INFLUENCE OF WEATHER CONDITIONS AND POLYMYXOBACTERIN APPLICATION ON YIELD AND QUALITY OF MALTING BARLEY IN UKRAINIAN FOREST- STEPPE

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Abstract. There is a growing interest to increase P availability and P uptake by crops using phosphate solubilizing bacteria. Therefore, barley seeds were treated with a liquid solution of Polymyxobacterin which contain phosphorus solubilizing bacteria (PSB) and compared with untreated barley seeds and that in combination with three fertilization treatments (a control without fertilization, the application of only mineral fertilizers and a combination of mineral fertilizers and farmyard manure) and that during the years 2007 and 2008. Maximum effectiveness of PSB application was found in favorable climate condition when applying both mineral and organic fertilizers with an additional yield increase of 1.37 t/ha in 2008. Furthermore, there was a slight increase in kernel plumpness and a decrease in protein content in 2008. On the other hand, no evident differences in starch content after PSB application were found in both years.

Keywords: grain quality, Hordeum vulgare L., malting barley, phosphorus solubilising bacteria, weather conditions, yield

Introduction

In the last four decennia the population on the earth has been doubled. The increasing number of humans needs more and more food, feed, fiber, water and other resources. To produce adequate amounts of good quality crops, the application of essential plant nutrients, such as N, P, K, S, Ca etc is needed.

As phosphorus is a finite resource, the P reserves will be depleted in a couple of hundred years if the application will go on like today. However vast areas of agricultural land are poor in phosphorus content and reduction of yield occurs if the soil has a phosphate (P) deficiency [12, 7]. The total phosphorus level of soils is mostly low in Eastern Europe and developing countries, usually no more than one-fourth to one-tenth that of nitrogen, and one twentieth that of potassium. The phosphorus content of these soils ranges from 200 to 2000 kg phosphorus in the upper 15 cm of 1 ha of soil, with an average of about 1000 kg P [12]. Furthermore, the phosphorus compounds commonly found in soils are mostly unavailable for plant uptake, often because they are highly insoluble [12]. The term available phosphate is used because phosphate is the most immobile of major plant nutrients and if it is not in a soluble form it is difficult for plants to get it.

When soluble sources of phosphorus, such as those in fertilizers and manure, are added to soils, they are fixed (changed to unavailable forms) and, in time, form highly insoluble compounds [12].

The efficiency of phosphate fertilizers can be increased by several ways: (i) by using P coated seeds as starter fertilization [26]; (ii) by adding organic material to soil [8]; (iii) by applying bio-phosphate fertilizers (mixed with spores of Actinomycetes) [15].

The P soil status plays an important role in yield and quality of malting barley, especially on calcareous soils like in Ukraine. Since 1989, the use of phosphorus fertilizers in Eastern Europe decreased dramatically, mostly because of waiving subsidies for mineral fertilizers. The trend of decrease in Olsen-P in soils without P added could be described by an exponential function of time [22]. To improve the availability of phosphorus in soils, the application of PSB (phosphorus solubilizing bacteria) has been reported by many authors [20, 18]. In developing inoculants that improve plant P nutrition and allow plants to use soil stocks of organic and inorganic P, *rhizobia* may present many advantages [2]. The microbial biomass is able to rapidly store significant amounts of easily soluble P and to prevent it from adsorption or other fixation processes [19]. PGPB (plant growth promoting bacteria) are thought to stimulate plant growth through any of the following mechanisms: (1) by altering the hormone balance in the host plant [9]; (2) by increasing mineral nutrient – stimulated nodulation as well as nitrogen fixation [11] and release of P from sparingly soluble mineral phosphates by producing high levels of gluconic acid from extracellular glucose [4], (3) by producing antibiotics and thus protect plants from diseases [34; 14], (4) by stimulating shoot growth and chlorophyll content, thereby increasing the available photosynthate for release by plant roots [10].

High effectiveness of PSB was reported on calcareous soils [30]. Kinetics of PSB acting in calcareous soils differs from acid and neutral soils. The difference lies in the solubilizing capacity of Ca phosphates whereas in acid and neutral soils phosphates are in the form of Al and Fe phosphates [13].

Steadily increasing prices for fertilizers make crop production more expensive. When used in conjunction with P fertilizers, PSB can reduce the required P dosage by 25% [33].

The objectives of this study were: to study the effect of weather conditions on yield and quality of malting barley (i) to study the effectiveness of PSB application on yield and quality of malting barley, (ii).

Materials and Methods

Site characteristics

The trials were carried out at the long-term experimental field of the Agrochemistry and Crop Quality Department of the National University of Life and Environmental Sciences of Ukraine, Kyiv during the years 2007 and 2008.

The local climate can be defined as temperate with annual rainfall of about 562 mm (273 mm of it falls during the vegetation period) and a mean annual air temperature of 7.5^{o}C with mean temperature during the vegetation period of 12.4^{o}C. The soil is a meadow-chernozemic calcareous loam. pH_{H2O} was 8.1, SOM content by Turin [35] is 4.22 %, mobile phosphorus and exchangeable potassium by Machigin [23] **(**extraction by 1%-$(NH_4)_2CO_3$) was 27.1 and 155 mg/kg respectively.

Treatments and design

Spring barley was grown in a 10-years crop rotation. The preceding crop was corn for grain. Six-row spring barley, cultivar Vakula, was sown in the third decade of March in 2007 and first decade of April in 2008. Seedling rate was 160 kg/ha. Half of barley seeds were treated with liquid Polymixobacterin (rate per ton of seeds: 150 ml of bacterial solution dissolved in 3200 L of water. 1 ml of Polymixobacterin contain 5 billions of *Paenobacillus polymyxa*). Crop management was handled according to standard farm practices.

The treatments, with or without liquid Polymixobacterin, were the control (without fertilizers), MF (mineral fertilizers with mean annual rate of 239 kg/ha ($N_{73}P_{81}K_{85}$) and FYM&MF (farmyard manure and mineral fertilizers with mean annual rate of 12 t/ha and 239 kg/ha, respectively).

The experiment is a 2-factor systematic block with three replicates. Plot size was 87.5 m^2.

Sampling and analyses

The soil was collected from the top layer (0-25 cm) and subsoil (25-50 cm). The soil was air dried, grinded and sieved. Mobile P was extracted with 1% NH_4CO_3 and measured colorimetrically by Machigin method [23]. The pH_{H2O} of air dried soil samples was measured in distilled water (1:5 w/v)) suspension using a glass electrode.

Germination rate of barley grains were determined after 5 days of sowing. Disease and pest control was conducted according to methods valid for plant protection. A small-plot harvester was used for harvest and the yields were converted to 14 % humidity. Protein and starch content was measured by infrared spectroscopy using an Infratek 1225. Kernel plumpness has been considered as the percentage of retained grains by a 2.5 mm sieve. Test weight of grains has been determined by using a one-litre corn balance. Analysis of variance has been performed by using Agrostat and Excel MS.

Results and discussion

Influence of weather conditions on yield of malting barley

The climatic conditions during the study ranged from poor to most favorable for malting barley growth (table 1). Adverse conditions included long and cold spring, hot and dry period at tillering and stem elongation stages and excessive moisture before harvest, occurred in our trials in Ukraine and in some other East European countries in 2007 [32].

Table 1. Air temperature (^{0}C) and rainfall (mm) during malting barley growth periods

	2007 year		2008 year		Long-term mean 1988-2008	
	^{0}C	rainfall, mm	^{0}C	rainfall, mm	^{0}C	rainfall, mm
March	5.6	15.1	4.3	40.5	0.2	32
April	8.4	12.8	10.0	92.5	8.4	46
May	18.1	20.2	13.8	61.7	15.3	48
June	20.0	62.1	18.5	14.9	18.5	64
July	21.0	76.8	20.5	51.3	19.6	83
Mean/Total	14.6	187.0	13.4	260.9	`12.4	273

A significant shortage (32% lower) of total precipitation at growing period of malting barley in 2007 as well as an imbalance of water supply within the growth period were the main reasons of low malting barley yield.

In 2008, a non significant (4%) shortage of total precipitation has been observed during the growing period. Mean temperature was lower than in 2007 by 1.2 ^{0}C but still higher (1°C) than the long-term mean. Better weather conditions in 2008 resulted in additional grain yields between 26 and 47% compared to 2007 (table 2). This confirms the study of Prikopa et al. (2005) [29] that weather conditions are responsible for 82% of yield variability. Thus, weather conditions are crucial in malting barley yield formation.

Weather conditions and grain quality

Protein content

Skladal (1961) [31] pointed out that yields and quality of barley are determined by weather conditions, farm practices, fertilizer applications and used cultivar. In our conditions, weather conditions and fertilizer applications are different.

Table 2. Yield of malting barley and Least significant Differences (LSD)

Treatments	Yield, t/ha			Fertilizers-influence difference, t/ha			PSB-influence difference, t/ha		
	2007	2008	mean	2007	2008	mean	2007	2008	mean
Control	2.83	3.82	3.33	0	0	0			
MF	4.79	6.73	5.76	1.96	2.91	2.44			
FYM+MF	4.23	7.15	5.69	1.40	3.33	2.37			
Control +PSB	3.01	5.51	4.26				0.18	1.69	0.94
MF+PSB	4.96	7.55	6.26				0.17	0.82	0.50
FYM+MF+PSB	4.50	8.52	6.51				0.27	1.37	0.82
$LSD_{05,}$ treatments				*0.57*	*0.67*	*0.66*			
$LSD_{05,}$ PSB							*0.46*	*0.55*	*0.54*
$LSD_{05,}$ treatments x PSB	*0.46*	*0.55*	*0.54*						

Table 3. Quality of malting barley

Treatments	Grain Protein		Starch		Kernel plumpness		Germination rate		Test weight	
	content, %				%				gram per L	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Control	10.3	8.2	62.9	64.0	90.6	87.3	96	96	617	622
MF	11.5	11.5	61.7	61.3	96.9	82.3	99	96	646	602
FYM+MF	11.3	11.1	61.9	61.7	96.8	85.6	98	97	643	607
Control +PSB	10.1	7.7	62.6	64.1	90.8	91.3	96	97	605	644
MF+PSB	11.1	9.6	61.9	62.3	95.4	91.5	99	98	625	654
FYM+MF+PSB	11.2	11.0	62.2	62.0	95.9	87.0	99	97	661	640
$LSD_{05,}$ treatments	*0.45**	*0.38**	*0.88*	*0.56**	*0.67**	*2.06**	*1.4*	*1.6*	*5.5**	*4.2**
$LSD_{05,}$ PSB	*0.37*	*0.31**	*0.72*	*0.46*	*0.57*	*1.68**	*1.1*	*1.3*	*4.5**	*3.4**
$LSD_{05,}$ treatments x PSB	*0.37**	*0.31**	*0.72*	*0.46**	*0.57**	*1.68*	*1.1**	*1.3*	*4.5**	*3.4**

* - difference is significant

In 2007, high temperature and a low precipitation resulted in reduced yields and especially higher protein contents compared to more favorable conditions in 2008 (table 3). The application of mineral (MF) or both mineral and organic fertilizers (FYM+MF) maintained soil fertility properties of the soil in general and nitrogen particularly, resulting in smaller differences in protein content. It has to be noticed that the protein content in grain in the fertilized plots exceeds the permissible level for malting barley, which is 11% for first grade grain and 11.5% - for second grade (according to DSTU 3769-98 [27]). It means that the nitrogen fertilization for malting barley should be limited.

Starch content

Beer quality is strongly related to starch content. The higher the starch content, the higher beer yield [21]. Fertilizers do not have a significant influence on grain starch content but lead to increase its gross yield [36].

Because of a strong inverse relationship between grain protein (GP) and starch content, Ukrainian standards does not have requirements to starch content in barley grain for malt. This inverse relationship has been proved in this study (figure 1) with rather high determination coefficients.

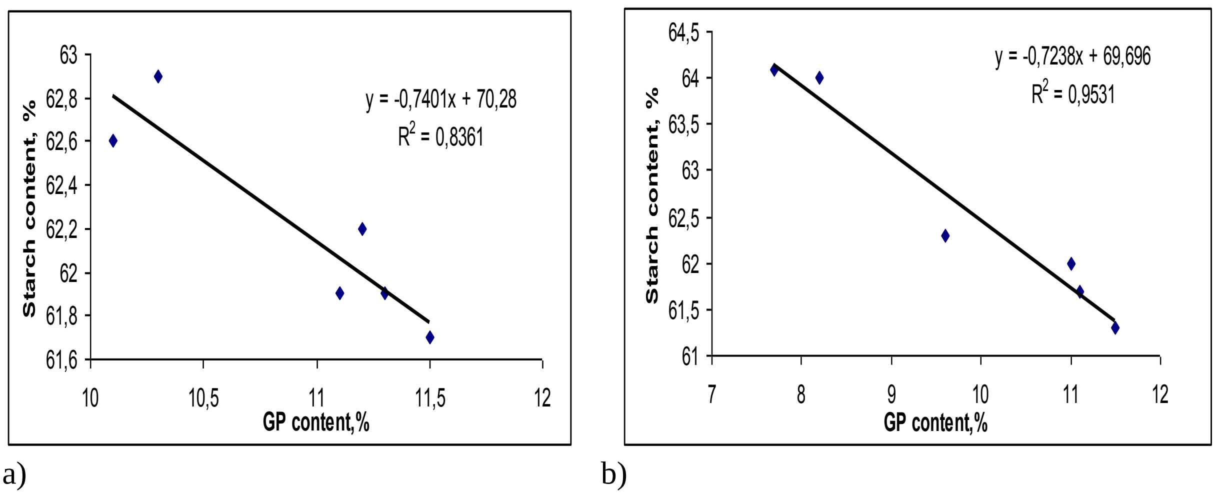

Figure 1. Correlation between grain protein (GP) and starch content in 2007 (left) and 2008 (right)

Kernel plumpness, germination rate and test weight

Kernel plumpness is influenced by nitrogen fertilizers. Increased N additions reduce kernel size, particularly in a year with moist spring and hot, dry summer conditions [24]. More available N might cause more small tillers to produce ears, giving smaller grains [28]. For high yielded cultivars high rates of N-fertilizers are the reason of yield increase with no influence on kernel plumpness [17].

Kernel plumpness was higher in 2007 compared to 2008. This confirms the results of Mckenzie et al. (2007) [24], showing a different precipitation distribution between both years. In June and July the amount of rainfall was 62.1 and 76.8 mm in

2007 and 14.9 and 51.3 mm in 2008, respectively. We can conclude from these data that an adequate amount of moisture in 2007 during grain filling facilitated to coarse grain forming and there was an adverse situation in 2008. From the other site poor yield of grain in 2007 needed less moisture for grain filling than heavy crop in 2008.

The germination rate was slightly reduced in treatments without fertilization in both years of research. Nevertheless germination rate remained high in all treatments and there was no evident influence of weather conditions on this quality index.

Test weight influences beer yield directly. Optimum level of test weight for malting barley is considered 670 g/L [5]. Our results show no separate influence of weather conditions and the test weight on the fertilized plots was close to the optimum figure.

Weather conditions and PSB

Microbiologists reported that microorganism require special weather conditions both temperature and water availability [25].

The weather conditions in 2007 and 2008 on PSB activity and its effectiveness were absolutely different. Dry soil conditions, which have been observed in 2007 were uncomfortable for PSB and resulted in a limited yield responses (table 2). On the other hand, the PSB-influence was 9 times higher in the control treatment, nearly 5 times higher in MF and 5 times higher in FYM+MF treatment (table 2). Our data confirm the significant variability of PSB influence on yield under different climatic conditions. Thus, in dry years irrigation should be applied to maintain favorable conditions for PSB.

PSB influence on yield

Six row spring barley is not widely recommended for malt production, but the American Malting Barley Association (2002) [3] recommended both (two- and six row) cultivars and made different requirements for them. Abeledo et al. (2008) [1] reported that physiological nitrogen efficiency for grain yield was significantly higher in the newest than in the oldest cultivar. Therefore, the influence of PSB on barley yield has been studied on a new six-row spring barley of Ukrainian origin, cultivar

Vakula, which is reported to be a high yielding cultivar with maximum yields up to 9.6 t/ha [6]. Today up to 1 million ha of arable land is cultivated with the Vakula cultivar [16].

The maximum positive PSB-influence on yield has been obtained on the control treatment in 2008 (an increase in yield of 1.69 t/ha, table 2). As mentioned above the PSB activity was higher in the weather conditions of 2008 compared to 2007. Such significant increase in yield in the control treatment could be due to Liebig's law. One or some parameters (as available P, protection from diseases etc.) were low in the control treatment without PSB application and increased after seeds treatment by PSB.

The influence of PSB on the fertilized treatments was higher on the combination of organic and mineral fertilizers compared to the treatment with only a mineral fertilization (0.27 and 1.37 t/ha yield increase on the treatments FYM+MF+PSB compared to 0.17 and 0.82 t/ha yield increase on the MF+PSB treatments, respectively in 2007 and in 2008). This difference of PSB activity can be attributed to a positive influence of organic compounds and a broad range of micro- and micronutrients in manure compared to the mineral fertilizer treatment.

PSB influence on malting barley quality

The application of PSB often leads to an improvement of P nutrition of plants [4]. Malting barley quality depends, besides N, also on the P and K soil status [21]. Especially in 2008, PSB application resulted in a decrease in grain protein content from 8.2-11.5 to 7.7-11.0 % (table 3). On the other hand, no significant differences in protein content after PSB application was observed in 2007. Dry conditions of that year caused a low activity of PSB and no evident effect on grain protein content.

No significant differences in starch content were noticed in both years of our research.

Seeds treatment by PSB in 2007 had no significant influence on kernel plumpness. In 2008, plumpness was minimal 1.4 absolute % higher in FYM+MF+PSB and maximal 9.2 absolute % higher in the MF+PSB treatment.

Test weight as well as kernel plumpness was not affected positively by PSB in 2007. In favorable conditions of 2008, the application of PSB led to an additional test weight of minimal 22 g/L in the control treatment to maximal 52 g/L on the MF treatment.

Conclusions

Weather conditions have a great effect on yield and some quality parameters of malting barley. The application of PSB has led to a yield increase of malting barley (up to 1.37 t/ha on the FYM+MF+PSB treatment) under the favorable weather conditions of 2008. Also some quality parameters like kernel plumpness and test weight of grains were positively influenced by PSB application in 2008. On the other hand, the grain protein content decreased more on the PSB objects which is positive for malting barley. Furthermore, there is no doubt that the effect of PSB application will change with various climatic conditions.

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