BENEFITS OF LOCALLY APPLIED BASIC FERTILIZATION FOR EFFICIENT POTATOES GROWING

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Currently, the most common approach to potato production in the Czech Republic uses the soil protection technology of bed destoning. By this method, a local application of mineral fertilizers is recommended. To make the potato production more efficient, we carried out a two-year small-plot experiment monitoring the effect of nitrogen dose and the fertilizer application method on potato production. Two doses of nitrogen fertilizer (70 kg N ha^{-1} and 130 kg N ha^{-1}) and two application methods (areal and local fertilization) were tested. The results for various experimental treatments were compared with a control plot. The best results (statistical significance $P = 0.05$) and the most efficient production of consumer tubers were achieved with the local application of 130 kg pure nitrogen per hectare (total yield 52.4 t ha^{-1}, consumer tuber yield 89.1 %). Fertilizers applied near the future root hair are more accessible to plants and thus improve the crop nutrient uptake. Moreover, the local application method reduces nitrate water pollution, which complies with the Nitrates Directive and EU legislative requirements.

potato, dose of fertilizer, nitrogen, yield, tuber

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INTRODUCTION

Potatoes are a crop with a high nutritional demand. The optimal amount of nutrients in the soil is critical for successful production. The uptake and utilization of nutrients from soil is a complex process that depends on the interaction of many external and internal factors (Ayyub et al., 2019). Hamouz et al. (2010) and Najm et al. (2012) mention that many of these factors, including sunlight, temperature, elevation, aspect, and slope, cannot be adjusted according to the producer's needs. The factors that can be influenced by the producer are the spatial arrangement of plants or the orientation of the rows within the plot. Soil conditions need to be respected and potentially adjusted to ensure a sufficient amount of nutrients for plant growth. If these factors are in a favourable condition, the genetic potential of the cultivated varieties can be exploited. Vokal et al. (2004) state that fertilization mostly affects the weight of tubers and to a lesser degree the number of plant stems and tubers on one plant. They further mention that fertilization affects not only the yield per hectare, but also the productivity of the entire sowing process.

Potato nutrient uptake depends on the length of vegetation. Furthermore, it is necessary to take into account both nutrient uptake by tubers and haulm. Potato mineral nutrient uptake ranges from 2.28 to 3.57 kg N, from 0.04 to 0.12 kg P, and from 3.7 to 5.41 kg K per 1 t of fresh tubers without haulm and with a growing period of about 120 days (Gopal, Khurana, 2006). According to Kolodziejczyk (2014), a potato plant needs 3.5 kg N, 0.5 kg P and 4.5 kg K per 1 t of tubers, and 2.8 kg N, 0.2 kg P and 4.0 kg K per 1 t of haulm. This data is in line with Belanger et al. (2002) stating that 1 t of potatoes with haulm with a corresponding growing time (about 120 days) take 4.2–5.5 kg N, 0.6–0.95 kg P and 6.1–7.4 kg K. The mentioned authors agree on that for a high production of tubers more K than N must be supplied.

Nitrogen fertilization plays an important role in the balance between vegetative and reproductive growth of potatoes (Workineh et al., 2017). Nitrogen promotes tuber size, high yield, and waxy potato flesh. On the other hand, overfertilization with N and its delayed application result in a later vegetative period and unripe tubers during harvest, which in turn leads to a higher mechanical damage and consequent shorter storability. An excess of nitrogen can lead to an increased susceptibility to potato late blight, it increases the content of harmful nitrates, and decreases the content of dry matter and starch. Additionally, using more nitrogen fertilizer leads to economic losses and its easy leaching from soil has far-reaching environmental consequences (Hamouz et al., 2007). For potato production, the amount of nitrogen determines the amount and structure of yield, the quality of tubers and their chemical composition. On the other hand, it is a source of nitrate pollution (Kolodziejczyk, 2014). In general, crop productivity heavily depends on nitrogen fertilization. Due to the large amount of energy that is required for the production and application of nitrogen fertilizers, and the environmental concerns connected to nitrogen excess, it is critical to increase the nitrogen utilization by crops (Xu et al., 2012; Lyu et al., 2021).

Given the increasing demands on the qualitative and quantitative levels of potato production, and the need to maximize the plant utilization of industrial fertilizers to consequently reduce the negative effects of nitrate leaching to surrounding ecosystems, our research brings a valuable insight for agricultural practice (Vos, 2009). Inorganic fertilizers can be applied in several different ways. An easy way is an even application to the soil surface with a spreader and consequent embedding using a rotary cultivator or harrows. The full amount of fertilizer can be either applied before planting or the application can be split to a first phase before planting and a second phase that should be performed when the plants are 10–15 cm tall (Jong et al., 2011).

The goal of local application is the placement of the fertilizer in the vicinity of the tuber. This type of application is mostly used when stones need to be removed from the soil. In that case, areal application is inefficient because the grooving and stone separation would disperse the fertilizer into the entire topsoil profile making it inaccessible to plants. The method of local application allows reducing the dose of mineral fertilizers by placing it close to the planted tubers in a smaller, more usable quantity. Compared to an areal application, it reduces the formation of nitrates and the risk of nitrate leaching to the subsoil. Nutrients released from fertilizers that are locally applied in furrows, are more accessible for plants (phosphorus) and are better protected against leaching (nitrogen), surface runoff and water erosion (Kasal, 2007).

In the Czech Republic, the application of solid fertilizers is primarily performed using adapters carried on the front arms of a tractor or adapters positioned in front of the planter on rear arms of the hydraulics. Fertilizer is applied along both sides of the planted tubers. Most common is a placement of the fertilizer in a row distanced about 75–115 mm from the tuber, the depth of the deposit is adjustable (Mayer et al., 2009).

For nitrogen fertilization, the dose of the fertilizer is critical for both the yield and its stability. It is desirable to gradually switch the nitrogen application to devices located directly on the planter. This method of application ensures an even distribution, reduction of losses and costs. At the same time, it creates a precondition for a significant reduction of the nitrogen fertilizer dose by 25–30 % which makes it more environmentally friendly (Vokal, Rasocha, 2002). Kasal (2007) states that local application is an effective method of fertilization that can lead to a reduction of the nitrogen dose by 10–15 % in compare with surface application, while also maintaining the yield and the quality of tubers. The application of a fertilizer directly to the furrows positively affects nitrogen utilization, which is especially noticeable for a single application of fertilizer dose (Maidl et al., 2002).

The utilization of supplied nitrogen varies based on the form of application. In the case of a local application of mineral nitrogen fertilizers, the estimated utilization is 45–65 %, for the areal application the utilization rate is 30–50 % (Kasal, 2007). Pickny, Grochollm (2003) found that fertilizers applied near the future root hair are more accessible to plants at the time of their highest intake. Using this method of application, nitrogen fertilizer can be incorporated in soils as a single-component or a part of multi-component fertilizers. When using multi-component industrial fertilizers, the overall fertilizer dose is determined by the nitrogen content (Vokal, Rasocha, 2002).

The objective of this research was to investigate the effect of nitrogen application method and dose on potato production. The goal of this project is to provide information that would make potato production more efficient while minimizing the agri-environmental impact especially in areas of dense potato production. It is desirable to use the maximum dose of nitrogen for efficient production while reducing unnecessary losses to the environment.

MATERIAL AND METHODS

Experimental site

The experimental site is located in the cadastral area of the village Chmelná, that lies on the boarder of the Central Bohemian Region and the Vysočina Region. The experimental field is divided into multiple subsections with similar biophysical properties and soil characteristics. The site is located in a potato production area where only specific certified and officially recognized potato varieties can be planted. The average elevation of the site is 485 m, with an average slope of 3.25°. The soil belongs to the Cambisol type, specifically modal Cambisol. The topsoil layer thickness is 25–30 cm. The soils are sandy loam with

Table 1. Characterization of experimental location

Year	Planting date	Harvest date	Altitude (m a.s.l.)	Average annual temperature °C	Annual sum of precipitation (mm)	Organic matter content (%)	pH	ppm (Mehlich 3)			
								P	K	Mg	Ca
2019	20.4.	15.9.	485	9.1	498	2.1	5.5	55	168	75	1651
2020	17.4.	4.10.	485	8.7	624	2.1	5.3	59	189	64	1548

Table 2. Summary of experimental treatments

Experiment	1	2	3	4	Control plot
Figure notation	AA 70	LA 70	AA 130	LA 130	UTC
Method of fertilizer application	areal applic.	local applic.	areal applic.	local applic.	no fertilization
Dose of pure nitrogen (kg $N.ha^{-1}$)	70	70	130	130	0
Dose of pure phosphorus (kg $N.ha^{-1}$)	11	11	20	20	0
Dose of pure potassium (kg $N.ha^{-1}$)	16	16	30	30	0
Dose of NPK fertilizer ($kg.ha^{-1}$)	350	350	650	650	0

a good infiltration ability, but are prone to acidification. Weather details on the period of the two-year experiment and locality characterization are presented in Table 1. Table 2 summarizes monthly precipitation and average temperatures at the site during the two growing seasons.

Layout of the experiment

For this experiment, we used the Antonia potato variety from the company Europlant, registered in 2008. The growing season is around 120 days. This variety is a cooking type A, characterized by a consistent waxy flesh. Winter wheat was the previous crop for both years of the experiment. Disking, characterized by shallow plowing, and organic fertilizer application took place after the winter wheat crop harvest. The field was plowed in the autumn and left in a rough furrow. The soil naturally subsided, and the large soil clods disintegrated into smaller structures during the winter. Roughly amids April, a removal of stones from the soil took place. This process consisted of grooving rough furrows that were then sifted to separate the soil clods and stones which also resulted in loosening the soil. This was followed by planting with a Reekie RMP 2JT potato planter (Scan stone, UK) With this technology, a mineral fertilizer is commonly placed under 'the heel', where the fertilizer is deposited in the proximity of the plant root system (Fig. 1). It was used for experimental sites where we tested the local fertilizer application. For other experimental sites the fertilizer applicator was switched off and a specific amount of fertilizer (based on the experimental treatment) was then applied on top of the soil to simulate areal application. The areal application was performed with a Lely SX2500 fertilizer spreader (Lely, Netherland) immediately before grooving. Experimental treatments are summarized in Table 2 while other agrotechnological measures and applications are described in Table 3. Standard integrated protection and leaf nutrition measures were practiced during the growing season as they would be performed on a regular potato production plot. For the experiment, we used the Yara Mila NPK 20-7-10 fertilizer (YARA Agri Czech Republic s.r.o.) which contains 20 % of total nitrogen (N), 3 % of phosphorus (P) and 4.6 % of potassium (K).

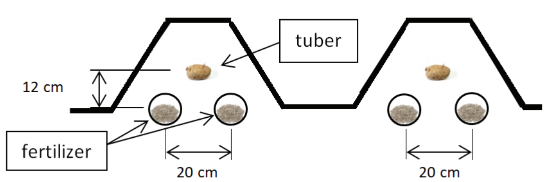

Fig. 1. Scheme of deposit fertillizer

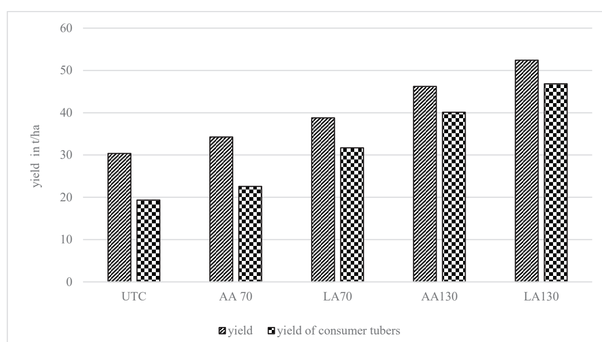

Fig. 2. Average total yield of potatoes and average yield of consumer tubers under various experimental treatments

Table 3. Summary of agrotechnological measures and applications at experimental sites

Date	Operation/ application
30.07.2018	disking + catch crops sowing
29.10.2018	catch crops mulching
30.11.2018	aplication of manure, dose 38 t/ha + ploughing to 28 cm
19.04.2019	grooving rough furrows + separation soil clods and stones
20.04.2019	planting + aplikacation of experimental variants
23.04.2019	aplikacation of herbicide Bandur (aclonifen), dose 4 L/ha
02.06.2019	aplikacation of insecticide Proteus 110 OD (thiacloprid, deltamethrin), dose 0.5 L/ha + leaf fertilization Galleko univesal, dose 0.5 L/ha
18.06.2019	aplication of fungicide Ridomil Gold MZ Pepite (mancozeb, metalaxyl), dose 2.5 kg/ha
30.06.2019	aplication of fungicide Ridomil Gold MZ Pepite (mancozeb, metalaxyl), dose 2.5kg/ha + leaf fertilization Galleko universal, dose 0.5 L/ha + Urea, dose 5kg/ha + leaf fertilization K-gel 175, dose 3.5 L/ha
13.07.2019	aplication fungicidu Revus top (difenoconazol, mandipropamid), dose 0.6 L/ha + insecticide Vaztak activ (alfa-cypermethrin) dose 0.25 L/ha
29.07.2019	aplication of fungicide Infinito SC (fluopikolid, propamocarb-hydrochlorid), ose 1.2 L/ha + insecticide Ecail Ultra (thiacloprid), dose 0.2 L/ha + Urea, dose 5 kg/ha
11.08.2019	aplication of fungicide Altima 500 SC (fluazinam), dose 0.3 L/ha + leaf fertilization K-gel 175, dose 3.5 L/ha
28.08.2019	aplication of fungicide Altima 500 SC (fluazinam), dose 0.3 L/ha
15.09.2019	harwest + evaluation of experimental variants
01.08.2019	disking + catch crops sowing
30.10.2019	catch crops mulching
30.10.2019	aplication of manure, dose 35t/ha + ploughing to 28 cm
16.04.2020	grooving rough furrows + separation soil clods and stones
17.04.2020	planting + aplikacation of experimental variants
07.05.2020	aplikacation of herbicide Arcade 880EC (prosulfocarb, metribuzin), dose 5 L/ha
13.06.2020	aplication of fungicide Ridomil Gold MZ Pepite (mancozeb, metalaxyl-M) 2.5 kg/ha +MgS 10 kg/ha + Urea 10 kg/ha + K-fenol mix 0.2 L/ha
24.06.2020	aplication of fungicide Revus Top (mandipropamid, difenoconazole) 0.6 L/ha + Kombiphos 2 L/ha K-gel 175 1.5 L/ha + K-fenol mix 0.2 L/ha +MgS 10 kg/ha
01.07.2020	aplication of fungicide Ridomil Gold MZ Pepite (mancozeb, metalaxyl-M) 2.5 kg/ha + MgS 10 kg/ha + Urea 10 kg/ha + K-gel 175 1.5 L/ha
08.07.2020	aplication of fungicide Vendetta (fluazim, azoxystrobin) 0.5 L/ha + Ecail Ultra (thiacloprid) 0.2 L/ha + MgS kg/ha + Kombiphos 2.5 L/ha
14.07.2020	aplication of fungicide Acrobat MZ WG (mancozeb, dimethomorph) 2 kg/ha + Galleko leaf 0.4 L/ha + K- fenol mix 0.2 L/ha + Kombiphos 2 L/ha
20.07.2020	aplication of fungicide Infinito (fluopicolide, propamocarb-hydrochloride) 1.5 L/ha + Galleko leaf 0.4 L/ha + MgS 10 kg/ha + K-gel 175 3 L/ha
27.07.2020	aplication of fungicide Revus Top (mandipropamid, difenoconazole) 0.6 L/ha + Galleko leaf 0.4 L/ha + K-fenol mix 0.2 L/ha + Kombiphos 2 L/ha
04.08.2020	Altima 500 SC (fluazinam) 0.4 L/ha+ MgS 10 kg/ha + K-gel 175 3 L/ha
10.08.2020	Infinito (fluopicolide, propamocarb-hydrochloride) 1.5 L/ha + K- gel 175 2 L/ha
19.08.2020	aplication of fungicide Altima 500 SC (fluazinam) 0.3 L/ha
04.10.2020	harwest + evaluation of experimental variants

Statistical analysis

Statistical analysis was performed using ANOVA (Proc GLM in SAS software, Version 9.4). Differences between mean values were evaluated by Tukey's HSD test at $P = 0.05$ significance level.

RESULTS AND DISCUSSION

The results suggest that both the dose of basic nitrogen fertilization and the method of its application statistically significantly affect the total yield and the consumer tuber yield (Fig. 2, Table 5). Similar results

Table 4. Monthly accumulated precipitation and temperature for months of potato growing season at the experimental location

	April	May	June	July	August	September
Monthly precipitation 2019 [mm]	19	82	37	61	59	81
Monthly precipitation 2020 [mm]	28	63	142	52	97	10
Longtime monthly precipitation 1981 - 2010 [mm]	43	70	75	72	73	46
Monthly average teperature 2019 [°C]	10.5	11.9	21.8	19.6	20.1	14.6
Monthly average teperature 2020 [°C]	9.9	11.7	16.8	18.4	19.5	14.6
Longtime monthly average temperature 1981 - 2010 [°C]	8.6	13.7	16.5	18.5	18	13.5

were outlined by M a t e j k o v a et al. (2010), who described the effect of nitrogen proportion in mineral fertilizers on various agricultural crops. Also M a k a n i et al. (2020) described the effect of nitrogen fertilization doses on potatoes quality and yield. The positive effect of local nitrogen application was mentioned, among others, by S h r e s t h a et al. (2018) who described an increase in maize yield with this method of application. The comparison of yield produced using various doses and methods of nitrogen application clearly shows that the local application is more effective, because potato plants can more efficiently use the nitrogen dose. B r a n t et al. (2020) also noticed a more effective utilization of locally applied fertilizer in a study that describes a technique of loosening wheel tracks between rows of hops in hop gardens with local fertilizer application to the root zone. Also Jiao et al. (2013) reported on that the potato plant makes better use of locally applied nitrogen.

The weight of tubers under the potato plant is one of the most important variables generating the yield. The nitrogen dose affects the weight of the potato tubers under each plant (Fig. 3). The tuber weight of fertilized plants is significantly higher ($P = 0.05$) than that of unfertilized control. At the same time, there is also a statistically significant difference in yield between the selected doses of nitrogen (Fig. 3). The results also show a statistically significant difference between the tuber weight for local and areal application. The tuber weight is significantly ($P = 0.05$) higher for both lower and higher locally applied nitrogen doses when compared to the areal application. K a s a l et al. (2007) also observe a significant difference in the tuber weight and note that the dose of nitrogen fertilizer can be lowered when the local application method is used.

Our results show that the local application of nitrogen fertilizer did not increase the number of tubers under a plant. The data presented in Fig. 4 and Table 5 show that the dose of nitrogen also did not significantly increase the number of tubers under a plant. H o l e j s o v s k y et al. (2020) and H a m o u z et al. (2010) pointed out that annual weather conditions tend to have a significant effect on the number of tubers.

K o l o d z i e j c z y k (2014) stated, that the yield of consumer tubers varied from 66 to 140 % with experimental treatments when compared to control. In that study the yield of consumer tubers ranged from 57.2 to 88 %. According to his results, the worst yield was achieved at the unfertilized control plots (57.2 %). Our study found that the difference in yield of consumer tubers between the treatment with local application of 70 kg N ha^{-1} (LA70) and the areal application of 130 kg N ha^{-1} (AA130) was 7.4 %. The highest yield of consumer tubers was achieved with the local application of 130 kg N ha^{-1} (LA130). It was significantly

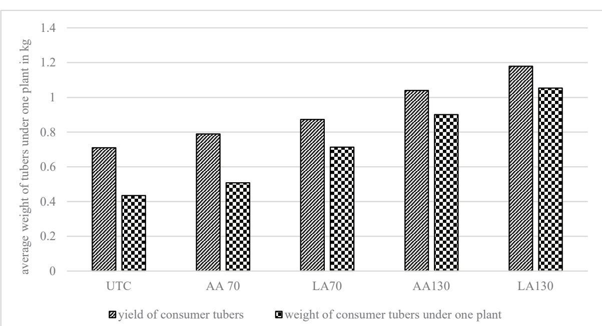

Fig. 3. Average weight of all tubers and consumer tubers under one plant using various experimental treatments

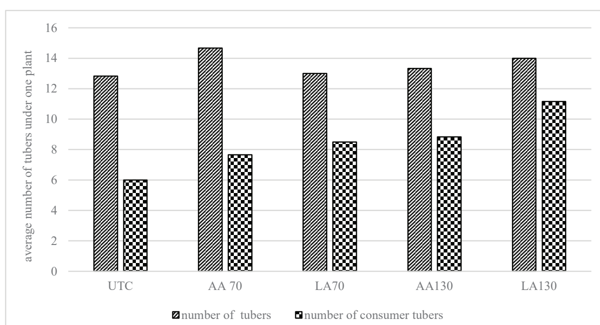

Fig. 4. Average number of all tubers and consumer tubers under one plant using various experimental treatments

Table 5. Statistical evaluation of experimental treatment results (average of two years of experiment)(GLM ANOVA)

Observed parameter	UTC	AA70	LA70	AA130	LA130	HSD
Yiled (t/ha)	30.35 e	34.28 d	38.77 c	46.2 b	52.41 a	2.2584
Average weight of tubers under 1 plant (kg)	0.709 e	0.789 d	0.873 c	1.04 b	1.18 a	0.0528
Average number of tubers under 1 plant	12.83 a	14.67 a	13 a	13.33 a	14 a	2.1853
Average weight of consumer tubers under 1 plant (kg)	0.435 d	0.508 d	0.713 c	0.901 b	1.053 a	0.08
Average number of consumer tubers under 1 plant	6 c	7.67 bc	8.5 b	8.83 b	11.17 a	2.2963
Yield of consumer tubers (t/ha)	19.35 d	22.58 d	31.7 c	40.12 b	46.86 a	3.5515
Yield of consumer tubers (%)	64.31 c	65.96 c	81.85 b	86.62 ab	89.26 a	7.2458

Differences between mean values were evaluated by Tukey's HSD (honestly significant difference) test at the level of significance P = 0.05.
Values with the same letters are not statistically significant, HSD = honestly significant difference.

higher (P = 0.05) in compare with the areal application of the same nitrogen dose (Fig. 5, Table 5). However, there is a statistically significant difference in the yield achieved with different doses of nitrogen fertilizer, which corresponds, for example, to the results of Wang et al. (2020) who described a statistically significant difference in potato yield in China when different nitrogen fertilization doses were applied.

In comparison with other experimental treatments, the local application of mineral fertilizer leads to a more efficient use of nitrogen dose. This can ultimately reduce the nitrogen dose while maintaining the required potato production. This finding is especially important for areas where high nitrogen doses can harm the environment. The effectiveness of local application was discussed, for example, by Kasal (2007) who found up to 20% higher nitrogen utilization for local application compared to areal application. In times of rising environmental and economic pressures, producers can use the local nitrogen application for potatoes to maintain effective production at the same dose of nitrogen. With this method of application, they can reduce the dose of nitrogen to maintain production and decrease the burden on the environment thanks to better nitrogen utilization.

CONCLUSION

The results suggest that both the dose of basic nitrogen fertilization and its application method statistically significantly affect both the total yield and the consumer tuber yield. The tuber weight of fertilized plants is significantly (P = 0.05) higher than in unfertilized control. At the same time, there is also a statistically significant difference in yield between the selected doses of nitrogen. The results show a statistically significant difference between the tuber weight for local and areal application and also that the local application of nitrogen fertilizer did not increase the number of tubers under a plant. The above results document that the local application of basic nitrogen dose leads to fertilizer savings while maintaining production and reducing the risk of nitrogen leaching into the environment. The benefits of the local application of mineral fertilizers consist in their greater utilization by potatoes, reduction of nitrate water pollution, and compliance with the Nitrates Directive and other EU legislative requirements.

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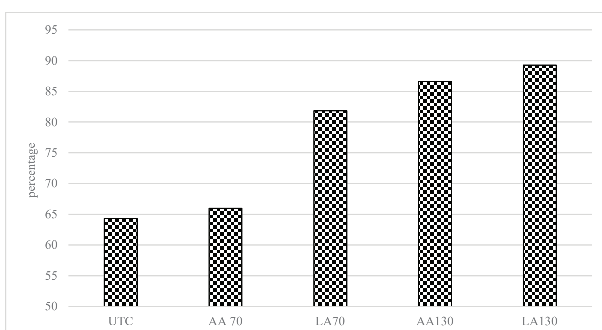

Fig. 5. Yield of consumer tubers for various experimental treatments (in %)

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