8 g + 72.8 g + 116.55 g ha^{-1}). The same treatments were applied to the wheat varieties in the growing season 2014–2015 on 15 May 2015 and 4 June 2015. In both wheat and triticale, during the second part of April, the growth regulator chlormequat (750 g ha^{-1}) was applied.

Before harvesting the length of ten plants per plot was measured, from ground level until the ear. Both wheat and triticale were harvested plot by plot using a combine harvester with a conventional threshing drum on 1 August 2014 and 3 August 2015. All straw was harvested 10 cm aboveground level and not chopped into smaller parts. After harvesting the cereals, the straw on the plots was left unchanged for 48 hours prior to the final straw yield assessment. To evaluate the straw drying process of each variety, samples were taken at different time points, at the moment of harvesting itself, 24 hours after and 72 hours after harvesting the cereals. To determine the percentage dry matter, a subsample of ca. 200 g was dried in an oven at 60 °C for several days until constant weight. The calculation of the percentage dry matter was based on the weight difference of the harvested straw and the oven-dried straw. To determine the water-holding capacity per variety, in each of the four replications a random sample of 300 g straw was taken. These samples were saturated with water (2.2 L water per sample) in a sealed receptacle (to avoid evaporation). After 48 hours the entire content of the receptacle was poured out over a sieve and the straw could leak for 15 minutes. The water-holding capacity per kg dry matter weight of straw was calculated based on the weight of the harvested straw before the saturation with water and the weight of the soaked straw after the 15 minutes of draining.

Statistical analysis

For statistical evaluation, the R software package (R core Team 2014) version 2.15.3 was used. The data are represented as box plots, which provide a graphical view of the median, quartiles, maximum and minimum of the data. The statistical analysis of the results was performed using Welch's *t*-test, or unequal variances *t*-test in case two groups of data were compared. In case more than groups had to be compared an ANOVA (analysis of variance) followed by a Dunnett *post-hoc* test, in case significant differences were observed. The normality of the residuals was checked with a Shapiro–Wilk test.

Results

Both growing seasons, 2013–2014 and 2014–2015, were favourable for cereal cultivation. The minimum and maximum temperatures were in line with the 30-year averages of Flanders. The growing season 2013–2014 was characterized by a warm winter (6.9 °C) and spring (13.2 °C) compared to 2014–2015 with average winter and spring temperatures of 4.4 °C and 11.9 °C, respectively. The amount of rainfall recorded in March 2014 was clearly lower compared the amount of rainfall in March 2015 (32.4 mm and 64.4 mm), whereas the amount of rainfall in July 2014 was clearly higher compared to the amount of rainfall in July 2015 (76.8 mm and 34.2 mm). During both growing seasons high grain yields were recorded, with slightly higher yields in 2014 compared to 2015. The grain yields of the wheat varieties in 2014 were 12.47 t ha^{-1}, 12.23 t ha^{-1}, 11.17 t ha^{-1}

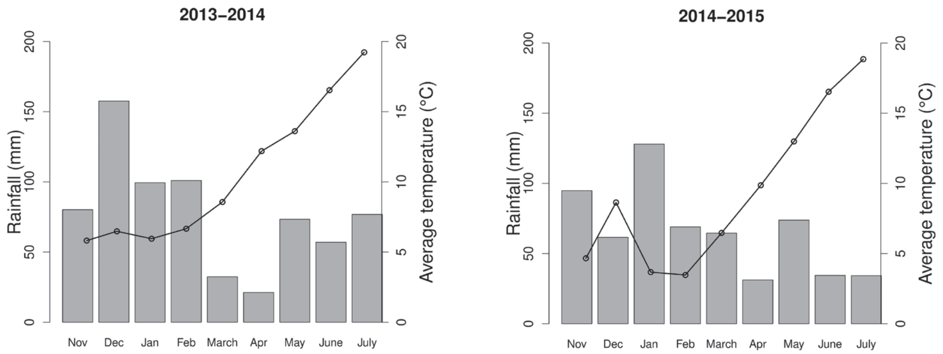

Figure 1. Monthly rainfall (mm) (barplot) and monthly average temperature (°C) (lines) during the growing seasons 2013–2014 and 2014–2015

and 11.40 t ha^{-1} for Henrik, Elixer, Sahara and Sokal, respectively. In 2015 these varieties yielded 10.59 t ha^{-1}, 10.91 t ha^{-1}, 10.26 t ha^{-1} and 10.31 t ha^{-1}. The triticale grain yields in 2014 were 10.45 t ha^{-1}, 10.29 to ha^{-1}, 11.52 t ha^{-1} and 11.85 t ha^{-1} for the varieties Borodine, Jocye, Vuka and Remiko, respectively. In 2015 these varieties yielded 10.27 t ha^{-1}, 10.61 t ha^{-1}, 10.93 ha^{-1} and 10.79 t ha^{-1}.

In Fig. 2 the straw dry matter yields (t DM ha^{-1}) of the four triticale and four wheat varieties obtained during both growing seasons are represented. The average straw DM yield of the triticale varieties was significantly higher compared to the average straw DM yield of the wheat varieties (p-value = 0.02 (2014) and p-value = 0.00 (2015)). However, in 2014 the difference in DM yield between wheat and triticale was less pronounced than in 2015. In 2014, the DM yield of the short straw wheat varieties Sokal and Sahara was significantly lower than the DM yield of the triticale varieties Borodine, Joyce and Vuka. However, between the triticale varieties Borodine, Joyce, Vuka and the long straw wheat varieties Elixer and Henrik no significant differences were observed during 2014. During the growing season 2015, each triticale variety had a significantly higher DM yield com-

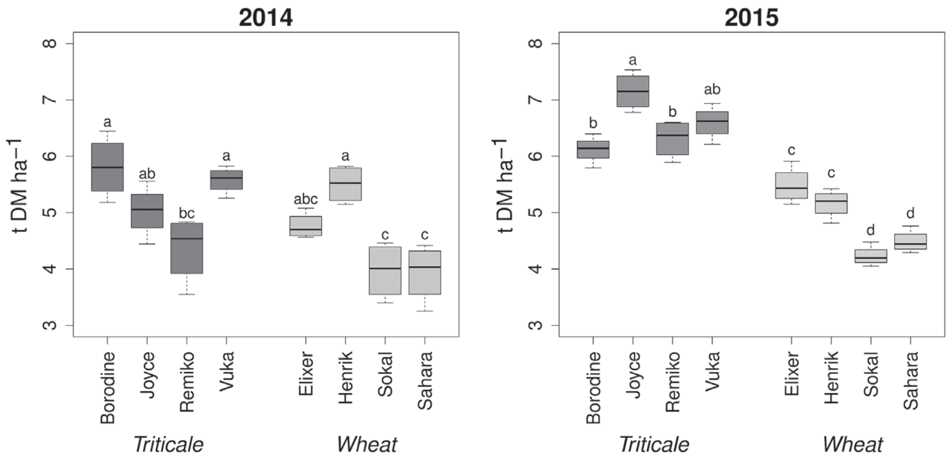

Figure 2. Dry matter yield (t DM ha^{-1}) of the four triticale and wheat varieties during 2014 and 2015. Different letters per variety point to significant differences according to a Dunnett test

pared to the wheat varieties. Also, between the varieties there were significant differences. The DM straw yield of the triticale variety Joyce was significantly higher compared to the triticale varieties Borodine and Remiko. Similar to 2014, in 2015 a significantly lower amount of straw was obtained from the short straw wheat varieties (Sokal and Sahara) compared to the long straw varieties (Henrik and Elixer).

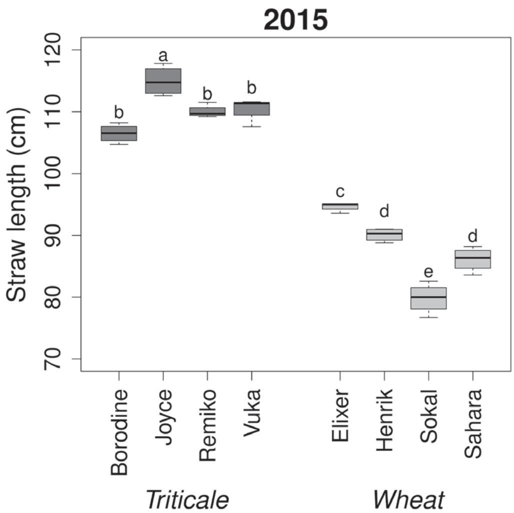

Figure 3. Straw length (cm) of the four triticale and wheat varieties during 2015. Different letters per variety point to significant differences according to a Dunnett test

In 2015, the straw length of the different varieties was measured (Fig. 3). Triticale straw was significantly longer compared to wheat straw. Furthermore, the differences in straw length between the wheat varieties were more pronounced compared to the differences between the triticale varieties. For both wheat and triticale there was a significant positive correlation between straw yield and straw length (r = 0.87 (wheat) and r = 0.54 (triticale)).

Furthermore, the percentages DM at harvest, 24 hours post-harvest and 72 hours post-harvest were determined. From Fig. 4 it is clear that the percentage dry matter at harvest in 2014 is clearly lower compared to 2015. This can mainly be attributed to the weather conditions. The amount of rainfall during July 2014 was 76.8 mm with an average relative humidity of 83%, whereas in July 2015 only 34.2 mm rainfall was recorded with an average relative humidity of 76%. Furthermore, the total rainfall five days before harvest in July 2014 was 13.6 mm, whereas in July 2015 the sum of rainfall during the five days before harvest was 3.4 mm.

Based on the data of both growing seasons, it can be concluded that the average percentage DM of wheat straw at harvest is significantly higher compared to the percentage DM of triticale straw at harvest (p-value = 0.002 (2014), p-value = 0.000 (2015)). Also, between the different wheat varieties and different triticale varieties clear differences were observed. In 2014, 24 hours post-harvest, there were still significant differences between wheat and triticale (p-value = 0.04), whereas in 2015, 24 hours post-harvest no significant differences (p-value = 0.40) were observed between wheat and triticale. Seventy two hours post-harvest no significant differences could be observed between the percentage DM of wheat straw and triticale straw (p-value = 0.40 (2014), p-value = 0.92 (2015)).

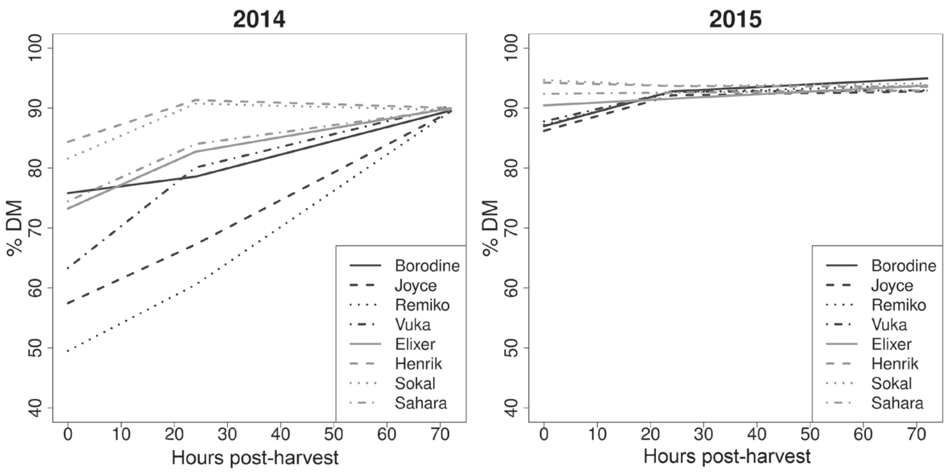

Figure 4. Change in dry matter percentage (% DM) in straw from the four triticale varieties (Borodine, Jocye, Remiko, Vuka) and four wheat varieties (Elixer, Henrik, Sokal, Sahara)

Figure 5 represents the variation in water-holding capacity of straw from the different triticale and wheat varieties during the two growing seasons. In 2014 the straw water-holding capacity was significantly higher compared to 2015 (*p*-value = 0.00). Between the triticale varieties never significant differences in straw water-holding capacity were detected (*p*-value = 0.068 (2014) and *p*-value = 0.89 (2015)). In 2014 significant differences between the wheat varieties were detected (*p*-value = 0.00). Straw obtained from the wheat variety Sokal had a significantly higher water-holding capacity compared to

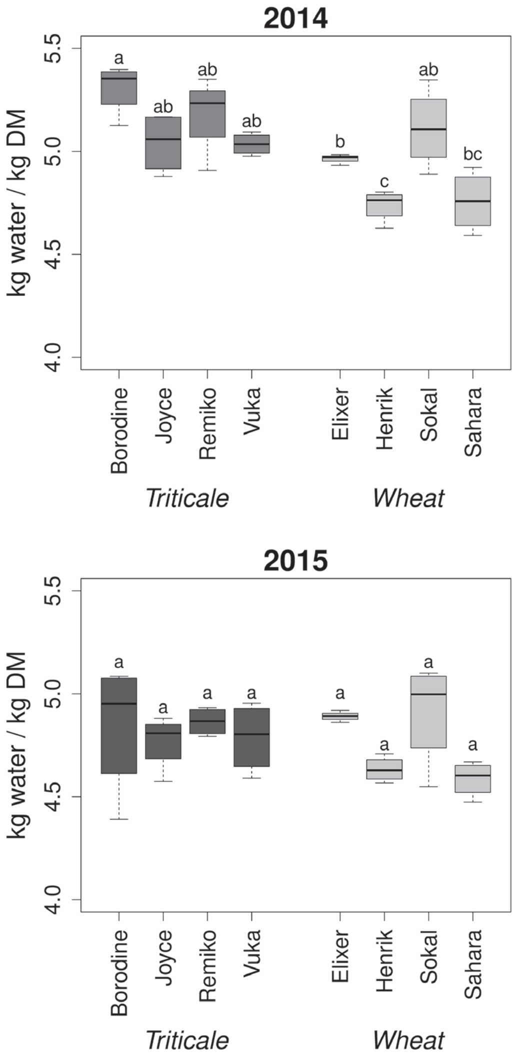

Figure 5. Straw water-holding capacity (kg water per kg DM) of the four triticale and four wheat varieties during 2014 and 2015. Different letters per variety point to significant differences according to a Dunnett test

straw of the wheat variety Henrik. Also, during 2015 the variety Sokal had, in average, the highest water-holding capacity, however the difference was not significant. Concerning the difference between wheat and triticale, in 2014 the water-holding capacity of the wheat varieties was in average significantly lower than the water-holding capacity of triticale (p-value = 0.03). In 2015 no significant differences between wheat and triticale could be detected (p-value = 0.31).

Discussion

Cereal straws are expected to play an important role in the shift towards a more sustainable agriculture and economy. Currently, there is a growing interest in animal welfare, the use of straw as bedding material has been reported to improve the welfare of animals (Tuyttens 2005). Furthermore, there is an increasing demand for straw from the bio-energy sector for the production of biomaterials and biofuels (Sun 2010). With the renewed interest in straw, evaluation of straw yield and dual purpose crops deserves special attention. Therefore, in this research the straw yield and water-holding capacity of four wheat varieties and four triticale varieties was studied.

The grain yield was higher in 2014 compared to 2015, whereas for the straw yield the opposite was observed, the straw yield was clearly higher in 2015 compared to 2014. According to Larsen et al. (2012) these fluctuations in yield between years can mainly be attributed to varying weather conditions. Large-scale experiments in Denmark approved that there can be a considerable temporal variation in straw yield, up to 46% variation in the yearly averages (Larsen et al. 2012). Also, according to Dai et al. (2016) climatic differences among regions, particularly available moisture, were identified as the driving factors behind straw yield variations.

Furthermore, there was a substantial variation in straw yield between the different wheat and triticale varieties. It is indeed known that straw yield potential is influenced by genetic factors (Donaldson et al. 2001; Engel et al. 2003). Concerning the difference between wheat and triticale, it was concluded that triticale resulted in a significantly higher straw yield compared to wheat. This is in accordance with the results of field trials from the Ghent University College, under suboptimal growing conditions the straw yield of triticale was 25% to 30% higher than the straw yield of wheat (Haesaert et al. 2007, 2009). The higher straw yield of triticale can partially be explained by that fact that the straw length of triticale is longer compared to the straw length of wheat. Indeed, we found a significant positive correlation between straw length and straw yield. However, differences in straw length do not always give rise to differences in straw yield. Larsen et al. (2012) found that winter wheat had a higher straw yield than winter barley despite similar straw lengths of both cereal species. This can be explained by the fact that straw yield also depends on thickness and density of the straw (Engel et al. 2003).

Also, the percentage dry matter directly after harvest significantly differed between the two growing seasons, this could be explained by the weather conditions around harvesting. The amount of rainfall in July 2014 was clearly higher compared to the amount of rainfall during July 2015. The percentage dry matter in straw of wheat directly after harvesting was clearly higher than the percentage dry matter in triticale straw. However, 72 hours after harvesting the percentage dry matter in straw of both cereal species reached the same level. Therefore, especially for triticale, once cut, it is important that it is left for a short period (72 h, in case of dry weather conditions) on the field to dry. As mentioned in Deininger et al. (2000), in practice the baling process often starts too soon. The straw should not be baled until it has dried sufficiently, otherwise decomposing inside the bale can occur.

As mentioned above the water-holding capacity is an important property in case straw is used as bedding material for livestock. Physical and chemical characteristics (amount of lignin, hemicelluloses, etc.) of organic bedding materials determine how well they will absorb and retain moisture and will thus influence the environment in livestock facilities (Spiehs et al. 2013). In average the water-holding capacity of triticale straw was higher compared to the water-holding capacity of wheat straw, however, only for 2014 a significant difference was noted. Furthermore, both for wheat and triticale significant differences between varieties were reported.

It can be argued that quality and yield of triticale grains is, especially for food purposes, inferior to the grain yield and quality of wheat. However, triticale can be grown on marginal and depleted soils unsuited for the cultivation of high quality wheat and it can be used as a break crop in a maize monoculture system. In these situations triticale cultivation can be preferred above wheat cultivation, thanks to low inputs needed for the cultivation and the fact that it can serve as both a protein source for feed and a straw source suited for bedding material.

In conclusion, this study revealed that triticale has the potential to produce high amounts of high quality straw and thus deserves a special attention. Especially in mixed farming systems dual purpose crops, having to potential to produce high grain yields and sufficient high quality straw for bedding are of special interest. However, it has to be added that there exist significant differences between varieties, further research is necessary to further unravel the potential of the various varieties under different environmental conditions.

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