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PRODUCTIVITY TRAITS OF RYE (*SECALE CEREALE*), KHORASAN WHEAT (*TRITICUM TURGIDUM*, SSP. *TARANICUM* MCKEY) AND QUINOA (*CHENOPODIUM QUINOA* WILLD) GROWN ON DEGRADED SOIL

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ABSTRACT

The productivity traits of rye, khorasan wheat and quinoa on degraded soil were investigated in a three-year research (2010-2012). The research was carried out in two localities: Stanari (ST) (Bosnia-Herzegovina) and at "TENT 2" in Obrenovac (OB) (Serbia). A significant interdependence between grain yield and aboveground biomass yield was observed in the investigated genotypes and localities. The resulting average grain yields in these localities ranged between 1,166-1,702 kg ha-1 (rye), 1,826-1,943 kg ha-1 (khorasan wheat) and 520-966 kg ha-1 (quinoa). Fluctuations in grain yields were due to different soil conditions – different nutrient contents and the distribution of precipitation at initial stages of crop development. This research confirmed that rye is a crop with minimum soil requirements and it can be successfully grown in poor soil. The second best biomass yield was obtained by khorasan wheat, while the lowest biomass yield was obtained by quinoa.

Key words: *Secale cereale*, *Triticum turgidum*, ssp. *Taranicum* McKey, *Chenopodium quinoa,* degraded soil, deposol, biomass, grain.

INTRODUCTION

When it comes to recultivation of degraded soil, crop choice depends on multiple factors, some of which are the level of soil degradation and its pedological properties, climatic conditions, future soil use and adaptability of crops to alternated agro ecological and soil conditions in areas degraded due to non-farm activities (Ikanović, 2010a). According to the literature available (Glamočlija et al., 2012a, 2013; Janković et al., 2013), most cereal grains - and primarily rye - due to their biological properties can be quite successfully grown on degraded soil, improving it to be used more productively – as agricultural soil. If the soil is not so degraded, cereal grains can be grown for use as animal feed or for siderite. To use biomass (or grain) for making animal feed, it is necessary to identify the content of harmful metals in plant biomass. If the content is high, the biomass is used for sideration, since this type of soil has very few major nutrients (NPK) and organic matter, and therefore poor biological activities both in surface and deeper layers. From all cereal grains, according to Zhelceva-Bogdanova (1995), Stallknecht et al. (1996), and Glamočlija et al. (2013), most suitable for the recultivation of degraded soil are rye (*Secale cereale*) and khorasan wheat (*Triticum turgidum*, ssp. *Taranicum* McKey), while according to Bois et al. (2006), quinoa (*Chenopodium quinoa* Willd) can be successfully grown in this type of soil in South America. Results of crop production on degraded soil depend on agricultural practices. Considering this type of soil is very poor in plant assimilates, side dressing has a greater effect than in conventional field crop production. The effect of organic and mineral nutrients used in the process of recultivation depends on the amount and distribution of precipitation over

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the year and the length of the growing season, as it was shown in the results of a study (Krümmelbein et al., 2010) on the ways of soil recultivation in mining areas in Germany. The goal of this particular research was to investigate a possibility of growing rye, khorasan wheat and quinoa on degraded soil (deposol) in different localities. The productivity of the investigated field crops were determined – grain yield and the yield of above-ground biomass, as well as post-harvest residues. The aboveground biomass was ploughed down to increase microbial activity and therefore to enhance the fertility of soil.

MATERIAL AND METHODS

The research was conducted in 2010, 2011 and 2012 on degraded soil (deposol), in two localities: ST in Bosnia-Herzegovina and at “TENT 2” in OB in Serbia. The field trials were set up in a randomised block design with four repetitions. The subject of this research was three cereal grains – rye (cultivar Oktavija, bred at the Faculty of Agriculture in Banja Luka), khorasan wheat (white awn population, unknown origin) and quinoa (cultivar KVL 52, bred in Denmark). Prior to setting up the trials, the soils were tested for agrochemical properties (Table 1).

Table 1. Agrochemical properties of soil fertility, the deposol-type soil

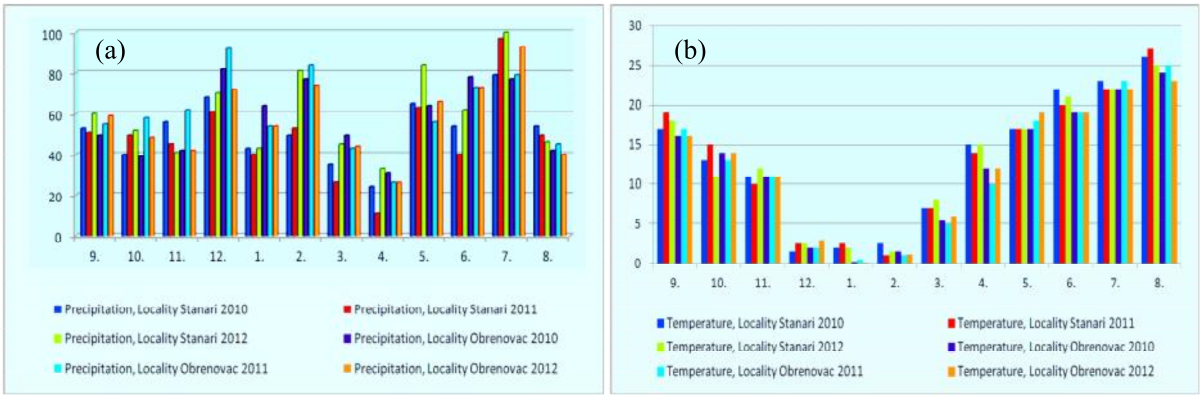
Values	pH		Organic matter (%)	Humus (%)	N (%)	Easy accessible forms	
	H_2O	KCl				P_2O_5 mg/100g	K_2O mg/100g
ST	5.8	4.6	1.6	0.01	0.0	0.38	1.94
OB	5.2	4.1	1.8	0.01	0.4	1.82	3.25

The results of this agrochemical testing showed that these soils were very acidic, pH of KCl ranging from 4.1 (OB) to 4.6 (ST), with a very small percentage of organic matter and humus, and having nitrogen salts content from 0% to 0.4%. When it comes to easily accessible phosphorus and potassium, these soils were also categorised as very poor. Numerous researchers, such as Bois et al. (2006), Resulović et al. (2008), and Veselinović et al. (2010) stated that most of technogenic soils contained very few major nutrients (NPK) and organic matter, so they had poor biological activity, both in surface and deeper layers.

Standard agricultural practices for this type of field crops were used in these localities, such as conventional basic tillage, harrowing and manual sowing. Winter rye was sown in October. Spring khorasan wheat was sown in mid-March and quinoa in the first ten days of April in all years of research. Manual weeding and hoeing were carried out. After harvest, at the stage of technological maturity of crops, the productivity properties, such as grain yield and biomass yield, were determined on both trial fields, using the method of measuring yields of grain and aboveground biomass for each elementary plot, from the previously determined measuring area. Data were analysed using analytical statistics, with STATISTICA 12 for Windows (StatSoft).

Meteorological conditions

During the research, the most important meteorological variables, such as the distribution and amount of precipitation and temperature conditions in the growing season, were monitored and analysed. Climatic conditions for crop production are quite unpredictable and changeable (Popović, 2010; Popović et al., 2011). Data on monthly precipitation and average air temperatures in the period 2010-2012 were retrieved from the hydro meteorological stations of Serbia and Bosnia-Herzegovina. Water regime in both localities was relatively favourable, when it comes to precipitation amounts and distribution. There was less precipitation in OB, but this did not seriously affect winter crops, since heavy rains provided enough water for early spring growth in all three years of research (Graph 1a).



Graph. 1. Total precipitation mm (a), and monthly air temperatures °C (b), ST and OB, 2010-2012

In tested periods, monthly heat distribution was enough for winter crops to grow and develop. The most favourable year was 2011. In that year, average temperatures in the pre-winter period (October, November and the first half of December) were above 10°C, which contributed to the optimum crop development in autumn and forming tillers before winter (Graph 1b). Heat distribution in the spring with gradually increasing temperatures to the early summer was optimal for crops to move from vegetative to generative growth stage. Observed by the localities, there were no great fluctuations in average monthly temperatures, although the temperatures in the vicinity of Obrenovac were 1-2°C lower in autumn and winter, but higher in spring and summer.

RESULTS

Data analysis showed some significant differences in productivity traits (grain yield and biomass yield) of the investigated cereal grains. On both localities (degraded soil), a considerably higher grain yield was obtained by khorasan wheat, and biomass yield by rye (Table 2).

Table 2. Grain yield and biomass yield of rye, khorasan wheat and quinoa on degraded soil, localities ST and OB*

Locality	Year	Grain yield, kg ha^{-1}			Biomass yield, kg ha^{-1}		
		Rye	Khorasan	Quinoa	Rye	Khorasan	Quinoa
(ST) (L1)	2010	1469^{bc}	1880^{ab}	538^{d}	2310^{c}	1676^{a}	744^{d}
	2011	1166^{c}	1826^{b}	520^{d}	2050^{d}	1690^{ab}	778^{c}
	2012	1278^{c}	1943^{a}	612^{c}	2558^{b}	1716^{a}	829^{b}
(OB) (L2)	2010	1624^{ab}	1892^{ab}	949^{a}	2708^{a}	1692^{ab}	972^{a}
	2011	1702^{a}	1882^{ab}	887^{b}	2446^{b}	1724^{a}	970^{a}
	2012	1698^{a}	1916^{a}	966^{a}	2550^{b}	1654^{b}	981^{a}
Average		1454	1843	752	2465	1698	884
LSD_{LY}	0.05	218.25	71.40	47.39	116.54	49.49	32.03
	0.01	297.66	97.38	64.64	158.95	67.50	43.69
Average $_{L1}$		1304^{b}	1883^{a}	557^{b}	2306^{b}	1694^{a}	784^{b}
Average $_{L2}$		1675^{a}	1897^{a}	934^{a}	2568^{a}	1690^{a}	974^{a}
LSD_{L}	0.05	126.00	41.22	27.36	67.29	28.58	18.50
	0.01	171.86	56.22	37.32	91.77	38.97	25.22
Average	2010	1547^{a}	1886^{ab}	744^{b}	2509^{a}	1684^{a}	858^{b}
Average	2011	1434^{a}	1854^{b}	704^{c}	2248^{b}	1707^{a}	874^{b}
Average	2012	1488^{a}	1930^{a}	789^{a}	2554^{a}	1685^{a}	905^{a}
LSD_{Y}	0.05	154.33	50.49	33.51	82.41	35.00	22.65
	0.01	210.48	68.86	45.70	112.39	47.73	30.89

*Different superscript letters within a column denote significant difference at $p \le 0.05$

Fluctuations in productivity traits were significantly affected ($p \leq 0.01$) by the interaction between year, locality and genotype (Table 3).

Table 3. Analysis of variance for productivity traits of rye, khorasan wheat and quinoa

Source of variation	df	Grain yield		Biomass yield	
		MS	p	MS	p
Repetition	4	0.0070101		0.000993	
Treatments / types	17	1.3335052		2.239738	
Year (Y)	2	0.0451086	≤ 0.05	0.087310	≤ 0.01
Locality (L)	1	1.4490711	≤ 0.01	0.503254	≤ 0.01
Genotype (G)	2	10.1196553	≤ 0.01	18.216790	≤ 0.01
Interaction:					
YL	2	0.8000144	≤ 0.01	0.423048	≤ 0.01
YG	4	5.0919872	≤ 0.01	9.248580	≤ 0.01
LG	2	11.1685828	≤ 0.01	18.610592	≤ 0.01
YLG	4	5.6673972	≤ 0.01	9.518887	≤ 0.01
Error	68	0.0099753		0.003022	

Data analysis of rye yield showed a significant effect of the interaction between year and locality (YL, $p \leq 0.05$). Unlike rye, for khorasan wheat, the effect of year (Y, $p \leq 0.05$) was significant and for quinoa - the effect of both year and locality (Y, $p \leq .01$) (L, $p \leq 0.01$) (Table 4).

Table 4. Analysis of variance for grain yield of rye, khorasan wheat and quinoa

Source of variation	df	Rye		Khorasan		Quinoa	
		MS	p	MS	p	MS	p
Repetition	4	0.012241		0.005126		0.001293	
Treatments/ types	5	0.256524		0.007749		0.221783	
Year (Y)	2	0.031658		0.014361	≤0.05	0.018301	≤0.01
Locality (L)	1	1.028601	≤0.01	0.001401		1.067853	≤0.01
Interaction YL	2	0.095351	≤0.05	0.004311		0.002231	
Error	20	0.027367		0.002929		0.00129	

Depending on year and locality, grain yield ranged from 1,166 kg ha^{-1} to 1,702 kg ha^{-1}. A significantly higher rye yield was achieved in OB, except in 2010 when the yield in ST was similar to the one in OB. Observed by year there were no significant fluctuations in rye yield in OB. As for ST, a significantly higher ($p \leq 0.01$) rye yield was achieved in 2010 than in 2011 (Table 2).

When it comes to khorasan wheat, fluctuations in grain yield ranged from 1,826 kg ha^{-1} to 1,943 kg ha^{-1}. Compared to grain yield achieved in 2012 in both localities, a significantly lower ($p \leq 0.01$) grain yield was achieved in 2011 in ST. Moreover, when observed by locality and year, there were no fluctuations in grain yield in OB.

Quinoa grain yield significantly fluctuated depending on locality and year. Fluctuations in grain yield ranged from 520 kg ha^{-1} to 966 kg ha^{-1}. Significantly higher ($p \leq 0.05$) grain yields were achieved in 2010 and 2012 in OB, unlike in ST where in 2010 and 2011 there were significantly lower ($p \leq 0.05$) yields of quinoa (Table 2). Significant fluctuations in quinoa grain yields were caused by soil conditions and the distribution of precipitation at initial stages of growth of this alternative crop.

Data analysis on biomass yield determined a significant effect of the interaction between year and locality (YL, $p \leq 0.05$) in case of rye, and the effect of year (Y, $p \leq 0.05$) and locality for quinoa (L, $p \leq 0.01$). The effect of year and locality was not confirmed in case of biomass yield of khorasan wheat (Table 5).

Table 5. Analysis of variance for biomass yield of rye, khorasan wheat and quinoa

Source of variation	df	Rye		Khorasan		Quinoa	
		MS	p	MS	p	MS	p
Repetition	4	0.002153		0.000803		0.000407	
Treatments/ types	5	0.266830		0.003304		0.058260	
Year (Y)	2	0.272970	≤ 0.01	0.001690		0.005710	≤ 0.05
Locality (L)	1	0.514830	≤ 0.01	0.000120		0.272653	≤ 0.01
Interaction YL	2	0.136690	≤ 0.05	0.006510		0.003613	
Error	20	0.007803		0.001407		0.000590	

Rye biomass yield ranged from 2,310 kg ha^{-1} to 2,708 kg ha^{-1}, depending on year and locality. A significantly higher ($p \leq 0.01$) biomass yield of rye was achieved in OB in 2010, and significantly lower ($p \leq 0.01$) in ST in 2011. Observed by year, in 2012 the same yields were achieved in both localities, while in 2010 rye biomass yield in OB was significantly higher ($p \leq 0.01$) than in ST (Table 2). When it comes to biomass yield of khorasan wheat, no statistically significant fluctuations were determined, observed by both year and locality. Almost the same average biomass yield of khorasan wheat (1,694 and 1,690 kg ha^{-1}) was achieved in both localities. The average yield fluctuated from 1,684 kg ha^{-1} to 1,707 kg ha^{-1} in different years (Table 2).

Depending on year and locality, quinoa biomass yield ranged from 981 kg ha^{-1} to 744 kg ha^{-1}. A significantly higher ($p \leq 0.01$) average biomass yield was achieved in OB. Observed by year, there were no statistically significant fluctuations in yields in OB, whilst in ST biomass yield fluctuated significantly (from 744 kg ha^{-1} to 829 kg ha^{-1}).

Based on the results of a correlation analysis (Table 6), it was determined that in the period 2010-2012 grain yields in both localities were statistically highly positively correlated with biomass yields (ST=0.63; OB=0.46).

Table 6. Correlations of the investigated variables for the alternative cereal grains, 2010-2012

Variable / Locality	Grain yield	Biomass yield	Temperature	Precipitation
ST	1.00	0.63**	-0.02	0.05
OB	0.46*	1.00	-0.11	0.14

An insignificant negative correlation was determined between grain and biomass yield (-0.41) of rye in OB. Grain yield was positively correlated with temperature and precipitation (0.29, 0.37), while biomass yield was negatively correlated with temperature (-0.31) but positively correlated with precipitation (0.41). As for khorasan wheat, an insignificant negative correlation between grain and biomass yield (-0.16) was determined in OB. Grain yield was insignificantly positively correlated with temperature and precipitation (0.09, 0.19) (Table 7).

Unlike rye and khorasan wheat, a positive correlation between grain and biomass yield (0.47) was determined for quinoa. Grain yield of quinoa was significantly positively correlated with precipitation (0.47*) and highly significantly negatively correlated (-0.73**) with temperature.

In ST, an insignificant positive correlation was determined between grain and biomass yield (0.26) of rye. Grain yield was insignificantly positively correlated with temperature and precipitation (0.01, 0.15), while biomass yield was highly significantly negatively correlated with temperature (-0.77**) but highly significantly positively correlated with precipitation (0.89**). When it comes to khorasan wheat in ST, an insignificant positive correlation between grain and biomass yield (0.28) was determined. Grain yield of khorasan wheat was highly significantly positively correlated with precipitation (0.78**) and highly significantly negatively correlated with temperature (0.81**). Biomass yield was significantly negatively correlated with temperature (-0.61*) but positively correlated with precipitation (0.51). Unlike rye and khorasan wheat, a highly significant positive correlation (0.74**) between grain and biomass yield of quinoa was determined in ST. Quinoa grain yield was highly significantly positively correlated with precipitation (0.94**), but highly significantly negatively correlated with temperature (-0.91**). Biomass yield was highly significantly negatively correlated with temperature (-0.81**) but highly significantly positively correlated with precipitation (0.72**) (Table 7).

Table 7. Correlations of the investigated variables in OB and ST, 2010-2012

Variable		Grain yield	Biomass yield	Temperature	Precipitation
Locality (OB)					
Rye	Grain yield	1.00	-0.41	0.29	0.37
	Biomass yield	-0.41	1.00	-0.31	0.41
Khorasan	Grain yield	1.00	-0.16	0.09	0.19
	Biomass yield	-0.16	1.00	0.55	-0.54
Quinoa	Grain yield	1.00	0.47	-0.73**	0.47*
	Biomass yield	0.47	1.00	-0.23	0.21
Locality (ST)					
Rye	Grain yield	1.00	0.26	0.01	0.15
	Biomass yield	0.26	1.00	-0.77**	0.89**
Khorasan	Grain yield	1.00	0.28	-0.81**	0.78**
	Biomass yield	0.28	1.00	-0.61*	0.51
Quinoa	Grain yield	1.00	0.74*	-0.91**	0.94**
	Biomass yield	0.74*	1.00	-0.81**	0.72**

DISCUSSION

In a three-year research on introduced quinoa genotypes KVL 37 and KVL 52, Glamočlija et al. (2012b) identified some statistically significant fluctuations in yields as a result of adverse weather conditions during the growing season of quinoa. Garsia et al. (2007) and Geerts et al. (2008) obtained similar results when observing the optimisation of water regime and the effect of drought on quinoa yield. Popović et al. (2011) and Janković et al. (2013) in their research stated that crops gave good yields in favourable years and that growing conditions could affect yields significantly. Biomass, i.e. post-harvest residues in field, represents a significant amount of organic mass suitable for ploughing down. Ploughing down of post-harvest residues on deposols is of great importance since their degradation activates microbial processes in soil, thus increasing the number of useful organisms and humus content (Janković et al., 2012; Glamočlija et al., 2013). Having studied the ways of deposol recultivation in coal mining areas and turning this type of soil into agricultural soil, Krümmelbein et al. (2010) concluded that productivity traits of crops depended on their possibility to absorb plant nutrients, but also on the amount of nutrients in degraded soil. During multi-annual research on the effects of different agricultural practices on recultivation of volcanic ash-soil, Podwojewski et al. (2008) came to a conclusion that the introduction of siderates in a crop rotation system can significantly improve chemical and physical properties of soil. The effect of the agricultural practices applied, as well as the yield of crops (barley, maize, pea and vetch) is greatly affected by the amount and distribution of precipitation, since this type of soil loses water from its rhizospheric layer very quickly due to small amount of organic matter and adverse physical properties. In their attempt to find the most efficient crop for deposol recultivation, Ikanović et al. (2010b) and Glamoclija et al. (2011) gave priority to plants with strong roots that were better in using nutrients from deeper layers of soil. These authors gave preference to sudan grass that had better tolerance to drought and high summer temperatures. According to numerous researches conducted on soils with different level of degradation, not only do sudan grass and the hybrids of sudan grass and sorghum thrive on degraded soil, but they can also give two-three cuts per year in conditions of increased mineral side-dressing, depending on natural water regime or irrigation.

CONCLUSIONS

Based on the results of this research on the productivity of the investigated alternative cereal grains, it can be concluded that these cereal grains differ significantly in productivity traits (grain yield and biomass yield). In both localities (degraded soil), significantly higher grain yields were achieved by growing khorasan wheat, and significantly higher biomass yields by growing rye. Fluctuations in productivity traits were affected by the interaction between year, locality and genotype. Fluctuations in grain yields were affected by different soil conditions, due to different nutrient content and the distribution of precipitation at initial stages of crop development. Rye is a crop with minimum soil requirements and it can be successfully grown in poor soil, which was confirmed by this research. The second best biomass yield was achieved by khorasan wheat and the lowest yield by quinoa. Statistically, grain yields in both localities were significantly positively correlated with biomass yield, and positively correlated with precipitation.

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