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Original Research

Effects of Weather Conditions on Yield of Tansy Phacelia and Common Sunflower Grown as Stubble Catch Crop

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Abstract

In our study conducted in north-central Poland in 2001-09 in the lessive soil of a very good rye complex, a relationship between the yielding of tansy phacelia and common sunflower grown as stubble catch crop and the weather conditions that prevailed during the growing period were estimated. The yield of the tested plants grown as stubble catch crop was significantly dependent only on the total precipitation occurring in the period from the beginning of July to the end of August. A good plant supply in water in one of those two months was sufficient to cultivate the catch crop successfully, and optimal total precipitation from the beginning of July to the end of August was 142 mm for tansy phacelia and 150 mm for common sunflower.

Keywords: catch crops, weather conditions, tansy phacelia, common sunflower

Introduction

Plant cultivation in stubble catch crop is currently justified mostly by a favorable effect on the soil environment, expressed in improvement of physical soil properties [1] and reducing the threat of eutrophication caused by leaching out of fertilizing components from soil [2-4].

Those objectives can be accomplished only when plants make abundant biomass, which can take up considerable amounts of mineral elements, and particularly of mineral nitrogen. This is possible only under conditions of favorable distribution of precipitation and air temperatures. Good stubble catch crops can take up from soil 60-240 kg of nitrogen and 160-310 kg of potassium [3, 5-7].

The weather conditions in east-central Europe are characterized by great variability and little predictability [8, 9]. From a multi-year study by Żarski and Dudek [10] concerning weather conditions, it follows that long-term average precipitation totals prevailing in the north-central Poland in the period from July to October are hardly lower from those which Demidowicz and Gonet [11] and Sypniewski et al. [12] regard as optimal for stubble catch crops. However, because of years with precipitation sum and distribution considerably differing from the average, cultivation in stubble catch crop of even the not very demanding non leguminous plants is burdened with a certain risk [13]. To reduce this risk, it is necessary to more precisely determine demands of those crops in respect to the basic weather factors, allowing planning of such cultivation. Success in stubble catch crop cultivation depends to a larger degree on weather factors than on soil conditions and cultivation technology [13, 14].

The growth, development, and yield of plants grown as stubble catch crop are largely affected by the weather conditions prevailing before seed sowing and during the initial plant growing stages [4, 11, 12, 14]. Plant supply in water, which affects seed germination rates and the dynamics of plant growth and development, plays an essential role [11-13].

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Table 1. Chemical properties of soil prior to the experiment.

Year	N_{TOT}*	C_{ORG}**	P_{AVAIL}***	K_{AVAIL}	Mg_{AVAIL}	pH in 1M KCl
	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)	($mg \cdot kg^{-1}$)	($mg \cdot kg^{-1}$)	($mg \cdot kg^{-1}$)	
2001	0.80	7.3	135	300	70.8	6.6
2002	0.70	6.7	106	315	69.8	5.7
2003	0.56	4.9	108	368	54.8	6.7
2004	0.62	5.4	72	308	54.8	4.8
2005	0.67	6.8	108	350	55.6	6.8
2006	0.62	6.6	111	385	54.0	6.6
2007	0.72	8.1	114	366	71.8	6.0
2008	0.71	7.5	109	302	54.8	5.9
2009	0.60	6.8	101	223	58.0	5.7
Mean	0.65	6.7	107	324	60.5	6.1

*N_{TOT} – total nitrogen content, **C_{ORG} – organic carbon content, ***P_{AVAIL}, K_{AVAIL}, Mg_{AVAIL} – available phosphorus, potassium, magnesium contents

This is of utmost importance in August, when the length and intensity of solar radiation makes it possible to obtain large daily increases in yield. A delay of sowing and moving the catch crop growth to the period with less favorable light conditions results in a significant decrease in green matter yield [14, 15]. The thermal conditions occurring in September and October have a considerable, although less significant, effect on the height of yield, making it possible to prolong the period of plant growth and development and partially compensating for earlier deficits [11, 16, 17].

The present study concerned two species of non-leguminous plants: common sunflower and tansy phacelia. These plants are characterized by a varied sensitivity to sowing time and air temperature during the growing period. It was assumed that there is a possibility of occurring varied responses of the tested plants to water supply at germination and to the thermal conditions prevailing, particularly at the end of the catch crop growing period.

The aim of this study was:

- to determine the optimal distribution of precipitation, allowing the dynamic growth and development and high yield of common sunflower and tansy phacelia grown as stubble catch crop in the lessive soil
- to estimate relationships between the air temperature in individual months of the growing period and the yielding of the tested plants
- to compare the yield of tansy phacelia and common sunflower grown as stubble catch crop, under various weather conditions

Material and Methods

Location, Design, and Course of Field Experiments

Strict field experiments were carried out in the randomized complete block design, in four replications, in 2001-09, at the Research Station Mochełek belonging to the University of Technology and Life Sciences in Bydgoszcz (17º51'E; 53º13'N). Sowing of stubble catch crops followed the harvesting of spring barley.

The experiment was conducted in soils of the very good rye complex, of IVa quality class, belonging to the type of lessive soils. Granulometric composition of topsoil is typical for fine Sandy Loam. Clay content is 19% in the layer from a depth of 10 to 25 cm and 17% in the layer from a depth of 38 to 46 cm. Deeper layers of soil are classified as Sandy Clay Loam, containing 26% clay at a depth of 74 to 92cm and 59% clay at a depth of 127 to 139 cm [18]. The soil was characterized by a slightly acid reaction, in 8 out of 9 years of this study abundance with the assimilable forms of phosphorus and potassium was high, and with organic carbon and total nitrogen relatively low (Table 1). The soil is characterized by high field water capacity ranging from 215 to 270 mm in depth from 0 to 100 cm [19].

The subject of this study was two species of plants grown as stubble catch crops: the tansy phacelia (*Phacelia tanacetifolia* Benth.) cv. Stala and the common sunflower (*Helianthus annuus* L.) cv. Wielkopolski. Catch crops were fertilized with phosphorus (26 $kg \cdot ha^{-1}$ P) and potassium (66 $kg \cdot ha^{-1}$ K) fertilizers, which were applied as a whole immediately after the previous crop harvesting.

After spreading the fertilizers, skimming was made at a depth of about 12 cm. Prior to sowing, the seedbed was prepared with a cultivation unit composed of a cultivator and a string roller.

Catch crops were sown with the plot seeder OYORD in a row spacing of 12.5 cm, from 3 to 12 August. Phacelia seeds were sown in an amount of 10 $kg \cdot ha^{-1}$, at a depth of about 2 cm, and sunflower achenes in an amount of 30 $kg \cdot ha^{-1}$, at a depth of about 4 cm.

After the catch crop sowing, an observation of plant development was conducted. The number of plants was determined after the finishing of emergences [$No. \cdot m^{-2}$]. Harvesting always was carried out after observing the first plant injuries by slight frosts, from 17 to 28 October, 70-79 days after sowing. Sunflower was collected in all the years during formation of inflorescences, and phacelia at the stage of budding or flowering. The harvested area of each plot was 27 m² (1.35 m × 20 m).

Measurements and Analyses

The content of organic carbon in soil samples collected before sowing was determined with the Tiurin method, total nitrogen content using the Kjeldahl method [20], content of assimilable forms of phosphorus and potassium with the Egner-Riehm method [21] and magnesium content using the Schachtschabel method [22]. The soil pH in 1 M KCl was determined with the potentiometric method [22].

During the harvesting of catch crops, the green matter yield of the plants was determined and 1 kg green matter was collected from each plot. The samples were weighed and dried in a dryer at 50ºC. The yield of dry matter was determined on the basis of a proportion of dry matter in green matter yield for each plot. The yield of post harvest residue was determined on the basis of samples collected from soil monoliths of 25×25×25 cm. The samples after initial sieving were rinsed out in a stream of water to clean the soil, and then remains of not decomposed straw and weeds were removed manually. After drying the samples on absorbent paper they were weighed on electric scales to an accuracy of 0.1g. Then the samples were dried at 50ºC and weighed again to determine the dry matter yield.

The assessment of the weather conditions during the field experiments was carried out based on the observations made at the observation and measuring point of UTP at Mochełek. Sielianinov hydrothermal coefficients were calculated based on the equation:

$$k = \frac{P\ 10}{\sum t}$$

...where:
P – total precipitation in the given period [mm]
Σt – total of average daily air temperatures from that period [ºC] [23, 24]

According to the classification presented by Skowera and Puła [23], we can distinguish the following conditions: extremely dry (k≤0.4), very dry (0.4<k≤0.7), dry (0.7<k≤1.0), rather dry (1.0<k≤1.3), optimal (1.3<k≤1.6), rather wet (1.6<k≤2.0), wet (2.0<k≤2.5), very wet (2.5<k≤3.0), and extremely wet (k>3.0).

The results obtained in individual years were subjected to the analysis of variance. Significance of differences was determined with Tukey's confidence half-interval, at the significance level α=0.05. Simple correlation coefficient r indicating the strength of the rectilinear relationship between weather conditions and catch crop dry matter yield, as well as the correlation relationship R showing the strength in the curvilinear relationships between these traits, were made in the program Statistica for Windows StatSoft. Inc.1984-1997.

Results and Discussion

Effect of the Weather Conditions on Germination and Emergences as well as the Growth and Development of Plants

Average air temperatures that prevailed during the experiment period were slightly higher in July and August and lower in October than long-term averages for this region (Fig. 1). Temperature distribution in individual years was most often similar. Only in 2001 was a cool September and a relatively warm October observed, in 2003 October was very cool, in 2004 temperatures in July were considerably below the average, and in 2006 July and September were substantially warmer than the average.

Yield of fodder plants is strongly modified by soil water availability [25, 26]. In the study carried out by Todorović et al. [25] the biomass yield of sunflowers grown in conditions of very good water supply was two times higher than in average conditions. To produce 1 kg of dry matter, non-legume fodder plants with C3 photosynthesis consume about 550-600 liters of water [27, 28].

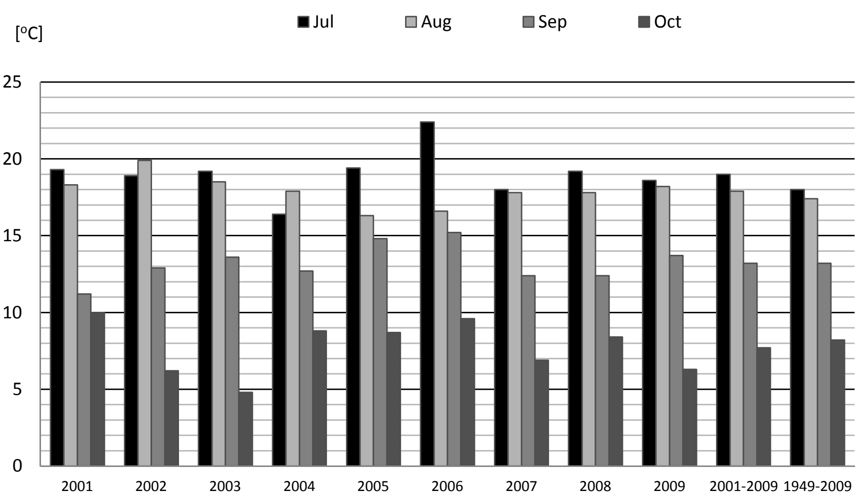

Fig. 1. Mean air temperature, July to October, [ºC].

Table 2. Sielianinov hydrothermal coefficient from July to October.

Years	July	Aug	Sep	Oct	Mean July-Oct
2001	2.44	0.88	3.65	0.63	1.90
2002	1.33	0.94	1.82	5.82	2.48
2003	1.78	0.31	0.41	2.28	1.20
2004	1.05	2.50	1.05	2.34	1.74
2005	0.56	0.86	0.40	0.56	0.59
2006	0.35	2.51	0.89	0.41	1.04
2007	1.88	0.76	1.01	0.93	1.15
2008	0.99	1.73	0.54	3.07	1.58
2009	2.05	0.31	0.84	3.39	1.65
Mean 2001-09	1.38	1.20	1.18	2.16	1.48
Mean 1949-2009	1.27	0.96	1.04	1.29	1.14

Favorable water conditions for plants grown as stubble catch crop occurred most frequently in the period of the study. The average total precipitation of 9 years in the period from July to October was higher than the long-term average recorded in this region (Fig. 2). Moreover, the average total precipitations in individual months were similar to those in the long-term period. However, significant diversification in plant water supply was observed in individual years of the study, particularly in the period preceding the sowing of the seeds and after sowing. In the course of 9 years of the study, July with heavy precipitations, followed by a dry or very dry August was observed four times (2001, 2003, 2007, 2009). In one year (2006), after a very dry July a high total precipitation was observed in August. In three years the precipitation conditions were favorable both in July and August (2002, 2004, 2008), and in one year (2005), drought was observed throughout this period.

During the study as many as 8 years with dry, very dry, or extremely dry periods occurred in the growing seasons of plants grown as stubble catch crop (Table 2). Only in 2004 was the Sielianinov hydrothermal coefficient above 1.0 throughout this period. In most growing seasons droughts were mild and preceded by periods of more favorable moisture conditions, which allowed accumulating sufficient water resources for plants in the soil. Only in one year (2005) did drought occur both before sowing the seeds and through the growing period.

The plant density of phacelia after emergences (Table 3) was positively correlated with the total precipitation prevailing in July and August (r=0.66; y=0.45x+94.83; n=9). No correlation was observed between the total precipitation in individual months and plant density after emergences. Germination and emergences of sunflower did not depend on total precipitation during sowing. Different responses of the tested plants to the total precipitation can result from a different sowing depth. Germination of sunflower, whose achenes were sown deeper than phacelia seeds, was to a lesser degree dependent on the occurrence of precipitation during sowing.

Effect of Weather Conditions on Plant Yield

Non leguminous plants grown as stubble catch crop in the north-central part of Europe generate an aboveground dry matter yield of about 2.0-5.5 t·ha^{-1} [3, 15, 16, 29]. In the present study, the aboveground dry matter yield of catch crops was considerably low and varied over the years (Table 4). Sunflower produced a significantly higher yield than phacelia. The lowest yield was harvested in 2005, where precipitation deficit occurred during all the growing period of catch crops. The yields of the tested plants in the years when low precipitation in August were preceded by high totals in July (2001, 2003, 2007, 2009) were high or very high. The literature data shows that the largest impact on the yielding of plants grown as stubble catch crop is exerted by precipitations occurring in July, August, and September [11, 12, 30].

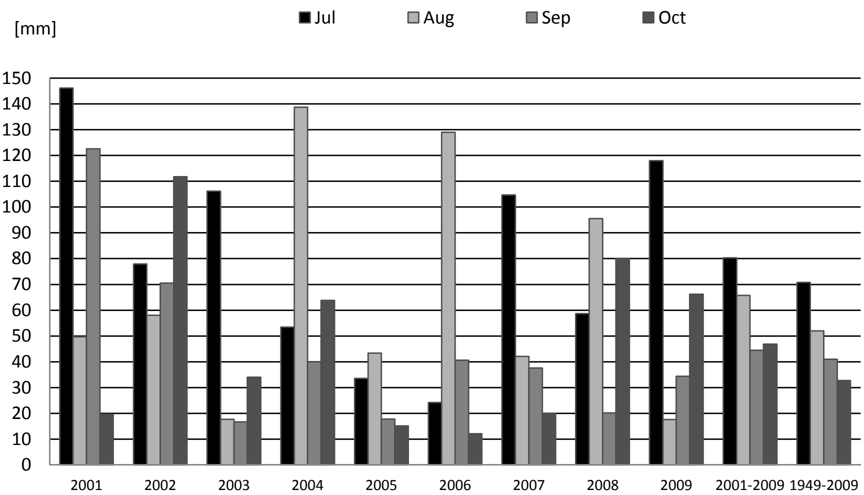

Fig. 2. Total monthly rainfall, July to October [mm].

Table 3.The number of plants after emergence [No.·m^{-2}].

Year	Tansy phacelia	Common sunflower
2001	175 (15.0*)	39 (4.9)
2002	182 (12.0)	41 (4.3)
2003	128 (10.3)	40 (2.9)
2004	187 (11.4)	40 (2.6)
2005	131 (11.6)	38 (2.8)
2006	149 (19.8)	45 (5.3)
2007	192 (19.5)	49 (6.6)
2008	158 (22.3)	37 (2.6)
2009	143 (7.5)	40 (1.8)
Mean 2001-09	160	41

*Standard deviation

The significance of the effect of precipitation occurring in September [11, 16] or the air temperatures prevailing in all the catch crop growing period on the generated dry matter yield, presented in the literature [11, 17], was not confirmed. The lack of this effect was connected with a very strong reaction of the tested plants to precipitation in July and August. The effect of the temperature in those months is more likely to be determined when precipitation in July and August are low enough to significantly limit the growth of plants in initial stages and thus reduce the yield of dry matter. During the period of 9 years of the study such conditions occurred only in one year (2005). Therefore, the obtained results do not allow making an assessment of this factor.

According to Brant et al. [17], water supply in the soil during seed sowing can be of greater importance for the growth and development of plants grown as stubble catch crop than the total precipitation that occurred during their growing period. The present study confirms that statement and shows that the total precipitation in July is good ground for taking a decision about cultivating the common sunflower and tansy phacelia in stubble catch crop. Whenever it was higher than the average, it made it possible to produce satisfying dry matter yield by those plants, even when drought occurred through all of August and September (2003 and 2009). Very high total precipitation in July can be undesirable, since that delays the ripening and harvesting of cereals, being the previous crop for plants grown as stubble catch crop and, consequently, they cause a delay of their sowing and shortening of the growing period. Excessive precipitation in July and August can also contribute to intensification in leaching nitrogen released from decomposing roots of previous crop plants to deeper soil layers and, in consequence, reduce generating the biomass of plants cultivated without additional fertilization with this component. In the study by Wojciechowski [31], excessive precipitation prevailing after sowing mustard even resulted in transferring the sown seeds to a deeper soil layer and thus hindered plant emergence. This is of the utmost importance with reference to plants with small seeds, such as tansy phacelia used in the present study. Moderate precipitation is the most desirable. A relationship between total precipitation and yield shows a curved line [11]. In the present study, relatively high yields of catch crops were obtained also in years characterized by low precipitation in July, but only when the total precipitation in August was higher than the long-term average for that month. Consequently, when assessing the precipitation demand of plants grown as stubble catch crops, the total precipitation of July and August

Table 4. Catch crop dry matter yield, [t·ha^{-1}].

Year	Aboveground matter			Post-harvest residue		
	Tansy phacelia	Common sunflower	LSD**	Tansy phacelia	Common sunflower	LSD**
2001	1.80 (0.35)	1.95 (0.12)	ns	2.29 (0.16*)	2.59 (0.28)	ns
2002	1.99 (0.20)	3.53 (0.33)	0.78	1.78 (0.23)	2.29 (0.25)	0.33
2003	3.09 (0.61)	3.56 (0.36)	ns	1.43 (0.29)	1.45 (0.32)	ns
2004	1.74 (0.21)	1.82 (0.19)	ns	0.74 (0.12)	1.06 (0.26)	ns
2005	1.00 (0.14)	1.60 (0.11)	0.18	0.98 (0.32)	1.16 (0.17)	ns
2006	3.36 (0.22)	3.96 (0.13)	0.43	1.14 (0.26)	1.97 (0.42)	ns
2007	3.12 (0.57)	3.38 (0.40)	ns	1.89 (0.22)	2.26 (0.25)	ns
2008	2.60 (0.36)	2.55 (0.21)	ns	1.43 (0.18)	1.89 (0.21)	0.35
2009	2.35 (0.27)	2.26 (0.10)	ns	1.35 (0.20)	1.56 (0.26)	ns
Mean 2001-09	2.34	2.73	0.14	1.45	1.80	0.11
LSD for years	0.69		-	0.54		-

*Standard deviation
**LSD – lowest significant difference for $\alpha = 0.05$; ns – non-significant

Table 5. Correlation coefficients between weather conditions and catch crop dry matter yield (n=9).

Factor	Months	Coefficient of simple correlations (r)		Correlation relationship (R)	
		Tansy phacelia	Common sunflower	Tansy phacelia	Common sunflower
Total rainfall	Jul	0.08	-0.06	0.18	0.25
	Aug	0.05	0.02	0.24	0.03
	Sep	-0.24	-0.12	0.31	0.44
	Jul + Aug	0.16	-0.07	0.83*	0.80*
	Aug + Sep	-0.10	-0.06	0.11	0.14
Air temperature	Jul	0.39	0.49	0.43	0.50
	Aug	0.04	0.24	0.33	0.32
	Sep	0.11	0.24	0.15	0.27
	Oct	-0.31	-0.42	0.38	0.47
Sielianinov coefficient	Jul	0.06	-0.10	0.08	0.17
	Aug	0.08	0.03	0.38	0.19
	Sep	-0.25	-0.17	0.30	0.43
	Jul + Aug	0.08	-0.17	0.83*	0.78*
	Aug + Sep	-0.11	-0.11	0.12	0.25

*significant for $\alpha = 0.05$

Table 6. Regression equations of catch crop dry matter yield depending on total precipitation and Sielianinov hydrothermal coefficient, 1 July to 31 August (n=9).

Plant species	Independent variable	Regression equation	R^2	p	Function extremum
Tansy phacelia	Total precipitation [mm]	$y=-0.0004x^2+0.114x-5.46$	0.69	0.0295	142
	Sielianinov coefficient	$y=-4.89x^2+12.7x-5.49$	0.69	0.0306	1.30
Common sunflower	Total precipitation [mm]	$y=-0.0004x^2+0.120x-5.07$	0.63	0.0493	150
	Sielianinov coefficient	$y=-5.12x^2+12.7x-4.62$	0.61	0.0591 (n.s.)	1.24

n.s. – non-significant

should be treated altogether, since if it is higher than the average in one of those months, it will be enough for this cultivation to be successful. If favourable conditions occur in July, taking a decision about catch crop cultivation does not carry a higher risk of failure.

A relationship between the yield of plants grown as stubble catch crop and many weather and soil factors makes it difficult to assess the individual contribution of particular parameters. The analysis of multiple regression for the effect of precipitation totals and average monthly air temperatures in individual months of the growing period on the dry matter yield did not allow formulating a mathematical model including their large part. Pearson's linear correlation coefficients (r), calculated for individual months, and the correlation relationship (R), between the weather conditions and the aboveground dry mass yield of catch crops, indicate a significant effect of total precipitation for the period of July and August on this variable and confirm a curvilinear course of this relationship (Table 5). The quadratic regression analysis shows that the optimal total precipitation of July and August amounts to 142 mm for tansy phacelia and 150 mm for the common sunflower (Table 6), and the most favorable Sielianinov hydrothermal coefficient for this period should be 1.30 and 1.24, respectively. Short periods with very dry or even extremely dry hydrothermal conditions that appeared during the growing season did not blight chances of obtaining a high dry matter yield, as long as they did not last longer than one month. Relatively high yields were also obtained under conditions of a prolonged water deficit. However, only when it appeared after the plants formed a rosette consisting of at least 5 leaves.

The dry matter yield of post-harvest residue (Table 4) was on average 36% lower than the aboveground biomass yield. The common sunflower produced a significantly larger mass of post-harvest residue (by about 24%) than tansy phacelia. The dry matter yield of post-harvest residue was highly diversified in the years. It was the lowest for both plants in 2004 and 2005 and the highest in 2001. The reason for poor yield in 2005 was probably unfavorable precipitation conditions during all the plant growing period, which also resulted in obtaining the low aboveground dry matter yields discussed above. In 2004 the total precipitation in August was very high and poorer plant development and, consequently, a low dry matter yield, may have resulted from the acid soil reaction. However, no significant correlation was indicated between the yield of residue and total precipitation before sowing and in the plant growing period.

Conclusions

The yielding of tansy phacelia and common sunflower, grown as stubble catch crop, depended mainly on the total precipitation prevailing in July and August. For successful catch crop cultivation under conditions of the lessive soil belonging to the very good rye complex, a good water supply in one of those two months is sufficient, and optimal total precipitation in the period from the beginning of July to the end of August is 142 mm for phacelia and 150 mm for sunflower. No significant relationship was shown between the total precipitation in September and October and the yield of the tested plants. The thermal conditions prevailing during the growing period of plants grown as stubble catch crop did not affect significantly the yield of aboveground dry matter and post-harvest residue.

The common sunflower generated a significantly higher yield of dry aboveground mass and post-harvest residue than tansy phacelia.

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