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Research Article

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Potentials of crops residues – A case study for the province Vojvodina

Potenziale von Ernterückständen – Eine Fallstudie für die Provinz Wojwodina

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Summary

Crop residues are targeted as energy sources and feedstock for diverse products. A six-year lasting investigation, aiming to determine the yield potentials of crop residues of mostly grown field crops wheat, soybean and corn in the province Vojvodina (Serbia), was performed. The three levels of potentials were distinguished: theoretical, technical and sustainable. Two seasonal weather conditions were distinguished – common and dry, and their impact on the biomass yield was analyzed. The yields were expressed as absolute and relative to grain yield since the grain yield is always measured, and is available in national statistics. During common seasons, technical potentials were about 56% for wheat, 45% for soybean and 41 or 51% for the two considered corn stover collection procedures. For dry seasons, the technical potential of all considered crops was reduced to between 30 and 50%. On field remained aboveground residual biomass and its relative (to grain) amount, which was between 43 and 60%, was defined. It was concluded that the defining of sustainable potentials is a very complex task. Besides the aforementioned, measures aimed to preserve soil fertility, some overlooked issues in the literature and practice were listed and commented on.

Keywords: Crop residues, potentials, sustainability, province Vojvodina

Zusammenfassung

Pflanzenreste werden häufig als Energieträger und als Ausgangsmaterial für verschiedene Produkte eingesetzt. Eine sechsjährige Untersuchung wurde durchgeführt, um die Potenziale der Pflanzenrückstände der meist angebauten Feldfrüchte Weizen, Soja und Mais in der Provinz Wojwodina zu untersuchen. Es wurden drei Potenziale unterschieden: theoretisches (gesamte oberirdische Restbiomasse), technisches (erntbares) und nachhaltiges Potenzial. Es wurde nach verschiedenen Wetterbedingungen, üblich und trocken, unterschieden und deren Auswirkungen auf den Ertrag analysiert. Die Erträge werden als absolut und relativ zum Getreideertrag dargestellt (Getreideerträge werden meistens gemessen und sind in nationalen Statistiken öffentlich zugänglich). Während der normalen Saisonen liegen die technischen Potenziale bei etwa 56 % für Weizen, 45 % für Soja und 41 oder 51 % für zwei betrachtete Verfahren zur Sammlung von Maisstroh. In trockenen Saisonen wird das technische Potenzial aller betrachteten Kulturen um 30 und 50 % reduziert. Auf dem Feld verbliebene oberirdische Restbiomasse beträgt relativ zum Körnerertrag zwischen 43 und 60 %. Es wurde festgestellt, dass die Definition nachhaltiger Potenziale sehr komplex ist. Maßnahmen zur Erhaltung der Bodenfruchtbarkeit und einige übergeordnete Aspekte werden aufgelistet und kommentiert.

Schlagworte: Ernterückstände, Potenziale, Nachhaltigkeit, Provinz Wojwodina

1. Introduction

Crop residues are commonly used as feedstock for many products and as a solid fuel, primarily intended for combustion. In modern times, re-application of crop residues started after oil crises, in the seventies of the previous century. As global warming was identified, and defined as one of the most significant problems, their use is supported due to greenhouse gases (GHG) emissions reduction effect. This is declared by many European documents, and the most significant is the recent Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. Lately, on the European Union level, bioeconomy was declared and supported (Anonymous, 2012). This includes utilization of bio-recourses as a fuel and a feedstock for many products, to replace fossil fuels, first of all oil. In this regard, crop residues, beside others, play an important role. However, it is important to know the potentials of these materials.

The term potentials should be clearly defined. The first is theoretical potential, that is, the whole aboveground biomass minus grain. This one has no importance for potential users, but can be used for the calculation of on-field remained residual biomass. The second is technical (or harvestable) potential, and presents the mass that can be collected, and potentially used. Removal of crop residues has an impact on soil fertility, its use causes additional costs, and has other reflections on environment and society. Only after considering many other complex impacts, the sustainable potential can be defined. In the recently published article by Scarlat et al. (2019), the term "environmental potential" of crop residues has been introduced, which comprises the one for which the collection does not result with reduction of soil fertility. Although environmental assessment is a component of sustainability, it should be emphasized due to its importance. However, authors of the article accented that this impact has not still been unambiguously elaborated. The best solution is to express the potential of crop residues relatively to the grain yield. The grain yield is always measured even in practice, and data on its production are available in national or regional statistics.

One important, and frequently omitted impact on the yield, that is, potential, are seasonal weather conditions. Almost everywhere, the farmers are faced with droughts, followed by considerable reduction of the main product, that is, grain, but residual biomass as well. This fact should be considered by defining the sustainable potential and supply security. Some of the issues related to sustainability of crop residues' harvest and utilization were tackled in previous researches, but the unique general approach does not exist. Typical positive example is the analysis of the sustainable potential of wheat straw was conducted in Germany (Zeller et al., 2012), but the authors were faced with many problems that needed specific local approaches. Another example presents consideration of impact on soil fertility is provided by Sekulic et al. (2010), who stated that the removal of crop residues should be evaluated based on the existing humus percentage in the soil. Blum et al. (2010) considered the impact of removal of residues on soil, whereby some measures to overcome it, like crop rotation, were considered. Powlson (2006) analyzed the same for the utilization of big amounts of wheat straw as energy source for power plant.

There are different statements on the share of corn residues' mass that can be removed without depleting soil fertility. Radhakrishna et al. (2012) suggested a value of up to 33%, Brechbill et al. (2011) 53.5% and Schechinger and Hettenhaus (1999) proposed a range between 40 and 50%. The highest share of 58% was mentioned by Wyman and Hinman (1990).

The main objective of the presented study that was performed in the Autonomous Province of Vojvodina was to define the technical potentials of important field crops. An additional objective was to identify and assess common and some overlooked impacts to define sustainable potentials.

2. Material and methods

2.1 Weather conditions and sampling area

Wheat, soybean and corn, in the period 2011 to 2016, were used to conduct the investigation. The samples of aboveground biomass were collected from plots of the advanced farms that practiced common up-to-date technology, at three to five locations in the province of Vojvodina, which is located in the north of Serbia, at least four to eight mostly used varieties or hybrids of each species were used. From the selected plots, five samples were taken, for wheat and soybean from one 1 m^2, and for corn from 1.4 m^2. As common seasons, those with average precipitations during vegetation periods (about 280 mm m^{-2}) were considered, and dry with a reduction of precipitation of more than 20%. There were three dry seasons for wheat and two for soybean and corn.

2.2 Sampling of wheat and soybean crop residues

Each sample was randomly taken from the field, avoiding the outskirts. Samples consisted of the total aboveground mass. The samples were processed as follows. Wheat was divided into: grain, chaff and stalks+leaves. Soybean was divided into: grain, stalks, branches+leaves and husks. Furthermore, stalks of both wheat and soybean straw were split into segments to determine the dry mass distribution in stems' height (Figure 1).

The amount of harvestable wheat straw, that is, the technical potential, included harvested stalks or mass, which is obtained by subtracting the amount that remains in the stubble and 30% of the harvested leaves (other remained on the field).

The amount of harvestable soybean straw included stalks, without those which, as in the previous case, remains in the stubble and 30% losses of branches/leaves (it is assumed that 70% of the leaves or branches/leaves are collectable). It is assumed that the overall baler losses (pickup device) for both crops were 10%.

The mass of each plant part was measured using the balance with an accuracy of 0.1 g. For the determination of moisture content, grains were dried using the standard procedure defined by ASABE (2008) and crop residue fractions according to the procedure defined by ASABE (2012).

Based on the determined values of moisture content for each fraction, yields expressed to dry matter were determined. For the stalks fraction, diagrams of cumulated mass were made, starting from the ground. They were used to determine the remaining mass of the stubble on field, depending on the height of cutting bar.

2.3 Sampling of corn crop residues

Each corn plant was divided into: grain, cob, husk, and stalk with leaves and tassels. The lowest 0.2 m of stalks was treated as unusable (not harvestable) (Figure 2).

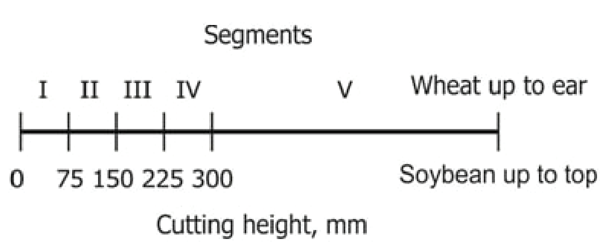

Figure 1. Wheat and soybean straw stalks segments
Abbildung 1. Segmente der Strohhalme von Weizen und Sojabohne

The amount of harvested stover was calculated based on the following harvest procedures data:

1. Two-pass harvest: Grain harvest by combine with snapper–head and integrated shredder-cornrower described in Straeter (2011) and Shinners et al. (2012). According to these authors, the stover is picked up from the windrow by a round or big rectangular baler. Cutting height was 0.2 m. Percentages of harvested fractions were 70, 80 and 90%, for stalks+leaves, cobs and husks respectively, with additional baling losses of 20%.
2. Multi-pass harvest: This is the conventional stover harvest procedure. The combine harvester is equipped with snapper-head and integrated shredder, but without windrower (chopped stover is spread). This first pass is followed by raking, forming windrow and baling. According to the previously cited authors, percentages of harvested fractions are: 70% for stalks+leaves and 40% for cobs and husks combined, with additional baling losses of 20%.

2.4 Sustainability issues

Common and overlooked impact on defining sustainable potentials of crop residues' removal were identified, based on own experiences and practice, and statements of other researchers.

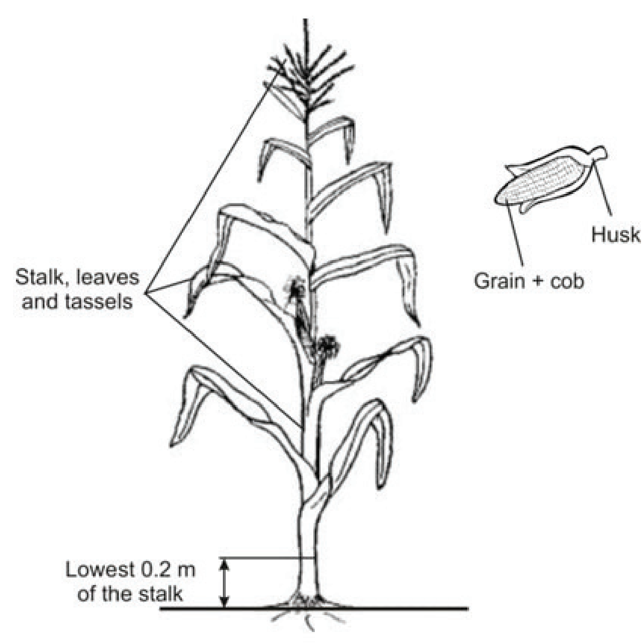

Figure 2. Above-ground fractions of corn plant
Abbildung 2. Oberirdische Fraktionen der Maispflanze

3. Results and discussion

3.1 Technical potentials of wheat crop residues

Figure 3 shows the cumulated relative mass of wheat stalks depending on the height for the years 2011 and 2012, as examples for a common (2011) and dry (2012) season. Based on this, the amount of stalks, which remained on the field, that is, stubble, depending on the cutting height, can be determined. Examples of cutting heights 10, 15 and 20 cm are indicated. On stubble remained mass of stalks was in 2011 about 16 and 26%, and in 2012 about 22 and 33%, for cutting heights 10 and 15 cm respectively. The average grain yields were 6.85 and 5.11 Mg ha^{-1}, with a harvest index (HI) of 0.48 and 0.49. The total average yield of the aboveground crop residues were 7.60 and 5.19 Mg ha^{-1}, respectively, for selected representative seasons (Table 1).

Average on field remained residual mass makes at least 50%. This should be respected by considering the impact of straw harvest on soil organic matter and preservation of soil potential. This is because many considerations of straw removal were overlooked. Harvestable mass, technical potential, in dry seasons was compared to the common values, reduced for 45%, and on field remained mass 18%, in average.

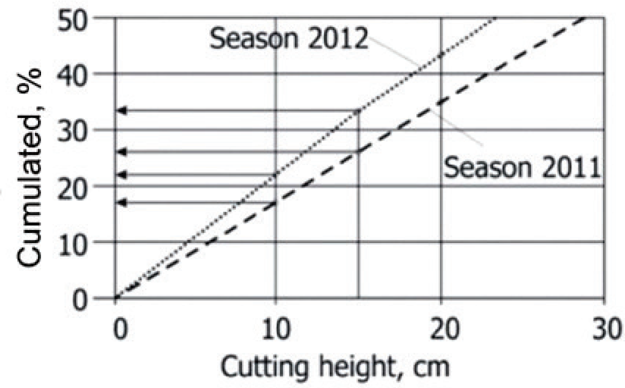

Figure 3. Cumulated percentage of wheat stalks mass depending on cutting height
Abbildung 3. Kumulierter Anteil von Weizenstroh in Abhängigkeit der Schnitthöhe

3.2 Technical potentials of soybean crop residues

The cumulated percentage of soybean stalks, average for all samples, is given in Figure 4, and on stubble remained mass for cutting bar heights 7.5 and 10 cm, here presented examples for common (2011) and dry season (2012). On stubble remained mass of stalks was in 2011 about 19% and 24%, and in 2012, about 25% and 32% for cutting heights 7.5 and 10 cm, respectively.

The all relevant data, the average values for all measurements are given in Table 2. The inconvenient weather conditions (drought) caused the reduction of harvestable mass of 38%, and on field remained mass of 22%, on an average.

Here is a percentage of on field remained mass even higher, 60% and more. Harvestable mass, technical potential, in dry seasons was, compared to common values, reduced for 38%, and on field remained mass 22%, on an average.

3.3. Technical potentials of corn crop residues

The obtained data on the yields of fractions are also calculated as relative, related to grain yield, and presented in Figure 5 for the selected representative seasons. Usable mass of aboveground residues makes about 85% of mass of harvested grain

Table 1. Obtained data for wheat (all data for dry matter, cutting bar height 15 cm), average for common and dry seasons
Tabelle 1. Ergebnisdaten für Weizen (angegeben wird die Trockensubstanz, Schnitthöhe 15 cm), Durchschnitt für übliche und trockene Saisonen

Parameter	Seasons	
	Common	Dry
Grain yield (Mg ha^{-1})	6.9	5.1
Harvest index	0.48	0.49
Mass of aboveground residues (Mg ha^{-1})	7.6	5.2
Mass of harvestable aboveground residues (Mg ha^{-1})	3.8	2.1
Percentage of harvestable mass in comparison with mass of grain (%)	55.5	40.0
Percentage of harvestable mass in aboveground residues (%)	50.0	39.3
On field remained mass (Mg ha^{-1})	3.8	3.1
Percentage of on field remained mass in aboveground residues (%)	50.0	60.7

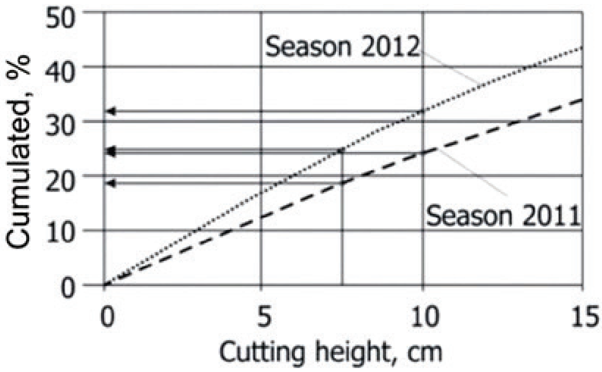

Figure 4. Cumulated percentage of soybean stalks mass depending on cutting height
Abbildung 4. Kumulierter Anteil von Sojabohnenhalmen in Abhängigkeit der Schnitthöhe

in 2011, and about 132% in 2012, common and dry seasons respectively. This significant change was the consequence of drought impact on grain yield. At the same time, the yield of aboveground mass was considerably reduced.

The results are presented in Table 3. In the common seasons, the HI was slightly lower than 0.5, but for dry ones, it was 0.43. Average grain yield in the common seasons was 10.3 Mg ha^{-1}, and 5.3 Mg ha^{-1} in the dry ones. For both types of seasons, the percentage of usable residual aboveground mass related to the total for the harvest procedures 1 and 2 was the same, 53 and 43% respectively, but the harvestable mass was considerably lower with procedure 2 than with procedure 1 in both seasons.

On field remained mass makes, depending on the harvest procedure, 43 to 53%, and this is not different for common and dry season. Harvestable residual mass, that is, the technical potential was in dry seasons, compared to common ones, reduced for 31%, and on field remained mass 30%, on an average.

3.4 Summary of technical potentials of crop residues

Summarized results of the investigation are presented in Table 4. Here, the potential reduction caused by drought are given, and this has a considerable impact on the supply security. Here, the presented data can be used for the planning of crop residues' potential, availability, considering also the impact of weather conditions. Presented data can be used for the evaluation of impact of crop residues removal, nearby others, on the preservation of soil fertility.

3.5 Overview of impacts on the sustainable potential

Impact of crop residues' removal on soil fertility has been investigated and reported frequently. However, it is still missing a clear approach for its quantification and evaluation. Here, some not elaborated or only tackled impacts are overviewed:

1. Impact of erosion, primarily wind erosion. This issue was partly elaborated related to the assessment of land surface coverage, ASABE standard (2012). Instruction for evaluation was given by extension service in USA (Hickman and Schoenberger, 1989). Some evaluations have been performed for wheat and soybean (Golub et al., 2013) and corn (Golub et al., 2016). Of course, the result depends on the applied soil tillage. This issue has environmental implications.
2. For users of big straw or stover, amounts are used almost exclusively for big bales. Collection of crop residues in this form is profitable only on bigger plots. For example, for round bales on plots over 5 ha, and big rectangular on plots over 10 ha (Martinov, 2015, 2016). This has an impact on realistic potentials. This issue has economic implication.

Table 2. Soybean grain and residue yields (at a cutting bar height of 7.5 cm), averages for seasons with common or dry weather
Tabelle 2. Korn- und Ernterückstände von Sojabohne (bei einer Erntehöhe von 7,5 cm), im Durchschnitt für die Saisonen mit üblichem oder trockenem Wetter

Parameter	Seasons	
	Common	Dry
Grain yield (Mg ha^{-1})	4.7	2.7
Harvest index	0.47	0.41
Mass of aboveground residues (Mg ha^{-1})	5.3	3.8
Harvestable mass of aboveground residues (Mg ha^{-1})	2.1	1.3
Percentage of harvestable mass in comparison to mass of grain (%)	44.7	48.1
Percentage of harvestable mass in aboveground harvest residues (%)	39.6	34.2
On field remained mass (Mg ha^{-1})	3.2	2.5
Percentage of on field remained mass in aboveground residues (%)	60.4	65.8

Table 3. Harvestable and remaining corn residues for the defined harvest procedures averaged for common and dry seasons
Tabelle 3. Erntbare und verbleibende Kornrückstände für die ausgewählten Ernteverfahren und gemittelte Ergebnisse für die üblichen und trockenen Saisonen

Season	HI	Harvest procedure	Harvestable mass			Remained mass, Mg ha^{-1}
			RY (%)	Mg ha^{-1}	PTM (%)	
Common	0.49	1	51	5.5	53	4.6
		2	41	4.5	43	5.6
Dry	0.43	1	72	3.8	53	3.3
		2	59	3.1	43	4.0

HI – Harvest index; RY – relative yield (to grain); PTM – percentage of total aboveground residual mass; harvest procedures: 1 – two pass harvest, 2 – multi-pass harvest

3. By the collection of crop residues, some nutrients are also removed, but not only organic matter. This issue, with economic implication, has been frequently reported, but very often with wrong interpretation. Mostly, the contents of elements were calculated, but not compounds usable for crops. Typical is the calculation of nitrogen losses, and less than 10% of it is in mineral forms.
4. For almost each case, the energy and GHG balance of crop residues' collection and utilization should be performed. In most of the cases, a voluntaristic approach is present. This issue has economic and environmental implications.
5. Impact of crop residues' collection and utilization has an impact on society, especially in rural areas. It is frequently mentioned, but not quantified by the utilization of scientific approach. This issue has economic and social implications.

Technical potential of crop residues fluctuate, depending on weather conditions, and other impacts (*e.g.*, diseases, insect infestations). This means some reserves of biomass should be planned and this has an impact on the feedstock overall costs. All above-mentioned make defining of sustainable potential a complex task, but it is not impossible.

4. Conclusion

For the most investigated crop residues, harvestable biomass is about one half of grain yield, and on-field remained biomass approximately the same as collected. This should be taken into consideration by elaborating soil fertility preservation. As it has also been stated by Scarlat et al. (2019), that the impact of crop residues' removal on soil fertility is still a topic for further research, and should include many influences, for example, proper crop rotation.
There are, beside the preservation of soil fertility, many (sometimes) overlooked issues, which have an impact on the defining sustainable potentials of crop residues. Some of them are possible to quantify, but detailed assessment should be performed for specific cases and locations. This also needs additional research on an international level.

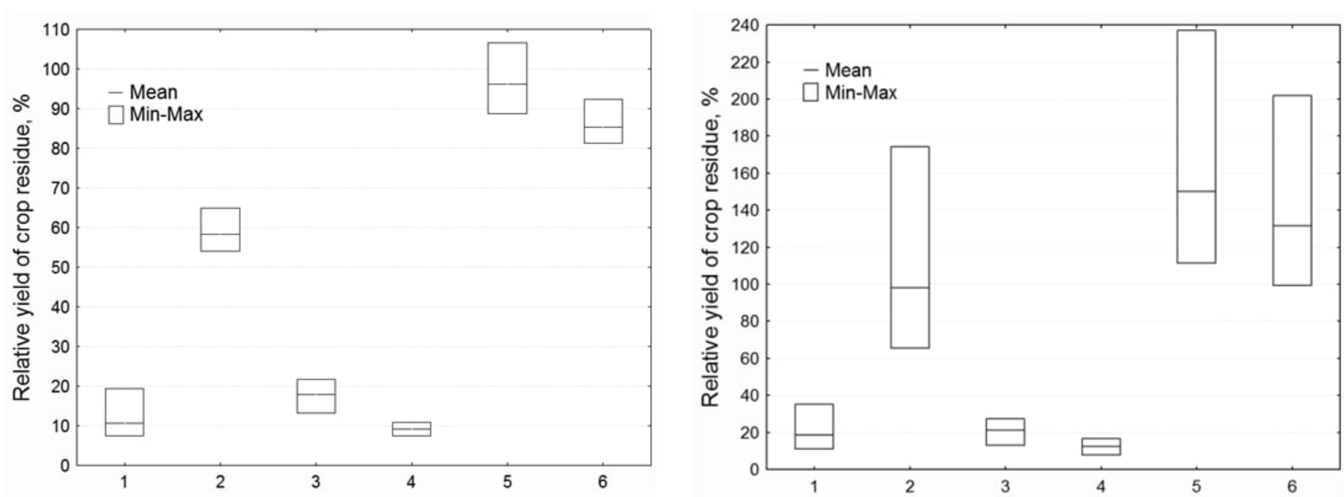

Figure 5. Range and average of relative yields of stover fractions: 1 – lowest 0.2 m of stalks, 2 – stalk+leaves, 3 – cobs, 4 – husks, 5 – total aboveground residues, 6 – sum of 2, 3 and 4 (usable mass of aboveground residues). Left: common season (2011); Right: dry season (2012)
Abbildung 5. Bereich und Durchschnitt der relativen Erträge der Ernterückstände: 1 – unterste 0.2 m der Halme, 2 – Halme + Blätter, 3 – Kolben, 4 – Lieschblätter, 5 – gesamte oberirdische Reste, 6 – Summe von 2, 3 und 4 (nutzbare Masse der oberirdischen Ernterückstände). Links: übliche Saison (2011); Rechts: trockene Saison (2012)

Table 4. Summarized results of the investigation expressed as relative harvestable, technical, potentials and on field remained biomass
Tabelle 4. Zusammengefasste Ergebnisse der Untersuchung angegeben als Relativwerte des erntbaren und des technischen Potenzials sowie auf dem Feld verbliebene Biomasse

Crop		Harvestable relative to grain (%)			Remained relative to grain (%)		
Common		Dry	Red. D to C	Common	Dry	Red. D to C	
Wheat		55	40	45	50	60	18
Soybean		45	48	38	60	66	22
Corn	1	51	72	31	47	47	28
	2	41	59	31	43	43	29

Red. D to C – reduction of mass in dry seasons compared to common seasons

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