Neth. J. agric. Sci. 25 (1977): 278-287

Maximization of arable crop yields in the Netherlands

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Accepted: 27 June 1977

Key words: potential production, light interception, crop growth rate

Summary

The yields in kg per ha were calculated of potatoes, sugar-beets and winter wheat for conditions under which water and mineral supply were not limiting growth rates.

These studies showed that the time at which a closed crop canopy can be obtained in spring, is an important criterion for the yield.

Growth analyses of maize and sugar-beets confirm that relatively high yields can still be improved by accelerating leaf development in spring.

Introduction

In the Netherlands average yields of arable crops are on a high level and still increase annually. Comparison of farm results showed that these physically high yields are due rather to applied experience on the correct cultivation measures, fertilizer application, disease control, choice of varieties, etc. (Zachariasse, 1974) than to the application of growing quantities of energy and labour (de Wit, 1975).

It will be interesting to know to what extent the average yields can be further increased with the materials and methods available at present, when water and mineral supply are not limiting. Another point of interest is whether the calculated yields at optimum water and mineral supply can be further increased.

Potential production rate

In calculating the highest possible (i.e. potential) production rate, a green, closed crop canopy is assumed optimally supplied with water and minerals. Growth rate of this simulated crop is determined by the quality of the closed crop canopy and the incoming radiation.

De Wit (1965, page 33) calculated for such a crop under standard conditions the maximum gross production for each 10th degree of latitude on earth. For the middle of each month the radiation in cal cm^{-2} day^{-1} (400-700 nm), H_c, and the production in kg of dry matter ha^{-1} day^{-1}, P_c, have been tabulated. Both values apply to a cloudless sky. Radiation from an overcast sky is supposed to be 0.2 of that on a clear day. The relevant production in kg of dry matter ha^{-1} day^{-1} is P_0. The basic data of de Wit (1965) for H_c, P_c and P_0 values have been interpolated by Rijtema & Endrödi (1970) for 52°N.

Following the procedure of de Wit with the values for H_c, P_c and P_0 found by Rijtema the gross production rate in kg of dry matter ha^{-1} has been calculated with the equation $P = FP_0 + (1\text{-}F)P_c$ in 52°N for the middle of each month. Where F is $(H_c\text{-}H_a)/0.8\ H_c$, $H_a = 0.5\ H_{sh}$, and H_{sh} the average of the daily global radiation in cal cm^{-2} day^{-1} at Wageningen from 1931-1966. The values obtained for the gross production rate have been recapitulated in Fig. 1 as line 1.

Gross production rate means that the respiration required in maintenance and internal translocation has not been taken into account.

Radiation from the sun intercepted by arable crops

The total annual production of an arable crop with optimum water and mineral supply is among others dependent on the amount of sun energy intercepted by that crop during the growing period (Sibma, 1970). Light intensity, the properties of the crop surface and the duration of the field period of the crop determine the total amount of energy intercepted by it.

To collect data on the duration and the extent to which the light is intercepted by arable crops, in 1970 regular measurements were carried out with photo cells above and under the leaf canopy of potatoes, beets and wheat. Well-tended crops were taken for this, grown at the experimental farm 'De Lovinkhoeve' in the North-east Polder, exploited by the Institute for Soil Fertility (IB) at Groningen.

With respect to these observations it is stated that the potato and winter wheat crops were not measured throughout the growing period. In potatoes the first part of the light interception was estimated by taking 15 May as the date of emergence and 15 June as the date on which the soil was completely covered by foliage. In sugar-beets 1 May was taken as the date of emergence and 20 June as the date of complete soil coverage. In winter wheat soil coverage before 1 April was negligible, before this date temperature is limiting growth. After 31 July it has been assumed that the green leaf surface gradually decreases until 15 August. A possible over-estimation of light interception due to dying and dead leaves intercepting part of the light at the end of the growing season is negligible for the different crops.

Light interception in percentages by potatoes, sugarbeets and wheat is reflected in Fig. 1 by line 2. The dates on which the observations were made have been indicated by a dot on line 2.

Calculated growth rate and annual yield

The growth rate of arable crops is not limited by temperature between 1 May and 1 October and should be equal to that of the standard crop in 52°N, as indicated by line 1 in Fig. 1. It is required, however, that the crop be disease-free, water and mineral supply be at an optimum and light interception almost 100 %.

Line 2 in Fig. 1 shows that the latter demand, complete light interception, is not always met by all the crops. Insufficient light interception, especially in sugar-beets, was found to be an important limitation to the growth rate in spring.

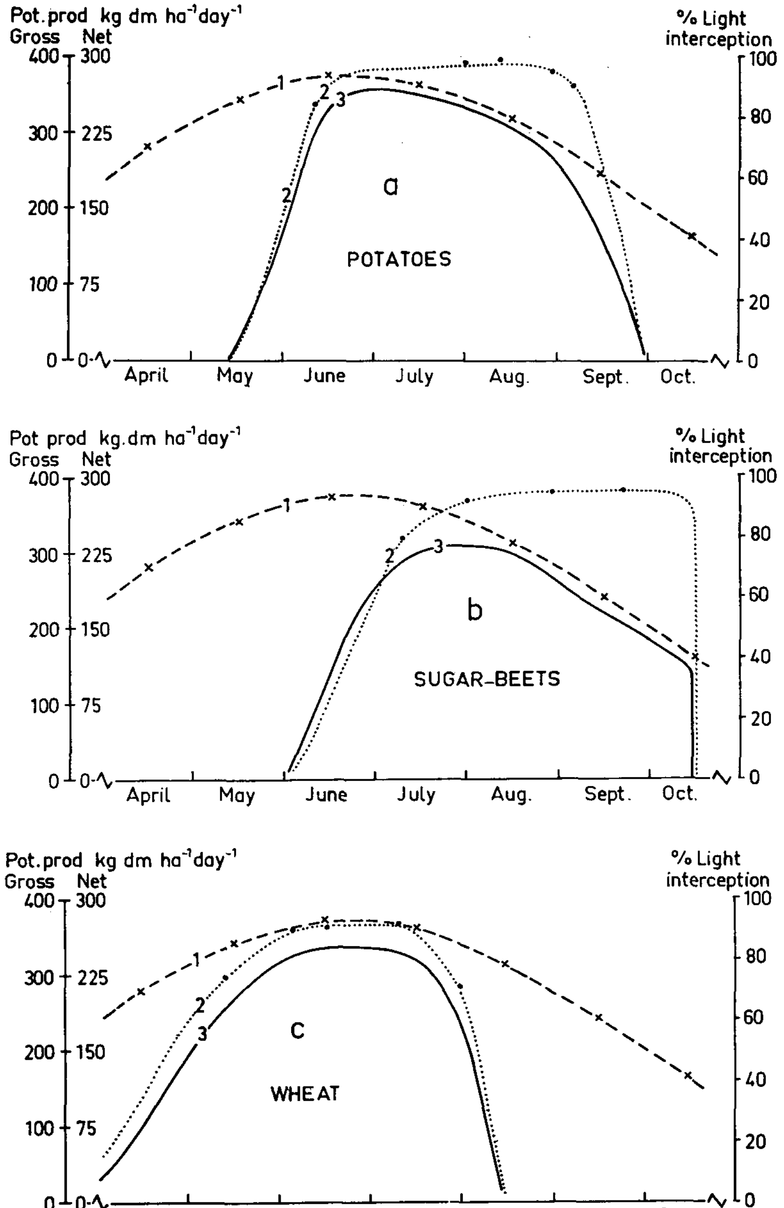

Fig. 1. Potential gross production rate (line 1), percentage of light intercepted by the crop (line 2) and calculated crop growth rate (line 3) of potatoes, sugar-beets and wheat.

For this reason, light interception was used as a conversion factor to calculate the growth rate of potatoes, beets and wheat from the growth rate of the standard crop. A linear relationship was assumed between the rate at which a crop intercepts the light and its growth rate with respect to the standard crop. The growth rates to be found on line 1 were multiplied by the percentage of intercepted light on line 2. The product of this multiplication is reflected as line 3 and indicates the gross production in kg dry matter ha^{-1} day^{-1} for the relevant crop. Integration of line 3 shows the gross yield of the crops in terms of kg of dry matter ha^{-1} at the end of the growing season. These values of the three crops have been mentioned in Table 1 as the gross production in kg of dry matter ha^{-1} $year^{-1}$.

Since de Wit (1965) calculated gross photosynthesis rates respiration should be subtracted before arriving at actual dry matter yields.

Fig. 2 shows respiration rates in kg of CH_2O ha^{-1} h^{-1} in dependence on the temperature in the canopy of closed potato crops in 1973 and 1975 (Bodlaender, personal comm.), measured with a mobile installation (Louwerse & Eikhoudt, 1975).

In July when maximum foliage is attained, above-ground respiration may also be considered to be at a maximum. At a mean temperature of 18 °C in July, the maximum above-ground respiration is 24 × 3.5 kg = 84 kg of CH_2O per ha per 24 h. Above-ground respiration has to be increased with that of the tubers.

Winkler (1970) established the respiration losses of the tuber sizes 1-2 cm, 2-3 cm and 3-5 cm diameter at 0.82, 0.42 and 0.38 mg of dry matter per gramme of tuber dry matter per hour. These respiration rates applying to the amount of tubers present in a good potato crop in July, show that the respiration of tubers is 10 to 20 kg of CH_2O ha^{-1} per 24 h. The total respiration at a maximum is 84 + 20 = 104 kg ha^{-1} day^{-1}. Line 1 in Fig. 1 indicates for gross photosynthesis in July 360 kg of dry matter ha^{-1} day^{-1}. Respiration in terms of gross photosynthesis therefore amounts to 28.8 %. Winkler calculated from his own data for the month of July

Table 1. Annual gross production of potatoes, sugar-beets and wheat calculated to net dry matter and fresh weight production

	Potatoes	Sugar-beets	Winter wheat
Gross production (kg DM ha^{-1} $year^{-1}$)	35082	36200	32552
Respiration (kg DM ha^{-1} $year^{-1}$)	8770	9050	8138
Total dry matter (kg DM ha^{-1} $year^{-1}$)	26312	27150	24414
Fallen leaves (kg DM ha^{-1} $year^{-1}$)	1500	2000	500
Harvested dry matter[1] (kg DM ha^{-1} $year^{-1}$)	24812	25150	23914
Main product (%)	85	67	40
Main product (kg DM ha^{-1} $year^{-1}$)	21090	16850	9566
Dry matter in main product (%)	22	22	85
Main product (kg ha^{-1} $year^{-1}$) fresh	95862	76590	11254
(Main product)[2] (kg ha^{-1} $year^{-1}$) fresh	(82307)	(65569)	(9722)

[1] Including roots.
[2] Main product when respiration is 35 % of the gross photosynthesis.

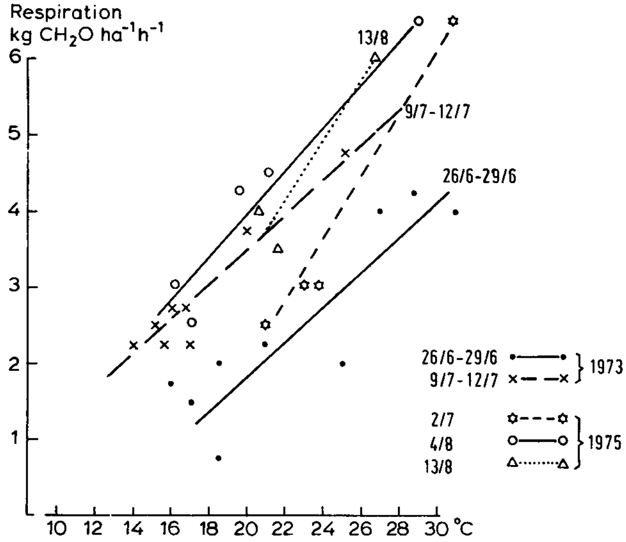

Fig. 2. Relation between temperature and respiration in kg CH_2O ha^{-1} h^{-1} of potato crops in 1973 and 1975 in succeeding stages of growth.

30 to 40 % of the net photosynthesis which corresponds to about 25 to 35 % of the gross photosynthesis. Burton (1964) states that respiration of potatoes is 25 % at a maximum.

In 1973 and 1974 de Vos assessed respiration in winter wheat varieties at 18 °C at 5 kg of CH_2O ha^{-1} h^{-1} which means 120 kg of CH_2O ha^{-1} per 24 h (Alberda et al., 1977). With some root respiration this means 35 % of respiration. Since the average temperature can assumed to be lower than 18 °C, 25 % of respiration was assumed in Table 1 to calculate the net production. The same calculation was repeated for a respiration of 35 %. Only the final result of the latter calculation, between brackets, has been mentioned in Table 1.

Bodlaender & Algra (1966) established that at very high production levels of potatoes 85 % of the total dry matter in over- and underground parts was embedded in the main product (tubers), and about 1500 kg of dry matter disappeared in the falling leaves. In sugar-beets at normal distance it was established that 67 % of the total harvested product consisted out of beets (Houba, 1973). For replacement of old leaves a dry matter loss of 2000 kg was assumed in this crop. After ripening of winter wheat about 40 % of the total dry matter consists out of grains (van der Zweerde, 1968; Jonker, 1958). It was assumed that 500 kg of dry matter per ha was lost in falling leaves not harvested. These data are averages for well-growing crops.

Table 1 shows the remaining main product in kg of dry matter per ha, after subtracting the losses for respiration, loss of leaves and additional products from the gross production. Next these calculated amounts of dry matter have been converted to fresh weights in kg ha^{-1} of potatoes and beets and to storable product of winter wheat, with the indicated dry matter percentages. At the bottom of Table 1 the amount of main product has been mentioned between brackets in kg ha^{-1}, with a respiration of 35 % of the gross photosynthesis with otherwise the same calculation procedure.

With optimum management yields of 95 (metric) tons of potatoes, 76 tons of sugar-beets and 11 tons of wheat are feasible in a year with average radiation. With 35 % of respiration these amounts are 82 tons, 65 tons and 10 tons, respectively.

Leaf development in spring
Comparison of the curve indicating potential production (line 1) with that of light interception (line 2) shows that the maxima of both lines coincide much better with wheat than with sugar-beets. In the latter crop light interception (see Fig. 1b) only attains its maximum when potential growth rate is already decreasing. In the period of great potential possibilities growth of sugar-beets is negligible because a crop canopy is lacking. When the leaf canopy has attained its full size, roundabout the last decade of June, the potential production level will decrease, limiting actual growth more and more. The latter process cannot be changed, but the date at which a closed canopy is attained in the field can be influenced. Advancing this moment will affect the yield of beets favourably.

The same can be said for maize. Slow spring development will be the cause that too little sun energy is intercepted in May and June to be used in the formation of dry matter, due to the lack of a closed green leaf canopy. Accelerating the date on which maize has formed a closed crop canopy should affect the final yield favourably.

With some field experiments with sugar-beets and maize a study was made to see if the development of the leaf canopy distinctly affects the yields of these crops.

Experiments

On 25 April 1975 silage maize of the cv. Cappela was sown at a row distance of 75 cm on moisture containing sandy soil at Wageningen. Before sowing the field was fertilized with 125 kg P_2O_5 ha^{-1} (basic slag) in November, 160 kg K_2O ha^{-1} (K40) in March, 20 tons of slurry + 30 tons of farmyard manure and 150 kg N ha^{-1} (ammonium nitrate limestone) in April. Immediately after sowing transparent plastic tunnels of 40 cm wide and 20 cm high were placed lengthwise over the rows in order to stimulate emergence and first leaf development (Pl+) and for comparison control treatments without plastic covers (Pl–). The plastic was stretched over bent tubes placed across the rows and removed on 20 May. The control treatments were in triplicate on plots of 4 m × 1.5 m = 6 m^2. Under otherwise similar conditions also hand-planted maize was compared. Only the plant distance in the row was somewhat more accurate here.

In 1976 this latter treatment was discontinued, but the experiment was extended. In this way a relatively early cultivar, Cappela, and a late cultivar, P 3853, could be harvested periodically, to compare the growth of both varieties with and without plastic covers. Spring dressing was similar to 1975; before emergence 2 kg of atrazine was sprayed in both years.

In 1976 in the same way emergence and first growth were stimulated in the sugar-beet, cv. Monohil, on sandy clay soil in the Northeast Polder. Some days after sowing on 23 March, small tunnels of 25 cm wide and 12.5 cm high were placed over the rows. Row distance was 50 cm and plant distance 17 cm in the row. On 5 March 80 kg N ha^{-1} (calcium nitrate), on 17 May 50 kg ha^{-1} (calcium nitrate) and on 26 May 50 kg N ha^{-1} (ammonium nitrate limestone) was applied.

In 1976 the sugar-beet experiments were sprinkled once and those of maize more times.

Results

Regularity in plant size was not affected by the presence of plastic tunnels. Emergence was stimulated only very slightly, but the treatment did stimulate leaf growth after emergence.

When the plastic tunnels were removed in the beets on 6 May and in the maize on 20 May, the leaf area index (LAI; m^2 leaves per m^2 soil) was advanced, as shown in the Fig. 3. The first dry matter yields were so low, that differences were not evident, as reflected in Fig. 4.

Fig. 4 shows that between the first and the second observation the difference in dry matter yield had increased. Better light interception caused by more rapid leaf development under the plastic tunnels was responsible for a higher growth rate after removing the plastic. These actual growth rates in kg dry matter ha^{-1} day^{-1} between two harvests are presented upon the growth curves.

The observation data in the third decade of July show that LAI $\geqslant 4$, which indicates that the crop canopies have been closed for some time and do not limit growth rate. After this date a difference in growth rate is not to be expected until

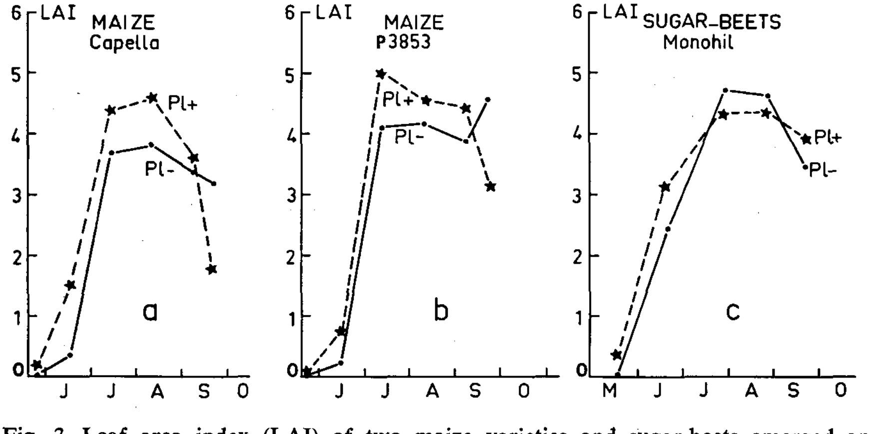

Fig. 3. Leaf area index (LAI) of two maize varieties and sugar-beets emerged and grown during some weeks under plastic (Pl+) and control (Pl—).

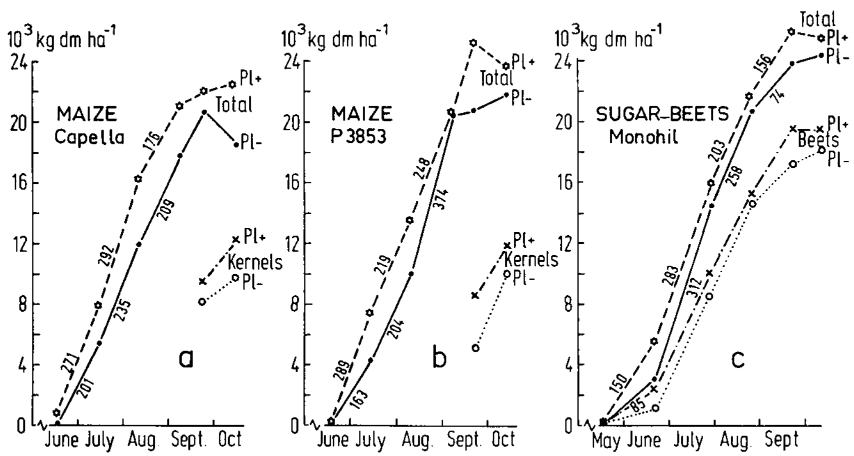

Fig. 4. Dry matter yields of two maize varieties and sugar-beets emerged and grown during some weeks under plastic (Pl+) and control (Pl—). Numerals upon the growth curves indicate crop growth rate in kg dm ha—1 day—1 for the concerning period.

senescence begins, which is accelerated in maize by the presence of plastic (see Fig. 3a and 3b).

The yields of the last two harvests have been summarized in Table 2, in such a way that a treated plot (Pl+) is comparable to an untreated plot (Pl–). With respect to the main product, all the yields were increased by Pl+ and the relation main product : total, was improved.

Discussion

Comparison of Fig. 1a, Fig. 1b and Fig. 1c (line 2 and 3) demonstrates that there are slight differences in the duration of growth of the crops taken as an example, but that the time in which they grow differs more widely. Because of the lower heat requirement of wheat, this crop forms a closed green canopy much earlier in spring than sugar-beets and potatoes. Therefore wheat grows in a period that the potential production level is high. The relatively early ripening of the crop limits the yield. From Fig. 1c it can be inferred that the duration of growth can be prolonged by earlier soil coverage as well as by prolonging the period of grain formation. Top dressing and adequate disease control at the end of the growing period are the measure by which is tried to achieve this effect already now.

In sugar beets, however, prolonging growth at the end of the growing period is hardly effective, since the potential production level is too low, then. Acceleration of reaching a closed canopy is effective, because not only the growth duration is prolonged, but also the crop is present when the potential production level is at a maximum.

Actual yields are not presented, because usually they show wide variation. Here we suffice with the observation that in practice they may vary from very low on soils hardly suitable for agriculture, to very high in the newly reclaimed IJsselmeer polders. In these potato and beet crops almost potential growth rates are attained during the period of a closed green leaf canopy. The data of Bodlaender & Algra (1966) and de Vos (1977) show that the calculated annual yields can actually be attained.

Table 2 records of the control plot (Pl–) of sugar-beets an average 24 tons of dry matter in total for the last two yields. In Table 1 the total dry matter yield of sugar-beets was calculated to be 25 150 kg. This proves that the actual yields are almost equal to the calculated ones. In fresh weight of beets the calculated amount of beets is 76 590 kg ha^{-1}. In the field experiment some 80 000 kg ha^{-1} was recorded. This was also due to a more favourable ratio foliage: beet than was assumed in the calculations. These high yields have also been caused by the radiant weather in 1976 (Sibma, 1970).

A frequently heard question is to what extent early spring development may affect the yield potential. This aspect is difficult to measure in experiments, because in that case varieties have to be used that differ in earliness. However, when varieties are compared that differ in earliness, it is possible that this earliness is genetically associated with other properties, and therefore the advantage of earliness cannot be inferred from the ultimate yield. By accelerating one group of plants of the same variety in spring, without changing other properties, a distinct idea can be formed of the advantage of a crop with a closed canopy early in spring. The experiments give evidence enough that only acceleration of the initial growth will have effects

Table 2. Comparison of dry matter yields of maize and sugar-beets grown under plastic until some weeks after emergence (P1+) and control P1—).

Exp. No.	Year	Crop	Cultivar	Harvest date	Treatment		Yield in kg dm ha^{-1}		
							main product	additional product	total
IBS 1805	1975	Maize	Capella	28 aug.	Sown	Pl+	6250	9330	15580
						Pl—	3880	9460	13340
					Planted	Pl+	6250	9750	16000
						Pl—	4110	9950	14060
CABO 30	1976	Maize	Capella	21 Sept.		Pl+	9490	12640	22120
						Pl—	8150	13480	21630
			P 3853	21 Sept.		Pl+	8460	16870	25330
						Pl—	5060	15840	20900
			Capella	15 Oct.		Pl+	12330	10318	22648
						Pl—	9710	8694	18404
			P 3853	15 Oct.		Pl+	11760	11984	23744
						Pl—	9970	11966	21936
CABO 31	1976	Sugar-beets	Monohil	21 Sept.		Pl+	19480	6400	25880
						Pl—	17320	6460	23780
				12 Oct.		Pl+	19460	5980	25440
						Pl—	18040	6372	24440

as to be expected from the calculations. The period between emergence and the time of a closed leaf canopy was shortened some 10 days by the plastic covers. The result of this acceleration of 10 days should have to be 10 × 200 kg dry matter. Table 2 shows that the yield increases are indeed in this order of magnitude.

For plant breeding this is evidence that acceleration in maize and sugar-beets is of distinct advantage to the yields. Finally, we point out that we do not think that practical application of the plastic tunnels as in our experiments will be profitable in agriculture.

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