Improving the productivity of winter wheat in Iran through rotation of wheat, fallow, soybean and alfalfa and manuring

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Einfluß einer Fruchtfolge mit Winterweizen, Brache, Sojabohne oder Luzerne auf Winterweizen kombiniert mit der Wirkung organischer Düngung im Iran

1. Introduction

1.1 Agriculture in Iran

About 10.4 % of Irans total area of 1.6 million km^2 is arable land of which 50.5 % is irrigated. Wheat is the most important food crop occupying 7.2 million ha, followed by barley with 1.8 million, pulses 1.0 million, rice 0.57 million, cotton 0.27 million, sugar beets 0.17 million, potatoes 0.16 million, watermelons 0.15 million ha etc. (FAO, 1997a).

Between 1993 and 2000 an annual population growth of 2.8 % is estimated (CIMMYT, 1996). 35.9 % of the economically active population work in agriculture. The per caput cereal production in 1996 was 114.0 % of 1989–1991 level (FAO, 1997a). The per caput cereal production in 1993/95 being 256 kg, an extra 46 kg per caput per year had to be imported. In the years of 1985–95 wheat yield grew by 4.1 % pa, with a worldwide average of only 1.2 % (CIMMYT, 1996).

Such an increase in grain yield and subsequent food security is linked to high inputs. The average amount of NPK applied per ha of cropped land is 61.9 kg. The country produces 500 000 t of nitrogen fertilizer and imports 104 000 t (FAO, 1997b).

Zusammenfassung

90 km westlich von Teheran in 1350 m Seehöhe, bei 370 mm Jahresniederschlag und 13,6° C Jahresmitteltemperatur wurde auf Gesteinsrohboden ein Fruchtfolgeversuch durchgeführt. Nach zweimaliger Brache (1993/94 und 1994/95) und Winterweizen, Luzerne, Sojabohne oder nochmals Brache in der Vegetationszeit 1995/96 wurde diese Beeinflussung auf den folgenden Winterweizen (1996/97) geprüft. Stallmistdüngung mit 0 bzw. 5 t/ha war der zweite Faktor dieses bewässerten Versuches, der als Splitplot Anlage mit 4 Wiederholungen angelegt wurde.
Der 1997 geerntete Winterweizen, der nach Brache, Winterweizen, Sojabohne oder Luzerne folgte, erbrachte gedüngt bzw. ungedüngt folgende sich hoch signifikant unterscheidende Erträge: 1,86/1,49, 2,57/2,09, 4,08/3,13 bzw. 4,83/4,10 t/ha. Derselbe positive Einfluß konnte für das Tausendkorngewicht, die Kornzahl/Ähre, die Ähren/m^2 und den Strohertrag gefunden werden.

Schlagworte: Weizen, Fruchtfolge, Sojabohne, Luzerne, Iran.

Summary

The effect of preceding crops on succeeding winter wheat was tested on a rendzic leptosol, 90 km west of Teheran (altitude 1350 m, rainfall 370 mm, average annual temperature 13.6°C). In 1993/94 and 1994/95 the field was maintained twice under fallow and planted with winter wheat, alfalfa, soybean or left fallow in 1995/96. Winter wheat was planted as the test crop in 1996/97 on all plots, with 0 or 5 t per hectar manure in a split plot arrangement in four replications. Both manure and rotation significantly and positively influenced winter wheat grain yield and yield components. Yields were 1.86, 2.75, 4.08 and 4.83 t/ha with manure and 1.49, 2.09, 3.13 and 4.10 t/ha without manure, when followed fallow, winter wheat, soybean or alfalfa respectively.

Key words: Wheat, crop rotation, soybean, alfalfa, Iran.

1.2 Crop rotation in semi arid areas

The most popular and traditional dryland farming is a rotation of a cereal crop followed by one or more years of fallow. EL MEJAHED (1993) found that with 24 % water savings through clean fallow, wheat every second year was more profitable than wheat grown every year. But water saving runs versus erosion control which has to be stopped with a vegetation cover before it becomes irreversible. This also provides a long-term yield advantage through maintenance of the soil organic matter (STEWARD and ROBINSON, 1997).

The integration of grain or fodder legume crops in the rotation, green manuring or mixed cropping is advised, but the vegetation cycle and the decomposition of organic matter has to be synchronised with the needs of the following crop (PRINZ, 1986; REYNOLDS et al., 1994; JONES and SINGH, 1995). ORAM and BELAID (1990) regret that the wheat-sheep farming system which is well adapted and sustainable in Australia with legumes originated from the Middle East has not become a common rotation in the West Asia – North Africa (WANA) region. But for the chronically N deficit soils the presence of grain legumes at a rate of only 3.5 % of the cropland is also not enough (BUDDENHAGEN, 1990). Fertilizer is not feasible and also manure is scarce. NAJAFI and RAJBAR (1995) in Iran reported yield advantages due to the application of organic fertilizer containing 110 kg N/ha.

1.3 The crops

Winter, spring and durum wheats are planted on 42.4 % of the arable land accounting for 74 % of the total cereal area. The country's average grain yield of this traditional staple food crop reached 1556 kg/ha (FAO, 1997a). In the Central Asean Region 46 % of the irrigated area (FAO, 1997c) is planted with wheat which receives 3 to 7 irrigations with a total amount of 350–600 mm (ACHTNICH, 1980).

Soybean with 87000 ha plays only a minor role as compared to pulses like chickpeas, lentils or faba beans in countries of the WANA region. There are adapted varieties of soybean, and with proper inoculation optimum N fixing and yield could be achieved (GRETZMACHER et al., 1994). The crop has to be irrigated with a peak water consumption in the flowering and pod filling stage. Under semiarid conditions, yield gain due to irrigation can be nearly 70 % over the unirrigated check (GRETZMACHER and WOLFSBERGER, 1990).

Alfalfa because of its origin in the Middle East is best adapted for drought tolerance, but for high productivity weekly irrigations in connection with cutting intervals of 25–30 days are necessary (ACHTNICH, 1980). In spite of higher water consumption, better and earlier yields can be obtained than with annual legumes (BLACKLOW et al., 1997). There are a lot of adapted varieties with good yield potential tested nearby the experimental site (YAZDI-SAMADI, 1994; NEMATI, 1991). DARWISCHI (1994) reported a still growing alfalfa area of 691 660 ha with an average yield of 6.5 t/ha in Iran.

The objectives of this experiment were to explore the possibilities to reduce off-farm inputs, to quantify the effect of rotation with N-fixing crops (alfalfa, soybean) and to show the direct (yield) and indirect (amelioration of soil structure) benefits of manuring.

2. Material and Methods

2.1 The experimental site

The "Magsal" experiment farm lies 90 km west of Teheran (35° 48′N, 50° 58′E) at an elevation of 1350m. It belongs to the subtropical zone with dry summers and wet winters. The average annual temperature is 13.6° C, falling below 0° C in the months December to February. The average annual preciptation of 370 mm is concentrated in the months from January to April. The weather conditions in 1996 and 1997 were close to the average figures, with 80 mm more rainfall recorded in 1996 because of high rainfall in March (109 mm).

The soil is classified as a loamy leptosol (FAO, 1993) with a pH of 7.6–7.9 and an organic matter content of 0.6–0.9 % in the top soil, with 2–6 ppm P_2O_5 and 90–150 ppm K_2O (CAL method). The texture in the deeper layers tends to be clay loam (DEWAN and FAMOURI, 1964).

2.2 The experimental parameters

The total experimental area was left fallow in 1993/94 and 1994/95 to neutralize previous cropping patterns. The preceding crops were fallow, winter wheat planted in October 1995, alfalfa planted in April 1996 and soybeans planted in May 1996. Winter wheat was planted in mid October 1996 on all the plots to test the residual effect of the rotation treatments. The soil preparation included plowing to

35 cm, discing and levelling, alternativ manuring and digging of irrigation furrows. Farmyard manure was incorporated into 5–10 cm depth at a rate of 5 t/ha and 0 as control. The two years old air-dried (app. 20–25 % water) rotted manure without straw had 2.0 % N, 0.6 % P_2O_5 and 1.8 % K_2O on fresh weight basis before application, giving a dosage of 100 N : 30 P_2O_5 : 90 K_2O.

Winter wheat, variety "Mahdavi" was hand planted at 20 cm rows with 360 seeds/m^2 on 20. 10. 1995 and harvested on 2. 7. 1996. The succeeding winter wheat on all plots was planted on 14. 10. 1996 in the same manner with 400 seeds/m^2 and harvested on 27. 6. 1997.

Alfalfa, variety "Hamadani" was hand seeded at 50 cm rows with 20 kg/ha on 13. 10. 1995 and had to be replanted on 26. 4. 1996 with 25 kg/ha, resulting in 66 plants/m^2. Three consecutive cuts followed on 12. 7., 6. 8. and 8. 9. 1996.

Maturity group III soybean, variety "Williams" was inoculated with "Helinitro" (600g/100 kg of seeds) and seeded on 3. 5. 1996 at a rate of 66 kg/ha and 50 cm rows to get 40 plants per m^2. Harvesting was on 9. 19. 1996.

Two irrigation furrows per plot were built by hand and water with a pH of 7.7 and a SAR of 4.3 from a nearby well was used. Wheat received 6, alfalfa 12 and soybean 13 applications based on soil moisture testing in monthly intervalls. No chemical pest control was used, weeds were removed by hand.

Parameters measured were nutrient content of the soil, especially nitrate, porosity and organic matter; for the crops vegetation stages, weeds, pests, grain and total dry matter yield and yield components were recorded (SCHABAZIAN, 1997).

The experiment was designed in a split plot arrangement with 4 replications, the size per unit was 10 m x 8 m which contains because of the irrigation channels the two levels of manuring, each 10 m x 4 m. The total area was 0.57 ha. The datas were processed using SAS (STATISTICAL ANALYSIS SYSTEMS INSTITUTE, 1988).

3. Results

3.1 Yield of precursor crops

The winter wheat in the first season gave a total dry matter yield of 5.68 t/ha when manured and 4.32 t/ha without manure. The respective grain yields were 2.06 and 1.58 t/ha with a highly significant difference. Similar difference for the straw yield (3.62 t versus 2.74 t/ha) was also apparent. The number of ears/m^2 ranged from 225 to 250 and was not significantly affected by manuring.

The three alfalfa harvests in early July, August and September 1996 produced dry matter yields of 2.64 t with manuring and 2.46 t/ha without manuring. This difference was significant. The latest cutting yielded in both cases 50 % of the total harvest.

Soybean yield was also significantly increased by 4.5 % due to manuring (4.64 t versus 4.45 t/ha). This increase was mainly related to differences in the number of pods, 45 with versus 40 per plant without manuring.

3.2 Performance of the winter wheat test crop

Rotation by manuring interaction for seed yield of winter wheat in 1996/ 97 was highly significant. The results of statistical analysis for yield, yield components and other agronomic attributes are shown in table 1. The combined effect of the two factors caused the grain yield to vary from 1.49 to 4.83 t/ha. All rotations were highly significantly different from monoculture wheat.

Alfalfa was the best preceding crop (4.83 t with manure and 4.10 t/ha without manure), followed by soybeans (4.08 and 3.13 t/ha with and without manure, respectively). Wheat after wheat yielded 2.57 and 2.09 t/ha, and wheat after 3 years of fallow gave only 1.86 and 1.49 t/ha with or without manure again.

Increases over the poorest rotation of wheat after fallow were 139 % for wheat after wheat, 215 % for wheat after soybean, and 267 % for wheat after alfalfa.

Averaged over rotations, the over all increase due to manure was 24 %; the least effect (17.8 %) being in the alfalfa rotation and the highest in the soybean rotation (30.4 %). The effect of manuring in all rotations was highly significant and positive.

Straw yield was highly significantly influenced by rotation and manuring interaction (Table 1). The main effect of manuring was significant. The least straw yields were 3.25 t/ha (manured) and 2.96 t/ha (unmanured), both after fallow. Alfalfa had the best yield with 7.22 t/ha and 6.06 t/ha with and without manure, respectively.

The harvest index was not influenced by an interaction of rotation and manuring, but the main effects were significant. The closest ratio was found after soybean without manuring (1:1.39) and with manuring (1:1.46), followed by alfalfa (1:1.49 with and 1:1.48 without manuring). The

Table 1: Yield, yield parameters and statistical analysis of Winter Wheat (1996/97) influenced by crop rotation and manuring
Tabelle 1: Ertrag und Ertragsparameter von Winterweizen (1996/97) in Abhängigkeit von Fruchtfolge und organischer Düngung

Area	Seedyield(t/ha)	SD	Ears/m²	SD	Kernels/ear	SD	Hundredseedweight(g)	SD	Straw(t/ha)	SD	Harvest Index	SD
Wheat following Wheat, manured	2,57	3,27	315	3,55	25,7	3,31	32,2	1,80	4,16	0,88	1,62	0,21
Wheat following Wheat, unmanured	2,09	1,06	319	3,40	21,7	2,10	29,8	1,68	3,45	2,71	1,65	0,12
Wheat following Alfalfa, manured	4,83	4,52	431	7,37	27,7	3,38	43,4	1,79	7,21	1,44	1,49	0,10
Wheat following Alfalfa, unmanured	4,10	3,10	401	4,19	23,3	1,73	42,0	1,94	6,06	1,48	1,48	0,08
Wheat following Soybean, manured	4,08	3,16	334	7,87	28,5	2,20	42,4	1,86	5,47	2,30	1,46	0,11
Wheat following Soybean, unmanured	3,13	1,85	312	5,59	23,8	2,09	43,1	1,33	4,35	3,04	1,39	0,10
Wheat following Fallow, manured	1,86	0,86	251	11,43	17,6	2,31	42,5	2,26	3,25	2,28	1,75	0,05
Wheat following Fallow, unmanured	1,49	0,64	225	3,40	20,7	3,43	30,2	1,63	2,96	1,36	1,99	0,14

SD=Standarddeviation

d1=Manured d2=Unmanured f1= Wheat following Wheat f2=Wheat following Alfalfa f3=Wheat following Soybean f4=Weat following Fallow

Seedyield (dt/ha)			Ears/m²			Kernels/ear			
Faktor	*F Value*	*Pr > F*	*Faktor*	*F Value*	*Pr > F*	*Faktor*	*F Value*	*Pr > F*	*Pr > F*
Rotation	860,5	0,0001	Rotation	1585,02	0,0001	Rotation	31,39	0,0001	0,0001
Replication	16,28	0,0002	Replication	5,19	0,0158	Replication	15,60	0,0002	0,0002
Rotation*Replication	6,15	0,0024	Rotation*Replication	1,06	0,4543	Rotation*Replication	0,83	0,5996	0,5996
Manure	219,5	0,0001	Manure	101,31	0,0001	Manure	19,53	0,0008	0,0008
Rotation*Manure	9,12	0,002	Rotation*Manure	17,89	0,0001	Rotation*Manure	11,10	0,0009	0,0009
Contrast	*F Value*	*Pr > F*	*Contrast*	*F Value*	*Pr > F*	*Contrast*	*F Value*	*Pr > F*	*Pr > F*
d1 f1-f2	696,13	0,0001	d1 f1-f2	1011,20	0,0001	d1 f1-f2	3,14	0,1017	0,1017
d2 f1-f2	553,08	0,0001	d2 f1-f2	500,97	0,0001	d2 f1-f2	2,01	0,1817	0,1817
d1 f1-f3	309,05	0,0001	d1 f1-f3	26,90	0,0002	d1 f1-f3	6,38	0,0266	0,0266
d2 f1-f3	146,65	0,0001	d2 f1-f3	3,92	0,0712	d2 f1-f3	3,38	0,0908	0,0908
d1 f1-f4	69,99	0,0001	d1 f1-f4	305,17	0,0001	d1 f1-f4	51,52	0,0001	0,0001
d2 f1-f4	50,11	0,0001	d2 f1-f4	658,33	0,0001	d2 f1-f4	0,79	0,393	0,393
f1 d1-d2	31,87	0,0001	f1 d1-d2	1,35	0,2686	f1 d1-d2	12,41	0,0042	0,0042
f2 d1-d2	72,45	0,0001	f2 d1-d2	68,18	0,0001	f2 d1-d2	15,03	0,0022	0,0022
f3 d1-d2	123,55	0,0001	f3 d1-d2	36,06	0,0001	f3 d1-d2	17,72	0,0012	0,0012
f4 d1-d2	19,00	0,0009	f4 d1-d2	49,4	0,0001	f4 d1-d2	7,67	0,017	0,017

Hundredseedweight(g)			Straw (dt/ha)			Harvest Index			
Faktor	*F Value*	*Pr > F*	*Faktor*	*F Value*	*Pr > F*	*Faktor*	*F Value*	*Pr > F*	*Pr > F*
Rotation	302,07	0,0001	Rotation	1976,74	0,0001	Rotation	41,05	0,0001	0,0001
Replication	24,55	0,0001	Replication	23,02	0,0001	Replication	0,32	0,8098	0,8098
Rotation*Replication	0,68	0,7167	Rotation*Replication	2,88	0,0455	Rotation*Replication	3,29	0,0290	0,0290
Manure	137,86	0,0001	Manure	557,83	0,0001	Manure	4,82	0,0486	0,0486
Rotation*Manure	77,36	0,0001	Rotation*Manure	34,47	0,0001	Rotation*Manure	3,09	0,0676	0,0676
Contrast	*F Value*	*Pr > F*	*Contrast*	*F Value*	*Pr > F*	*T tests (LSD) :*			
d1 f1-f2	293,57	0,0001	d1 f1-f2	1950,52	0,0001	Alpha= 0.05			
d2 f1-f2	351,19	0,0001	d2 f1-f2	1418,22	0,0001	df= 12			
d1 f1-f3	247,08	0,0001	d1 f1-f3	357,28	0,0001	MSE= 0.009035			
d2 f1-f3	415,54	0,0001	d2 f1-f3	167,41	0,0001	Critical Value of T= 2.18			
d1 f1-f4	248,28	0,0001	d1 f1-f4	171,17	0,0001	east Significant Difference= 0.1036			
d2 f1-f4	0,47	0,5043	d2 f1-f4	50,18	0,0001	T Grouping	Mean	FF	FF
f1 d1-d2	13,48	0,0032	f1 d1-d2	103,87	0,0001	A	1,86875	1	1
f2 d1-d2	4,27	0,0612	f2 d1-d2	278,8	0,0001	B	1,64000	2	2
f3 d1-d2	0,99	0,3397	f3 d1-d2	260,99	0,0001	C	1,49000	3	3
f4 d1-d2	351,19	0,0001	f4 d1-d2	17,58	0,0012	D	1,36875	4	4

wheat-wheat rotation gave 1:1.62 with and 1:1.65 without manuring. The largest ratio was after fallow with 1:1.99 without and 1:1.75 with manuring. The better the fertility, the lower the percentage of straw was.

The number of ears per m^2 varied from 225 for the unmanured fallow treatment to 431 for the manured alfalfa plot giving a 192 % increase (Table 1).The interaction between the factors was highly significant. Gains due to manuring were 7.5 %, 7.1 % and 11.6 % for alfalfa, soybean and fallow treatments, respectively.

Rotation by manuring interaction was also highly significant for the number of seeds per ear. Manuring influenced this attribute significantly outyielding the control by 18.4 %, 18.9 % and 19.7 % for wheat, alfalfa and soybean, respectively. The number of kernels per ear decreased by 15 % due to manuring when wheat succeeded fallow.

Similarly, thousand kernel weight was highly significantly affected by the factors' interaction. The range of values for this character was between 29.8 g and 43.4 g with clear influence of both factors (Table 1).

Manuring brought an advantage of 8.1 % after wheat, 3.3 % after alfalfa and 40.7 % after fallow, but decreased by 1.6 % after soybean.

3.3 The N status of the soil

In the 30 cm top soil, the NO_3-nitrogen content of about 119 kg/ha in November 1995 was decreased to 56 kg N/ha after the harvest of the first winter wheat in July 1996 (see table 2). Manuring did not have a significant effect. The rotation built up the nitrate content again. In November 1996, the NO_3-N contents for manured versus unmanured were 113.4 and 108.7 kg/ha after alfalfa, 99.0 and 98.8 after soybean, 78.6 and 76.6 after fallow, and 54.6 and 54.2 kg/ha after wheat. NO_3-N was highly significantly influenced by rotation. Manuring, however, did not show the expected advantage.

By the end of June 1997, after the last harvest, NO_3-N contents were 91.8 kg/ha versus 86.2 after alfalfa, 79.2 versus 77.1 after soybean, 65.4 versus 63.7 after fallow, and 47.5 versus 46.5 kg /ha after wheat. The results indicate a highly significant positive effect of rotation on the nitrate content and of soil fertility.

4. Discussion

Because of replanting alfalfa and not the optimal cutting frequency of at least 6 cuttings the yield of 2.64 t/ha is not compatible with harvests of 15.3 t/ha found by SAEED and EL NADI (1997) under comparable conditions. Another source of lower yield potential is the longer irrigation interval. SAEED and EL NADI (1997) found, that weekly watering of alfalfa gave nearly 20 % higher yields than using the same amount but applied in a beweekly interval as was done with 12 irrigations in the current experiment.

Comparison of wheat grain yield harvested in 1996 (2.06 and 1.58 t/ha) with those of fallow-wheat in 1997 (1.86 and 1.49 t/ha) did not have apparent relevance to water saving advantage due to clean fallow as stated by EL MEJAHED (1993) as water was not the limiting factor.

In the semiarid zone a cereal following food legume usually shows a slightly higher yield than follwing fallow or a cereal (SAXENA, 1988). In other experiments the cereal yielded most after fallow (JONES and SINGH, 1995).

Table 2: Soil-nitrate of Winter Wheat (1995–1997) in 0–30 cm deep NO_3-N (kg/ha)
Tabelle 2: Bodennitratgehalt bei Weizen (1995–1997) in 0–30 cm Bodentiefe NO_3-N (kg/ha)

Area	19. 11. 95	SD	16. 02. 96	SD	19.04.96	SD	02. 07. 96	SD
Wheat, manured	119,5	6,4	52,2	4,2	66,2	2,5	56,6	2,9
Wheat, unmanured	115,2	2,6	50,1	3,1	64,1	3,6	56,9	3,0
	21. 11. 96	**SD**	**18. 02. 97**	**SD**	**22. 04. 97**	**SD**	**20. 06. 97**	**SD**
Wheat following Wheat, manured	54,6	4,9	47,5	4,6	50,5	1,9	47,4	2,3
Wheat following Wheat, unmanured	54,2	5,3	45,2	1,8	48,4	3,4	46,5	2,3
Wheat following Alfalfa, manured	113,4	2,5	66,4	2,5	85,0	4,1	91,8	4,1
Wheat following Alfalfa, unmanured	108,7	2,1	61,9	5,4	80,0	2,3	86,2	3,4
Wheat following Soybean, manured	99,0	5,4	57,0	2,7	68,4	6,0	79,2	4,7
Wheat following Soybean, unmanured	98,8	4,8	55,7	3,8	66,7	3,3	77,1	2,9
Wheat following Fallow, manured	78,6	3,7	55,3	3,5	71,7	6,4	65,4	3,5
Wheat following Fallow, unmanured	76,6	3,1	54,5	4,4	69,1	5,8	63,7	4,3

SD = Standarddeviation

Results in Australia over a period of 10 years showed identical wheat yields at a level of 1460 kg/ha unaffected by monoculture or rotation with legumes. As these trials were grown under rainfed conditions, the availability of water had a far stronger influence on the yield than the higher yield potential with legumes in the rotation (JONES and RUSSELL, 1996). With irrigation, the grain yield of wheat could be increased by 215 % when preceded by soybean and 267 % when wheat follows alfalfa.

At two experimental sites in Ethiopia TILAHUN et al. (1996) found, that wheat yield could easily be doubled over the unfertilized control from 781 kg to 1616 kg/ha by using 60 kg N/ha of chemical fertilizer. In comparison using manure with an equivalent of 100 kg N/ha increased yield by 25 % over the 1.48 t/ha level after fallow.

The wheat yield increase over all rotations by manuring of about 24 % and 24.8 % in the fallow wheat rotation does not compare with the doubling of the wheatplant dry matter yield reported by REES et al. (1993) using 4 t/ha of manure containing the comparable ammount of 103 kg total N with a N recovery rate of 26.3 %.

REYNOLDS et al. (1994) found in one of their experiments no statistically signifacant effect of the green manure treatment on the wheat yield but in another due to berseem clover incorporation an increase by 24 %.

Under semiarid conditions in Tunisia SANAA and VAN CLEEMPUT (1997) demonstrated, that over a period of two dry years accumulated nitrate was used by wheat in the following wet year. This results indicate the importance of the manure and crop rotation for nitrogen build up.

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