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Effects of tillage method and fertilizer type on the yield of Sudan grass (*Sorghum bicolor* L.)

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Abstract: The Sudan grass plant (*Sorghum bicolor* (L.) Moench subsp. *drummondii*) density and yield were determined in this 2-year research with different tillage systems and fertilization at 3 locations. After harvesting the main crops, 3 tillage treatments were applied: conventional (CT) mouldboard ploughing (25–30 cm deep), followed by disk harrowing and sowing: reduced tillage 1 (HDH) with 2 passes by a disk harrow (15–20 cm deep), followed by seedbed preparation, and reduced tillage 2 (LDH) with a single pass by a disk harrow. Soil penetration resistance was measured at each tillage treatment. A total of 5 side dressing fertilizer treatments were applied: the control (NO), calcium ammonium nitrate (CAN) 100 kg ha^{-1} in granular form, 60 kg ha^{-1} urea applied as foliar fertilizer (UF), 8 L ha^{-1} of foliar fertilizer Profert Mara (0.9 kg N, 0.22 kg P, 0.38 kg K, 0.24 kg Ca, 0.01 kg S, and 0.03 kg Mg) (PM1), and double rate PM1 (PM2). Significant differences ($P \geq 0.05$) among the tillage treatments were present (19.023, 18.934, and 17.489 t ha^{-1} of dry matter for CT, HDH, and LDH, respectively). The tillage treatments resulted in significant differences ($P \geq 0.05$) in the average plant density in both experimental years, with the greatest plant number with HDH (104.11 m^2) and highest soil penetration resistance value with CT (more than 2.00 MPa). All of the fertilizer treatments resulted in a higher yield than the control (14,698 kg ha^{-1}). CAN, UF, and PM1 were not different among themselves, whereas PM2 resulted in significantly higher dry matter yield. The results suggested better effects of foliar than granular fertilizers for postharvest-sown Sudan grass in the drought of 2009 or the over-wet conditions of 2010.

Key words: Fertilization, foliar plant nutrition, second crop, soil management, reduced tillage

1. Introduction

High yields in modern agriculture are achievable due to the genetic potential of crops and agrotechniques, where fertilization makes up to 50% of the crop yield. Nitrogen is one of the most important nutrients used in agricultural systems and contributes strongly to the economic performance, sustainability, and improvement of cropping systems (Delgado and Shaffer, 2008); however, nitrogen use efficiency is usually reported to be lower than 50% (Newbould, 1989) and the losses of added nitrogen fertilizers can be very significant. Today, the imperative is to continue the development, estimation, and adoption of new management practices that increase nitrogen recovery and reduce potential losses to the environment (Delgado and Shaffer, 2008). It is important to reduce environmental pollution under the specific agroecological conditions through the reduction of fertilizer requirements and nitrate levels in groundwater. Therefore, it is crucial to choose an optimal fertilization system (Sparks, 2009; Abido et al., 2017). One of the potential solutions that may contribute to reducing environmental pollution by excess nitrogen is foliar fertilizer application, since the total amount of applied nutrients is significantly lower with a higher utilization ratio (Gooding and Davies, 1992). The use of combined NPK foliar fertilizers for different crops is more common (Galić et al., 2006; Kannan, 2010), but the results have not always been positive (Haq and Mallarino, 2000), so there is a need for further research to determine their actual effectiveness. Another way to reduce nitrogen pollution is the use of summer catch crops in the period between cash crops. Summer crops can be used for food production, fodder, green manure, and biomass for producing energy (Kemp, 2011). They ensure extra profit, and contribute to the sustainability and diversification of both production and the market. Furthermore, grown as a postharvest crop, they can utilize nitrogen that remained after the main crop was harvested (Anderson et al., 1986), and thus reduce leaching and prolong the cycle of circulation of nitrogen in the soil. Summer catch crops are usually grown in unfavorable weather conditions (precipitation deficiency), in which traditional technology, including ploughing and mineral fertilizer incorporation

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in the soil, does not often result in positive effects. Sudan grass is a summer catch crop that is highly resistant to heat and drought with the potential to make nutritious forage and material for bioenergy in almost all types of soil (Rooney et al., 1987; Sani et al., 2011; Iqbal, 2015). It is a fast growing plant that is highly adaptable to different soil and climate conditions, and can penetrate compacted subsoil and help with the renovation of compacted fields (Mariguele and Silva, 2002). Many factors affect the yield of Sudan grass and an adequate tillage method and fertilization have an important role for increasing the yield (Abimiku et al., 2002). Sudan grass requires good soil fertility and, usually, when used as a summer catch crop, the addition of nitrogen from the application of nitrogen fertilizer, linearly increases its nitrogen content (Hermanson et al., 2000). In recent years, many investigations have shown the need to reduce conventional tillage systems in the production of crops (Jug, 2006; DeVuyst and Halvorson, 2004; Severiano et al., 2013; Celik et al., 2017). Tillage is one of the most expensive and demanding processes of agricultural production. Intense traffic by agricultural machinery can lead to greater soil compaction, which is one more important factor that directly and indirectly influences plant growth (Lipiec et al., 2012; Kunz et al., 2013). Soil penetration resistance, as an indicator of soil compaction, primarily depends on the soil water content and soil type. Measured values of penetration resistance have usually shown significantly higher results due to lower soil water content and higher bulk density (Costantini, 1997; Van Quang et al., 2012).

The high cost of energy points towards alternative and economically reasonable tillage methods, which can be achieved by choosing the most effective tillage system for certain agricultural conditions (Bayhan et al., 2006). Therefore, the aim of this study was to determine the effects of different tillage methods and fertilizer types on the yield of Sudan grass (*Sorghum bicolor* (L.) Moench subsp. *drummondii*) sown in postharvest cultivation under different climate and soil conditions.

2. Materials and methods

2.1. Experimental site

This research was conducted in the eastern part of Croatia, which is located in the lowlands of the southern parts of the Pannonian region (Figure 1). The mean annual temperature in the research area was 11 to 21 °C, with the

Figure 1. Location of three field experimental sites.

coldest period in January, when the minimum temperature may be below –25 °C, and the warmest period in July and August, when the maximum temperatures may exceed 40 °C. According to the spatial orientation and distribution of the research area, there was a temperature increase from the west towards the east and from the southwest to the northeast. The average amount of precipitation decreased in same direction and varied from 650 to 700 mm (Bašić et al., 2007). The field experiments were carried out at 3 different locations (Table 1) during the summers of 2009 and 2010 on soils determined according to the FAO IUSS Working Group WRB (2015).

2.2. Experimental methods

The Sudan grass, cultivar SUSU, was used in both years. The experiments were set up in a split-plot design and replicated 4 times, with 3 levels of tillage and 5 sublevels of different fertilization types, where the plot size for fertilization was 2 × 5 m. The tillage treatments were as follows: conventional tillage (CT), executed by moldboard ploughing at a depth of up to 25–30 cm, followed by 2 light disk harrow passages at 10–15 cm with a seedbed preparation cultivator, with the finest seedbed preparation and no previous crop residues on the soil surface; 1 passage with a heavy disk harrow up to 15–20 cm (HDH), followed by 2 passages of a light disk harrow and seedbed preparation cultivator, with around 30% of the soil surface covered by the previous crop's straw; and single passage by a heavy disk harrow up to 15–20 cm (LDH), followed by seedbed preparation cultivator, with coarse seedbed preparation and over 50% of the soil surface covered by the previous crop's residues. Preseeding fertilization was omitted for the postharvest-sown Sudan grass. The sowing was performed with available cereal seeders at a depth of 2–3 cm. After emergence, the number of plants in an area of 1 m^2 was counted. In 2009, seeding was performed in the first week of July, while in 2010, it was in the third week of July. The subtreatments of fertilization were as follows: no side fertilizer control (NO); 2 applications of 100 kg ha^{-1} calcium ammonium nitrate (27 kg N) in granular form (CAN); 2 applications of 60 kg ha^{-1} urea (28 kg N), applied as foliar fertilizer (UF); 2 applications of 8 L ha^{-1} of foliar fertilizer (PM1), which contained both macro (0.9 kg N, 0.22 kg P, 0.38 kg K, 0.24 kg Ca, 0.01 kg S, and 0.03 kg Mg) and micro (B, Cu, Fe, Mo, and Zn, in traces) nutrients, and a double rate of PM1 (PM2), also applied twice. Fertilization was performed 4 and 6 weeks after sowing in each year.

2.3. Soil sampling and analysis

Soil samples were collected from the experimental site at a depth of 0–30 cm and prepared for the laboratory analyses, which included methods commonly used for soil fertility control (pH_{KCl} and pH_{H2O}, plant-available P and K, soil organic matter content, hydrolytic acidity, and carbonate content). The soil samples were prepared for physiochemical analyses according to the International Organization for Standardization (ISO) 11464 procedure (ISO, 1994b). The soil pH was measured in a 1:5 (w/v) suspension of soil in H_2O and in 1 mol dm^{-3} KCl suspension, respectively, using a pH meter (inoLab-IDS Multi 9420) according to the ISO 10390 (ISO, 1994c). Ammonium lactate-acetic acid extractant, as described by Egner et al. (1960), was used for the AL P and AL K extraction, followed by spectrophotometric and flame photometric analyses, respectively. The soil organic matter content was estimated by the method prescribed by the ISO 14235 (ISO, 1998) through the determination of organic carbon (C) by sulphocromic oxidation. The hydrolytic or potential acidity of the soil was determined by the ISO 14869-2 (ISO,

Table 1. Information of the 3 field experiments sites.

	Valpovo 45°38′ N/18°23′ E	ŠirokoPolje 45°24′ N/18°28′ E	Poljanci 45°07′ N/18°11′ E
Soil	Luvisol	Luvisol	Gleysol
pH (H_2O)/KCl	5.80/4.79	5.79/4.95	5.98/6.67
Organic carbon (%)	1.55	3.26	2.20
$CaCO_3$ (%)	-	-	1.27
Hy	-	3.46	-
AL-P_2O_5 (mg 100 g^{-1})	8.6	19.6	12.3
AL-K_2O (mg 100 g^{-1})	12.59	22.63	12.99
	2009/2010	2009/2010	2009/2010
Preceding crop	Winter barley/winter wheat	Winter barley/oilseed rape	Winter barley/oilseed rape
Soil preparation	Autumn moldboard ploughing, disk harrowing, seedbed cultivator		
Fertilization	120 kg ha^{-1} N, 100 kg ha^{-1} P, 120 kg ha^{-1} K		

2002), while the carbonate content was determined by the ISO 10693 (ISO, 1995). The soil particle size distribution (Table 2) was determined using the pipette method, with sieving and sedimentation after dispersion with sodium pyrophosphate, and interpreted according to the texture triangle (Van Reeuwijk, 2002; Soil Science Division Staff, 2017). A soil cone penetrometer, with a built-in data-logger (model SN from Eikelkamp, with cone diameter 2.00 cm and 60° cone angle), was used for recording the soil penetration resistance at a depth up to 50 cm, at 25 locations per plot, 3 weeks after seeding. Parallel soil samples were taken with an auger for soil moisture determination, every 5 cm, up to 50 cm (4 samplings per plot) (Table 3). Measurement of the soil moisture content was performed using the gravimetric method (Pernar et al., 2013).

2.4. Plant sampling and analysis

Harvests were performed manually in the last week of September 2009, and the second week of October 2010. The Sudan grass aboveground biomass was collected in the full growing milky-waxy ripe stage by cutting and collecting plant material from a 1/4 m^2 frame at 4 randomly selected places in each experimental plot. Harvested Sudan grass biomass was weighted and subsampled. The plant samples were dried at 60 °C and then weighed for moisture content estimation. The statistical analysis of variance (ANOVA) of the experiment was performed using the Statistical Analysis System, v.9.2 (SAS Institute Inc., USA) statistic package. The Fisher protected least significant difference means comparisons were performed at a significance level of P = 0.05 for the year, soil tillage, side-dressings and their interactions, as well as for the soil penetration resistance among the different tillage treatments at the same depth, using the soil moisture for the given depth as a covariate component.

3. Results and discussion

The weather during both seasons is given in Table 4. The summer of 2009 was hot and dry, with severe drought (especially from July through September at the Široko Polje site) and practically all of the necessary moisture for the postharvest crop was supplied by the soil retention capacity only. On the other hand, the summer of 2010 was extremely wet, with 500 mm of rain from June to October, which caused numerous floods, not only in Croatia, but also in other European countries. A large amount of precipitation from July through August favored development of the Sudan grass, which obtained greater plant density and average yield in 2010 compared to 2009. This was similar to that reported by Sowiński and Szydelko (2011), who pointed out the importance of water supply in the period of the highest demand of Sudan grass for water. Sudan grass development and yield is strongly dependent on water availability and favorable precipitation distribution, which was also confirmed by Habyarimana et al. (2004) and Kanton et al. (2000).

Plant emergence was affected by the tillage treatments. The highest average plant number was recorded with HDH (Table 5), with the lowest soil penetration resistance (Figure 2) in the light soil (Table 2) in the mentioned year, which coincided with that of Sowiński and Szydelko (2011). Unlike that, Stipešević et al. (2010) found significantly reduced emergence of Sudan grass followed by multidisk harrowing. Soil penetration resistance was recognized as a limiting factor to the emergence of maize (Weaichet al., 1992). The highest penetration resistance was recorded with CT when compared to the reduced tillage treatments at all of the measured depths. Celik et al. (2017) found lower penetration resistant with conventional tillage when compared to reduced tillage systems. The measured soil penetration resistance showed soil compacted layers at depths of 15 and 30–35 cm for all of the tillage treatments, which was a direct consequence of disk harrowing and ploughing for many years at the same depth (Figure 2). This was previously reported by Birkás (2002), who confirmed the formation of tillage pans at depths of 12–18 cm and 25–30 cm caused by continuous disking and ploughing for many years. CT resulted in the highest soil penetration

Table 2. Distribution of the soil particles and soil texture classes of the experimental sites.

Location	Depth (cm)	Soil texture	Sand (%)	Silt (%)	Clay (%)
ŠirokoPolje	0–35	Silt loam	2.63	75.81	21.56
	35–60	Silt clay loam	1.98	69.67	28.36
Poljanci	0–43	Silt loam	2.14	25.86	72.00
	43–65	Silt clay loam	2.40	28.64	68.96
Valpovo	0–40	Silt loam	7.65	72.79	19.56
	40–78	Silt clay loam	5.30	65.69	29.02

Sand: 2–0.05 mm, Silt: 0.05–0.002 mm, Clay: <0.002 mm.

Table 3. Spatial variability of the soil moisture content (%) on a dry basis for the 3 locations (2009 and 2010).

Year	2009				2010		
Location	Depth (cm)	CT	HDH	LDH	CT	HDH	LDH
Valpovo	0–5	15.2	15.5	15.8	20.9	24.1	24.7
	5–10	15.5	15.1	15.3	21.3	23.9	24.0
	10–15	15.6	15.6	16.2	21.9	24.8	24.5
	15–20	15.6	15.8	16.5	22.2	25.2	25.7
	20–25	16.0	16.3	16.7	22.8	26.0	26.8
	25–30	16.2	16.7	16.9	23.6	26.0	27.1
	30–35	15.7	16.9	17.1	24.1	26.5	27.8
	35–40	16.9	17.0	17.3	24.7	27.3	28.0
	40–45	17.4	17.2	17.5	25.6	28.0	28.9
	45–50	17.9	17.8	18.0	26.9	28.2	29.4
ŠirokoPolje	0–5	14.1	14.6	15.9	20.7	23.8	25.1
	5–10	14.2	14.4	16.2	20.8	23.2	24.7
	10–15	14.5	15.0	16.6	22.0	24.0	24.9
	15–20	14.7	15.2	16.7	22.9	24.3	25.2
	20–25	14.9	15.9	16.9	23.1	25.0	25.9
	25–30	15.3	16.3	17.4	24.0	25.3	26.3
	30–35	15.9	16.7	17.5	24.8	26.3	26.8
	35–40	16.3	17.0	17.7	25.1	26.8	27.1
	40–45	16.8	17.9	18.0	26.0	27.7	28.9
	45–50	17.8	18.0	18.4	26.6	28.9	29.1
Poljanci	0–5	16.0	16.8	17.5	20.2	23.2	24.6
	5–10	16.1	16.6	17.3	19.9	22.8	24.1
	10–15	16.9	17.9	18.4	21.6	23.5	24.5
	15–20	17.0	18.1	18.4	22.0	24.0	24.9
	20–25	17.6	18.8	18.7	22.7	24.7	25.2
	25–30	18.0	19.3	19.0	23.4	25.0	25.9
	30–35	18.5	19.8	19.6	23.8	25.6	26.1
	35–40	19.1	20.5	20.2	24.1	26.2	26.9
	40–45	20.1	21.9	20.9	25.0	27.1	27.8
	45–50	24.0	22.8	22.6	25.3	28.4	28.9

resistance at 30–35 cm, which indicated the formation of plough pans and was related to the research of Filipović et al. (2005). LDH proved to be the most suitable regarding the soil compaction of the plough pan depth (Figure 2). In a dry year, such as 2009, when soil moisture conservation was an issue, the primary task was to minimize soil disturbance by using shallower tillage and better soil surface mulch, as the harvest residues were superior to ploughing. On the contrary, excessive water was managed better with deeper tillage in 2010, where the rhizosphere had better drainage and the soil dried faster than with shallow tillage, which was similar to the research of Jug et al. (2006) and Košutić et al. (2005). HDH showed no significant difference when compared to CT and LDH in both years; however, the Sudan grass emergence and yield response were better when compared to CT in 2009 and to LDH in 2010. Regarding the average of both years, there were no statistical differences between tillage treatments. The highest Sudan grass yield in 2009 was achieved with LDH, with significant differences when compared to CT (Table 6). Agbede and Ojeniyi (2009) found higher Sorghum yields with reduced tillage when compared

Table 4. Average monthly temperature (T) and precipitation (P) of the experimental sites in the summer.

		Jun.	Jul.	Aug.	Sep.	Oct.	
Valpovo							Mean
T (°C)	2009	19.2	23.2	22.9	19.1	11.5	19.2
	2010	20.4	23.2	21.7	15.6	9.1	18.0
P (mm)	2009	63	14	61	10	55	41
	2010	234	32	111	108	67	110
ŠirokoPolje							Mean
T (°C)	2009	18.9	22.8	22.5	19.2	18.3	20.4
	2010	19.9	22.7	21.2	15.9	15.1	19.0
P (mm)	2009	109	1	1	1	10	24
	2010	249	109	95	2	45	100
Poljanci							Mean
T (°C)	2009	18.9	22.3	22.3	18.8	11.9	18.8
	2010	20.6	22.7	21.6	15.9	9.3	18.0
P (mm)	2009	103.8	61.6	28.7	29.9	45	53.8
	2010	177	42	44	98	58	84
Average	1961–90						
	T (°C)	19.5	21.1	20.3	16.6	11.2	17.7
	P (mm)	88	65	59	45	41	59

Table 5. Plant density after emergence (m^2).

Location	Valpovo		ŠirokoPolje		Poljanci		Till (mean)	
Year	2009							
CT	80.66	b	62.00	b	74.33	b	72.33	B
HDH	88.66	a	71.66	a	82.33	a	80.88	A
LDH	78.33	b	55.66	c	59.66	c	64.55	B
Location (mean)	82.55	A	63.11	C	72.11	B		
Year	2010							
CT	97.66	b	117.66	b	90.00	a	101.77	B
HDH	104.33	a	129.33	a	78.66	b	104.11	A
LDH	89.00	c	121.00	b	73.66	c	94.55	C
Location (mean)	97.00	B	122.66	A	80.77	C		

[†]Means labeled with the same lowercase or uppercase letter for same Till in each location or Means group were not statistically different at $P < 0.05$.

to ploughing, while Abimiku et al. (2002) reported that the Sorghum yield decreased with reduced tillage. LDH resulted in the lowest Sudan grass yield (Table 6) and plant density (Table 5) in 2010, which was most likely caused by the excessive precipitation mentioned in that year. The same treatment had the lowest yield of Sudan grass for the 2 year average at the Poljanci site (Table 7). All of the above refers to important Sudan grass performance dependence on the site-specific climate and soil type, as was claimed by Agbede and Ojeniyi (2009).

All of the fertilization treatments resulted in higher Sudan grass yield in comparison with the control, which was consistent with that of Ogundare et al. (2015), who reported a significant increase in the grain yield of Sorghum

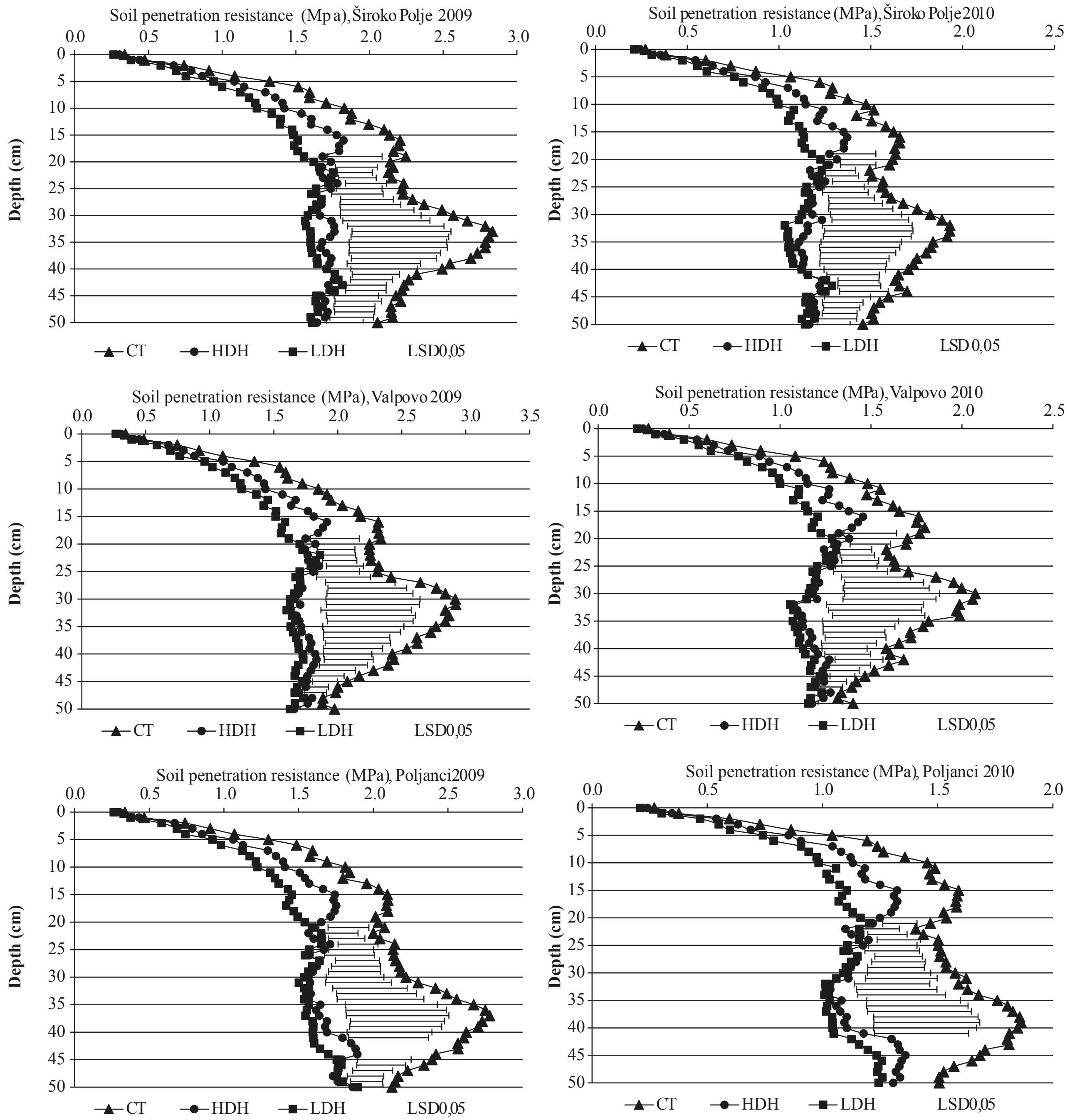

Figure 2. Soil penetration resistance (MPa), from the experimental sites (Valpovo, ŠirokoPolje, and Poljanci) in 2009 and 2010: conventional tillage based on ploughing (CT), multiple-disk harrowing (HDH), single-disk harrowing (LDH).

with the foliar application of foliar fertilizer. Regarding the control, CAN showed no significant difference in 2009, but in 2010, a difference was present (Table 6). The obtained results can be explained by the drought period in 2009 (only 13 mm of rain from July to October) (Table 4). Such weather conditions led to the low breakdown of the CAN granules and resulted in the poor uptake of nitrogen via the root system of Sudan grass from the granular fertilizer.

Foliar fertilization led to a higher Sudan grass yield when compared to the control and CAN. This can be explained by insufficient nutrient supply via the roots caused by a lack of water in the soil where the foliar fertilization was more effective when compared to the soil fertilizer application, which was also confirmed by HU et al. (2008). On average, CAN, UF, and PM1 resulted in insignificant differences among themselves, while PM2 showed the highest average

Table 6. Average yield (kg ha^{-1}) of the Sudan grass in 2009 and 2010.

	NO	CAN	UF	PM1	PM2	Till (mean)
			Year 2009			
CT	4808 a	5558 a	6673 a	6897 a	7333 a	6254 B
HDH	6040 a	6453 a	6866 a	6891 a	8880 a	7011 AB
LDH	5986 a	6359 a	8171 a	7180 a	8451 a	7229 A
Fert (mean)	5611 B	6123 B	7237 AB	6965 AB	8222 A	
			Year 2010			
CT	26062 a	31577 a	32978 a	31626 a	36720 ab	31793 A
HDH	20912 a	28810 a	33096 a	32121 a	39345 a	30857 A
LDH	24380 a	27916 a	28697 a	28014 a	29739 b	27749 B
Fert (mean)	23784 B	29434 AB	31590 AB	30587 AB	35268 A	
			Means			
CT	15435 a	18568 a	19829 a	19262 a	22027 a	19023 A
HDH	13476 a	17632 a	19981 a	19470 a	24113 a	18934 A
LDH	15183 a	17138 a	18434 a	17597 a	19095 a	17489 B
Fert (mean)	14698 B	17779 AB	19414 AB	18776 AB	21745 A	

[†]Means labeled with the same lowercase or uppercase letter for same Till and Fert or Till × Fert average in each year or Means group are not statistically different at P < 0.05.

Table 7. Average yield (kg ha^{-1}) of the Sudan grass for the 3 locations.

	NO	KAN	UF	PM1	PM2	Till (mean)
			Valpovo			
CT	15368 a	18126 a	19478 a	18996 a	21757 a	18745 A
HDH	13468 a	17697 a	20104 a	19555 a	24068 a	18978 A
LDH	15037 a	17247 a	18436 a	17662 a	19201 a	17517 B
Fert (mean)	14624 B	17690 AB	19339 AB	18373 AB	21675 A	
Široko Polje						
CT	16563 a	19733 a	21168 a	20560 a	23671 a	20339 A
HDH	14458 a	18779 a	21381 a	20775 a	25838 a	20246 A
LDH	16359 a	18288 a	19703 a	18818 a	20407 a	18715 B
Fert (mean)	15793 B	18933 AB	20751 AB	20051 AB	23305 A	
			Poljanci			
CT	14375 a	17373 a	18629 a	17998 ab	20443 a	17764 A
HDH	12504 a	16422 a	18461 a	18083 a	22433 a	17581 A
LDH	14155 a	15880 a	17164 a	16312 b	17678 a	16238 B
Fert (mean)	13678 B	16558 AB	18085 AB	17464 AB	20185 A	

[†]Means labeled with the same lowercase or uppercase letter for same Till and Fert or Till × Fert average in each location or Means group are not statistically different at P < 0.05.

Sudan grass yield, with significant differences regarding the control and CAN. The results were confirmed by Ogundare et al. (2015), who recorded the highest yield of Sorghum by spraying with a double dose of foliar fertilizer, which was similar to that reported by Kolota and Osinska (2002).

4. Conclusion

The present study of the effects of tillage and different fertilization systems on postharvest-sown Sudan grass in northeastern Croatia suggested an effective application of foliar fertilizers in relation to granular fertilizers for postharvest-sown Sudan grass, both in drought, or excessively wet conditions. The highest yield of Sudan grass was obtained with the reduced tillage system as a result of minimum soil disturbance with the lowest dosage of nitrogen under various environmental conditions. In order to more effectively overcome extreme weather conditions, the results indicated that the reduced tillage treatments (HDH and, especially, LDH) used for postharvest-sown Sudan grass establishment should cover good soil moisture retention capability for drought as well as reasonable percolation of excess water below the Sudan grass rhizosphere for the avoidance of water logging. At the same time, HDH and LDH resulted in lower tillage penetration resistance.

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