

COMPARATIVE TESTING OF SORGHUM, SUDANGRASS AND MAIZE SOWN AS A SECOND CROP AFTER WHEAT AND FALLOW PREDECESSORS

Stanimir ENCHEV, Velimir DONCHEV

Agricultural Academy, Agricultural Institute - Shumen, 3 Simeon Veliki Blvd, Shumen, Bulgaria

Corresponding author email: stanimir_en@abv.bg

Abstract

The research was carried out between 2021 and 2023 in the experimental fields of the Agricultural Institute - Shumen, Bulgaria. The aim of this study was to establish the yield structure and productivity of grain sorghum, Sudangrass and grain maize tested as a second crop after wheat and fallow predecessors. The results over three consecutive years indicate that fallow is a better predecessor and the plants sown on it develop much more intensively and accumulate more mass than the wheat predecessor, despite the shorter vegetation periods. The green mass yields of Sudangrass, sown on fallow significantly exceeded the yields obtained with the wheat predecessors. Similar results were obtained with sorghum and maize. In all three years, maize and sorghum with a fallow predecessor managed to form seeds and reach the milky-wax maturity stage, which is an important prerequisite for the production of green silage. Crops sown on fallow, despite their early sowing, lag behind in growth and form only short stems and foliage.

Key words: sorghum, Sudangrass, maize, productivity, predecessors.

INTRODUCTION

Growing more and better quality produce is the goal of any agricultural production. For summer cash crops and for those grown for green manure after cereal crops in the conditions of Northern Bulgaria, precipitation is insufficient, especially after a predecessor that uses a large part of the water accumulated in the soil from autumn-winter precipitation. Often after harvesting the wheat crop, the productive moisture in the 0-25 cm layer is exhausted. When maintaining fallow (for the implementation of the administrative measures under Regulation (EU) 2021/2115 of the European Parliament and of the Council of December 2, 2021, it is necessary that the plot is in good agricultural condition by July 15), the soil is moisture-retained and enriched with easily accessible nutrients. Sowing summer crops for the purpose of obtaining cash produce, fodder or for green manure has been a widespread practice for centuries. The problems facing such production are not few. On the one hand, the relatively short growing season does not allow crops to develop their potential, and on the other hand, plant development in the driest and hottest months is a challenge. The search for crops with a short growing season and high yield potential under

stressful conditions requires efforts to be directed towards better understanding their genetic and physiological capabilities in order to use them in breeding. Also, the environmental standards that have been imposed administratively in recent years require improved field management. Intercrops are a key component of the cropping sequence in minimum tillage farming systems. They allow for minimizing the accumulation of diseases and the rotation of herbicide groups to combat herbicide-resistant weeds (Kirkegaard et al., 2008; Angus et al., 2015; Kirkegaard & van Rees, 2019).

Integrating cover crops into cropping systems has costs and benefits, both internal and external to the farm. Benefits include promoting pest suppression, soil and water quality, nutrient cycling efficiency, and main crop productivity. Costs of growing cover crops include increased direct costs, potentially reduced income if green manures interfere with other attractive crops, difficulties in predicting nitrogen mineralization, and production costs. The benefits of cover crops are generally higher in irrigated systems (Snapp et al., 2005). Crop production systems in semi-arid regions may not have the potential to profitably use cover crops due to reduced subsequent yields of wheat

(*Triticum aestivum* L.) after the cover crop. There is no evidence of yield reduction for subsequent spring crops (Nielsen et al., 2016). Increasing soil organic carbon is easiest with cover crops in cropping systems. Their advantage over other management practices is that they do not cause yield losses, such as extensification, nor carbon losses in other systems, such as organic fertilizer applications. However, the effect of green manuring of cover crops on soil carbon stocks has been widely neglected (Poeplau and Don, 2015).

Cover crops are a more reliable means of increasing main crop yields than fallow and produce the highest amount of biomass and should be considered when the goal is to quickly build soil organic matter (Snapp et al., 2005).

In low-rainfall environments, high frequency of winter cereals is preferred to optimize productivity and risk. However, high-intensity cereal crops often result in reduced water use efficiency and increased inputs to address emerging nutritional, disease and weed problems. Incorporating green manures into subsequent cereal crops has been shown to increase yields by at least 1 t ha across a range of soil types and has beneficial effects on nutrient cycling and delivery, along with some short-term effects on *Rhizoctonia solani* infection in subsequent cereal crops, while there is no convincing evidence of improved water balance for subsequent crops (McBeath et al., 2015). Han et al. (2021) found a difference in the accumulation of all types of nutrients in the topsoil from lower soil horizons, as well as increased uptake by the subsequent crop. This also helps to conserve nitrogen from denitrification. The obtained data on grain yields and fertilizer application indicate the importance of the formation of a mulching layer of plant residues on the surface of ordinary and southern chernozems in no-tillage systems. This layer contributes to the gradual accumulation of nitrogen, protects the soil from erosion, and increases the number and mass of combthworms. Nitrogen in direct-tillage systems on chernozems in Russia is characterized by high mobility and the ability to undergo significant transformation. In this context, additional research and special experiments are needed to obtain better knowledge of the behaviour of nitrogen in

different cropping systems. In particular, the relationships between nitrogen flows, agrophysical properties of the soil (the distribution of aggregates by size at the macro and micro levels) and the specificity of organic matter in different subtypes of chernozems under different cultivation technologies need to be clarified. In general, the role of direct-tillage systems in agricultural practices has become more significant in recent years. The application of the system of cultivation of crops with minimal and zero tillage is considered a positive factor for maintaining and restoring soil fertility (Zavalin et al., 2018). Not all crops are suitable for cultivation in summer sowing.

C₄ and C₄-like plants have higher water use efficiency than C₃ plants (Tanigawa et al., 2024). They are equipped with a CO₂-concentrating mechanism that mitigates photorespiration (the wasteful Rubisco process of fixing O₂ instead of CO₂) and improves CO₂ assimilation (Leegood, 2002; Keely and Rundel, 2003).

Crops with C₄ photosynthesis are exceptionally suitable for summer sowing and suppress plant parasitic nematodes and soil-borne diseases (Snapp et al., 2005).

Analysis of the productivity of grain maize, grain sorghum and Sudan grass sown after wheat harvest under different climatic conditions contributes to better planning and management of farms. The goal is to study typical crops with C₄ type of photosynthesis because they better utilize moisture during extreme droughts and high temperatures, and provide reliable yields.

MATERIALS AND METHODS

The experiment was conducted on the experimental fields of AI - Shumen in 2021-2023. The area in which the experiment was conducted is located in the zone of typical temperate continental climate. It is characterized by cold winters and hot summers. The relief is flat. The soils are typical and leached chernozems. The average annual precipitation is about 620 mm. The distribution is very uneven. Usually the maximum precipitation is in May and June. This is very important, because this allows for the successful development of field crops sown in the fall. The soil nutrient supply

is moderate with a humus content of 3.4%, N - 48 mg/kg, P₂O₅ - 5.7 mg/100 g., K₂O - 134 mg/100 g, B - 1.3 mg/100 kg, Mn - 45 mg/kg., Zn - 0.1 mg/kg, Mo - 0.1 mg/kg. After wheat, the necessary amounts of NH₄HPO₄, KNO₃ and NH₄NO₃ were applied to compensate for the nutrients extracted from the crop. Water-soluble fertilizers were selected to quickly compensate for the losses. The fields for the experiment over the years were different, grouped in one array. The predecessor of wheat for all three years was corn. The treatments for the predecessor included three treatments with a disk harrow in different directions and the application of fertilizers before sowing. Sowing was carried out at a depth of 3-4 cm with subsequent rolling with light articulated rollers. The wheat was sown in comble October in the year preceding the sowing of the catch crops. Since we do not believe that the sowing dates of the predecessor have an impact on the experiment, the exact dates are not indicated. For the needs of the experimental setup, the following crops were selected:

1. Hybrid grain corn PR 9400;
2. Grain sorghum - Maxired variety;
3. Sudan grass - Enje-1 variety.

The experiment was carried out in two variants: Variant 1. Sowing of grain corn, grain sorghum and Sudan grass immediately after harvesting the predecessor wheat

Variant 2. Sowing of grain corn, grain sorghum and Sudan grass on a cultivated field with a predecessor fallow.

In variant 1 (predecessor wheat), the area was kept free of weeds by vegetative treatment with herbicides. Special attention was paid to their selection so that they did not affect subsequent crops, due to the very short time from application to sowing. In addition, the crop affects weeding through competition for nutrients, water and light.

In variant 2 (predecessor fallow), the area was kept clean by cultivation. The time for mechanical processing was adjusted to be immediately after rain in order to preserve the accumulated moisture.

The mass and germination of 1000 pcs. seeds for each of the three crops, according to the pleated filter paper method in a thermostat at 26°C.

The field experiment was based on the long plot method. Each variant was on an area of 100 m²,

with each crop occupying 25% of the area. Sowing was done manually at a depth of 6 cm for grain maize and 4 cm for Sudan grass and grain sorghum.

After the predecessor wheat, in different years the sowing was carried out on different dates, depending on its harvesting period. In 2021, the harvest was on June 28, with the sowing of the intermediate crops being carried out on July 1st. In 2022, the predecessor was harvested on July 3rd, and the sowing was carried out on July 4th. In 2023, the predecessor was harvested on July 5th, and the sowing of the intermediate crops was carried out on July 6th. When sowing, we made efforts to reach a moist layer to allow the seeds to germinate with the moisture available in the soil and to mulch the rows with straw as much as possible. The sowing rates of the tested crops are as follows: corn for grain - 65,000 seeds per hectare, sorghum for grain 350,000 seeds per hectare, Sudan grass 400,000 seeds per hectare. The seeds and the experimental plots were tested for the presence of phytopathogens and enemies. Due to their absence, chemical disinfection of the seeds for sowing was not carried out. During the growing season, no serious attacks from diseases and enemies were observed, probably due to the uncharacteristic period of development, as well as the dry and hot weather. Weed control was carried out by hand weeding. The green mass was harvested at the beginning of October, immediately before the first autumn frosts. The composition of the yield of fresh and dry mass was determined and an analysis of the components of the yield was performed - stems, leaves, panicles, combs.

The aim of the study is to establish the yield structure and productivity of grain sorghum, Sudan grass and grain maize tested as a second crop after predecessors wheat and fallow.

RESULTS AND DISCUSSIONS

The results shown in Table 1 show the mass and germination of seeds from the three crops.

It is evident that the weight of sorghum seeds, due to their small size, is almost 1:10 compared to corn seeds, and Sudan grass 1:16. Accordingly, 340 g: 21.6 g. The mass of the seeds is within normal limits for the species and determines a reserve of nutrients available to the plants after germination. The germination of all

three crops is excellent with an average germination of over 95%, with Sudan grass being lower. This is especially important when determining the sowing rates of the crops.

Table 1. Mass and germination of seeds of grain maize, grain sorghum and Sudan grass

Grain maize		Sudan grass		Grain sorghum	
Mass (g)	Germination rate (%)	Mass (g)	Germination rate (%)	Mass (g)	Germination rate (%)
340.4	98.0	20.8	95.0	36.6	96.0
341.2	99.0	22.0	96.0	36.0	98.0
340.6	98.0	22.2	95.0	36.0	97.0
340.7	98.3	21.6	95.3	36.2	97.0

Table 2 shows the precipitation and temperatures during the testing period, and for better illustration, previous months are also included, since the precipitation in them is outside the vegetation period of the experiments, they create a reserve of moisture in the soil, which can subsequently be used during the vegetation period.

Meteorological data during all three years of conducting the experiments indicate an increasing water deficit and a tendency towards extreme deviations from agroclimatic norms. The annual precipitation for all three years is around the average norm for the region, with 2022 even slightly exceeding the norm, but for the three months of vegetation they are in acute shortage. 2021 is distinguished by less precipitation than 2022, but due to their more correct distribution at the beginning of the period, the crops showed the highest results. 2023 is the most unfavourable year in terms of moisture. On the one hand, the precipitation that fell was far below the norm, and on the other hand, a large part of it was at small due to the short day, low temperatures and fading vegetation. During the three years of testing, the crops actually sprouted normally and developed with moisture accumulated as a reserve in the soil. Then they slowed down their growth, and this was very characteristically seen in the crops sown after a predecessor of wheat, practically stopping their growth. With a predecessor of fallow, the growth slowdown was not so noticeable and the crops developed much better. The high average temperatures in the region also contributed to the stress on the plants. The

second and third ten days of July, as well as the beginning of August, were very hot in all three years of testing, with average daily temperatures of 24-26°C. The record for the three years was the second ten days of July 2023, with an average temperature of 27.5°C. This led to a delay in crop development.

Table 2. Meteorological data for the experimental area

Years	Month	Rainfalls, mm					Temperature			
		Decades			Amount	Norm	Decades			Average
		I	II	III			I	II	III	
2021	VI	16.7	136.4	11.7	164.8	41	17.6	17.7	25.3	20.2
	VII	16.5	3.4	1.2	21.1	64	18.9	22.5	26.7	23.4
	VIII	0	0	6.7	6.7	42	24.6	25.4	22.5	24.1
	IX	0	1.7	1.4	3.1	53	18.5	21	15.3	18.3
	Total for the period				290.8	305				
2022	Month	Rainfalls-mm					Temperature			
		Decades			Amount	Norm*	Decades			Average
		I	II	III			I	II	III	
	VI	52.7	73.3	1.2	127.2	41	21.2	20.2	22.6	21.3
2022	VII	0.6	0	3.7	4.3	64	23.5	22.9	26.1	24.2
	VIII	0	27.6	3	30.6	42	25.1	24.4	24.8	24.8
	IX	28.9	9.6	16.7	55.2	53	20	19	16.2	18.4
	Total for the period				309.1	305				
2023	Month	Rainfalls-mm					Temperature			
		Decades			Amount	Norm	Decades			Average
		I	II	III			I	II	III	
	VI	13.3	11.4	44.7	69.4	64	13.8	15	17.9	15.6
2023	VII	34.6	3.1	0	37.7	64	23.8	27.5	25.3	25.5
	VIII	0	6.7	0.6	7.3	42	24	24.9	20.8	23.1
	IX	0.9	47.8	0	48.7	53	22	20.4	21.3	21.2
	Total for the period				275	305				

*mean of vegetation rainfalls for 50 years period

After germination, despite the initial stress caused by drought, the crops managed to accumulate vegetative mass in the initial stage of their development. Grain maize, due to its larger seeds and, accordingly, the larger supply of nutrients in the endosperm, logically overtook grain sorghum and Sudan grass in the initial stages. It quickly accumulated biomass and grew in height. An important detail is that on a field with a fallow predecessor during the three years under consideration, grain maize failed to reach comb development, but managed to develop only leaf mass. Drought and high temperatures led to typical physiological

features - strong shortening of the internodes, shrinkage of motor cells and curling of the leaves, reduction in chlorophyll content. On a field with a fallow predecessor, the development of grain corn was accelerated and not only were the plants taller, but they were also able to set combs, and in all three years of the experiment the crop reached milky-wax maturity of the grain. The physiological changes were not so well expressed. The stems reached a length characteristic of the variety and the comb formation, flowering and pollination proceeded normally.

Grain sorghum quickly sprouted in both predecessors. However, we can note that in the predecessor fallow, it quickly accumulated biomass and grew in height, reaching the height and thickness of the stem normal for the variety, with the phases of sweeping, flowering and pollination occurring normally. At the end of the experiment, it reached the flowering phase - milky-wax maturity in all three years. On the predecessor, wheat reached the development of only leaf mass, with strongly shortened internodes with insignificant stem height, and only in 2021 did it manage to reach sweeping, but the panicles remained sterile.

In Sudan grass, we found similar data to grain sorghum. In the predecessor fallow, although with a delay in sowing until July 15, it sprouted normally in 3-4 days. It quickly caught up with that sown on stubble and grew in height, reaching a height of 2 m in 2021, and at the end of the growing season it was in the sweeping phase. In the following years, the effect was almost the same. On the predecessor wheat, after normal germination and topping of the crops and reaching the 2nd, 3rd leaf phase, its growth slowed down significantly. By the onset of autumn, it managed to make 5-6 leaves with greatly shortened internodes on the stem. The plants were severely stressed and with a reduced chlorophyll content.

The average data on green mass yield are shown in Table 3.

As can be seen from the table, 2021 is distinguished by higher green mass yields than the following two for all crops. Despite the relatively lower precipitation compared to 2022, they are grouped at the beginning of the period and create a reserve of moisture, which was subsequently utilized by the plants. In addition,

2021 is the coolest of the three years of testing and with the lowest evapotranspiration coefficient. Corn yields on fallow exceed those of 2022 by 0.514 t/ha or 2% and those obtained in 2023 by 1.755 t/ha or 6%. This trend is also maintained for the predecessor wheat stubble, where the difference is 0.908 t/ha or 14% and 1.563 t/ha or 27%. For Sudan grass rye, the decrease on fallow for 2022 and is 11,250 t/ha or 21% and 13.25 t/ha or 26% for 2023, and on stubble 1,185 t/ha or 37% for 2022 and 1.2 t/ha or 38% for 2023. For sorghum on fallow, the yield reduction in 2022 and 2023 is respectively 6 t/ha or 22%, and 8 t/ha or 28% for 2023, and on predecessor wheat 0.65 t/ha or 25%, and 0.43 t/ha or 17%.

Table 3. Total yield of green mass of crops sown after predecessors fallow and wheat (t/ha)

Year	Grain maize yield (t/ha)		Sudan grass yield (t/ha)		Grain sorghum yield (t/ha)	
	Fallow	Wheat	Fallow	Wheat	Fallow	Wheat
2021	30.87	5.87	52.30	3.21	28.85	2.65
2022	30.36	4.96	41.71	2.03	22.70	1.99
2023	29.11	4.31	39.10	2.01	20.81	2.22
Mean	30.11	5.05	44.38	2.41	24.12	2.28
GD1 %	6.058	5.0	9.34	4.04	4.56	9.13
P%	5.2	16.1	6.45	3.45	5.61	3.12

The differences between the yields after the different predecessors are greater. Maize harvested on stubble in 2021 gives only 19% of the yield on fallow. In 2022, 16%, and in 2023 only 14.8%. On average for the three years of testing, the reduction is 25 t/ha. In Sudan grass, the different predecessors have a stronger influence. In 2021, the yield obtained after the predecessor wheat is only 6.1% of the yield obtained after the predecessor fallow, with the difference being 49 t/ha, and in 2022 and 2023, respectively 4.8 or 39.5 t/ha and 5.1% or 37 t/ha. In sorghum, the yields obtained with wheat as the predecessor are respectively 9% or 26 t/ha, 8.7% or 20.5 t/ha and 10.6% or 18.5 t/ha of those obtained with fallow as the predecessor. The strongest influence of the predecessor on the difference in yield is found in Sudan grass. Due to the small seeds and the few reserve nutrients in the endosperm, it germinates and develops extremely slowly on stubble, being strongly oppressed by drought and high

temperatures. The difference in yield over the years between fallow and stubble reaches 18 times, with the largest differences being found in 2021.

Table 4. Analysis of yield components for grain maize, grain sorghum and Sudan grass with a fallow predecessor

Year	Fallow predecessor - total yield of green mass (t/ha)								
	Grain maize			Sudan grass			Grain sorghum		
	Sta lks	Lea ves	Cobs	Sta lks	Lea ves	Pani cles	Sta lks	Lea Ves	Pani cles
2021	19.382	9.825	1.666	41.080	10.752	0.517	20.035	5.810	3.005
2022	20.530	8.700	1.130	30.440	10.925	0.347	15.767	4.572	2.365
2023	19.580	8.266	1.273	28.785	9.615	0.700	13.452	3.991	2.167
Mean	19.830	8.930	1.356	33.435	10.430	0.521	16.751	4.858	2.512
GD1%	5.941	5.043	0.565	4.248	1.678	0.396	3.509	1018	0.565
P%	6.52	13.42	9.33	2.76	3.5	16.51	4.56	4.13	3.21

In corn, the composition of the yield with a fallow predecessor did not differ significantly during the three years of testing. In 2021, with a higher total yield, the percentage of stems in the total yield was 62%, leaves 32%, and combs 5%. In the following two years, the share of stems increased by 5% to 67%, while leaves decreased by 5% and combs by 1%. In Sudan grass, the trend was the opposite. The share of stems was the largest in 2021, 78%, in the following two years it made up about 73%, this is due to the increase in leaf mass in 2022 and 2023 to 26% and 25% and almost no change in panicles. The composition of the yield in sorghum almost did not change during the tested years. The share of stems in 2021 was the largest, making up over 70% of the yield. In the following two years it drops to 69% and 68%. The share of the yield taken up by the leaves is 19.4% in 2021 and increases to 20% in the following two. In the case of cornflowers, the relative yield in 2021 and 2022 is 10% of the total mass, and in 2023 11% (Table 4).
The yield composition of the predecessor wheat in all three crops consists exclusively of leaves. This is due to the low height of the plants and the very shortened stem during harvesting. The highest yields of corn were obtained in 2021 -

5.875 t/ha., and the lowest in 2023 - 4.312 t/ha
When reviewing the data on the Sudan grass yield, it is striking that the highest was obtained in 2021 - 3.215 t/ha, and the lowest in 2022 - 2.032 t/ha. The yield of grain sorghum varies from 2.65 t/ha for 2021 to 2 t/ha for 2022, with the smallest variation in productivity being found in this crop (Table 5).

Table 5. Green mass yield with wheat as predecessor (t/ha)

Years	Wheat predecessor - total yield of green mass (t/ha)		
	Grain maize	Sudan grass	Grain sorghum
2021	5.875	3.215	2.650
2022	4.967	2.032	1.998
2023	4.312	2.257	2.220
Mean	5.052	2.336	2.298
GD1%	2.745	0.323	0.563
P%	11.82	12.33	5.35

Table 6. Green mass of post-harvest residues for different predecessors (t/ha)

Year	Post-harvest residues in a predecessor fallow (t/ha)			Post-harvest residues in a predecessor wheat (t/ha)		
	Maize	Sudan grass	Grain sorghum	Maize	Sudan grass	Grain sorghum
2021	10.810	13.905	6.185	2.875	3.105	4.393
2022	8.575	12.730	5.717	2.465	2.448	3.948
2023	9.325	10.610	5.935	1.975	2.258	3.424
Mean	9.903	12.415	5.945	2.439	2.604	3.922
GD1 %	5.685	2.490	0.580	0.652	1.032	0.371
P%	13.5	4.32	3.2	5.82	8.62	2.06

From the three years of harvesting corn after a predecessor fallow, an average of 9.900 t/ha. post-harvest residues were obtained. The most in 2021 – 10.810 t/ha., and the least in 2022 – 8.575 t/ha, with a significant variation. They constitute 25% and 23% of the total yield, respectively. Sudan grass with the same predecessor gave the most post-harvest residues in 2021, and the least in 2023, respectively 13.90 t/ha and 10.61 t/ha., varying from 21% to 24% of the total yield. In sorghum, post-harvest residues vary relatively little, between 5.717 t/ha in 2022 to 6.185 t/ha in 2021. It constitutes 17% and 21% of the total yield, respectively.
With wheat stubble as the predecessor, the amount of post-harvest residues in maize is between 2.875 t/ha and 1.975 t/ha, with the

weight ratio between the obtained yield and plant residues being from 46% to 49%. In Sudan grass, their amount is less than that in maize and sorghum, with their amount varying from 2.010 t/ha to 3.105 t/ha. The percentage ratio is similar to maize - 49% to 54%. The yield in sorghum is from 2.000 t/ha to 2.650 t/ha, with the percentage ratio plant residues/yield being between 60% and 66%.

In 2021, Sudan grass recorded the highest amount of plant residues - 3.105 t/ha, and the lowest in 2023 - 2.258 t/ha. The highest amount of plant residues after the predecessor wheat was recorded for grain sorghum. Yields are relatively constant with little variation. Expressed in absolute values, they range from 4.393 t/ha in 2021 to 3.4224 t/ha in 2023 (Table 6). This is due to the relatively thick stems of the plants in their lower part and the high sowing rate.

CONCLUSIONS

Sowing corn, sorghum and Sudan grass as a second crop for green fodder or for green manure after fallow is appropriate in view of the unfavorable agroclimatic conditions caused by drought. The obtained average yields of 30 t/ha corn, 44 t/ha Sudan grass and 24 t/ha sorghum confirm the possibility of their use in agricultural production.

The yields obtained from the three crops after the predecessor wheat in the three years of conducting the experiment are unsatisfactory and in the presence of droughts question their use in practice as a second crop.

The obtained green mass yields with the predecessor fallow significantly exceed those obtained with the predecessor stubble. The increase in corn on fallow is 25 t/ha, with Sudan grass 42 t/ha, and with sorghum 22 t/ha.

The amounts of plant residues obtained with the predecessor fallow are superior to those obtained with the predecessor wheat. The differences in the average amount for corn are 7.5 t/ha, for Sudan grass 12 t/ha, and for sorghum 2 t/ha.

For the predecessor wheat, the yields are insignificant, with post-harvest residues representing the majority of the biomass obtained.

REFERENCES

- Angus, J.F., Kirkegaard, J.A., Hunt, J.R., Ryan, M.H., Ohlander, L., Peoples, M.B. (2015). Break crops and rotations for wheat. *Crop and pasture science*, 66(6). 523–552.
- Han, E., Li, F., Perkons, U., Küpper, P.M., Bauke, S. L., Athmann, M., & Köpke, U. (2021). Can precrops uplift subsoil nutrients to top soil? *Plant and Soil*, 463. 329–345.
- Keeley, J.E., Rundel, P.W. (2003). Evolution of CAM and C₄ Carbon-concentrating mechanisms. *International Journal of Plant Sciences*, 164(S3). S55–S77.
- Khaledian, M.R., Mailhol, J.C., Ruelle, P., Mubarak, I. (2012). Impact of direct seeding in mulch on yield, water use efficiency and nitrogen dynamics of maize, sorghum and durum wheat. *Irrigation and Drainage*, 61(3). 398–409.
- Kirkegaard, J., & van Rees, H. (2019). Evolution of conservation agriculture in winter rainfall areas. In *Australian agriculture in 2020: From conservation to automation* (pp. 47-64). Australian Society of Agronomy.
- Kirkegaard, J., Christen, O., Krupinsky, J., Layzell, D. (2008). Break crop benefits in temperate wheat production. *Field crops research*, 107(3). 185–195.
- Leegood, R.C. (2002). C₄ photosynthesis: principles of CO₂ concentration and prospects for its introduction into C₃ plants. *Journal of Experimental Botany*, 53(369). 581–590.
- McBeath, T.M., Gupta, V.V.S.R., Llewellyn, R.S., Davoren, C.W., Whitbread, A.M. (2015). Break-crop effects on wheat production across soils and seasons in a semi-arid environment. *Crop and Pasture Science*, 66(6). 566–579.
- Nielsen, D.C., Lyon, D.J., Higgins, R.K., Hergert, G.W., Holman, J.D., Vigil, M.F. (2016). Cover crop effect on subsequent wheat yield in the central Great Plains. *Agronomy Journal*, 108(1). 243–256.
- Poepplau, C., Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. *Agriculture, Ecosystems & Environment*, 200. 33–41.
- Snapp, S.S., Swinton, S.M., Labarta, R., Mutch, D., Black, J.R., Leep, R., O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy Journal*, 97(1). 322–332.
- Tanigawa, K., Yuchen, Q., Katsuhama, N., Sakoda, K., Wakabayashi, Y., Tanaka, Y., Sage, R., Lawson, T., Yamori, W. (2024). C₄ monocots and C₄ dicots exhibit rapid photosynthetic induction response in contrast to C₃ plants. *Physiol Plant*. 2024 Jul-Aug.
- Zavalin, A.A., Dridiger, V.K., Belobrov, V.P., & Yudin, S.A. (2018). Nitrogen in chernozems under traditional and direct cropping systems: a review. *Eurasian Soil Science*, 51. 1497–1506.