Original scientific paper

Alterations of maize grain yield in function of tillage and fertilization regimes in rain-fed cropping

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Abstract

Maize is one of the most important crops in the world. Successful production depends primarily on meteorological, but also on other environmental factors. The aim of this study was to define the most efficient tillage system (no-till, reduced or conventional tillage) and amount of fertilizer (Ø, 330 or 660 kg ha^{-1} of N:P:K) for high maize yield (FAO 700 maturity group) under rain-fed conditions, according to results of a long-term maize cropping experiment (1991-2010) under climate change. The present variations in the meteorological conditions induced variations in the achieved maize grain yield, indicating positive and significant dependence of all three tillage systems and fertilization regimes on amount of precipitation. Conventional tillage could diminish negative impact of meteorological factors, particularly of temperature to some extent, while the higher fertilizer inputs could increase grain yield to some level, but they are highly dependable on meteorological factors, particularly temperature. Environmental impact emphasized 330 kg ha^{-1} of N:P:K as expedient fertilization regime in reduced tillage, as well as 660 kg ha^{-1} of N:P:K in conventional tillage, as best suited practices to unfavourable environmental conditions.

Key words: maize cropping, fertilization, tillage, yield prediction

Introduction

Maize is one of the most important crops in the world. Successful production depends primarily on meteorological, but also on other environmental factors. It was found that climate change increase the disparities in cereal production between developed and developing countries (Rosenzweig and Parry, 1994) due to vulnerability of extensive technologies in developing countries (reduced fertilizer inputs and application of irrigation) to the potential impact of global warming. This could be a crucial point in some integrating systems of agricultural development, such as sustainable development of the agro-food industry (Adzic and Birovljev, 2011). According to Schlenker et al. (2002), the economic effect of climate change on agriculture requires different assessment for dryland areas, where climate change is equivalent to an exogenous shift in the fixed input associated with new supplies.

Rain-fed cropping is still the most abundant practice in the world. Variations in cropping practices, which include different measures, enable environmental factors to be overcome, especially during periods of extreme weather conditions. Different studies concerning variations in cropping measures (tillage practices, fertilization amounts and rates) indicated that under rain-fed conditions on chernozem, conventional tillage is the best practice to lower energy inputs and increase maize yield (Videnović et al., 2011). Moreover, increased amounts of fertilizer could compensate yield deprivations arising from reducing some tillage operations (Tolimir et al., 2001). According to forecasting models, some inputs could be defined as necessary, while some others have no real effect on grain yield. Mechanistic models based on systems of nonlinear differential equations can help in providing a quantitative understanding of complex physical or biological phenomena (Schlenker et al., 2002; Igesias et al., 2011). Forecasting in the variability of a complex environment could be improved by non-linear models, such as the Weibull analysis (Kress and Miller, 1985a, 1985b).

The aim of this study was to define the most efficient tillage system (no-till, reduced or conventional tillage) and amount of fertilizer (Ø, 330 or 660 kg ha^{-1} of N:P:K) for high maize yield (maize hybrid of FAO 700 maturity group) under rain-fed conditions, according to results of a long-term maize cropping experiment (1991-2010) under conditions of climate change.

Material and methods

The research was conducted in Zemun Polje (44°52'N 20°20'E), in the vicinity of Belgrade, on a slightly calcareous chernozem, within an ongoing long-term experiment, analyzing a 20-year period (1999-2010) in rain-fed conditions. The field experiment was arranged in a split-plot design with 4 replications. An elementary plot was 19.6 m^2 (2.8×7 m) with a plant density of 64,935 plants/ha. Maize hybrid ZPSC 704 was sown with a four row planter for direct maize sowing (John Deere 7200 Max Emerge II), between the 20th and 25th of April every year, depending on the weather conditions.

The effects of three tillage systems were investigated: no-tillage (NT), reduced tillage (RT) and conventional tillage (CT). In the NT treatment, sowing was performed without preceding soil tillage. In the RT treatment, tillage was performed with a rotavator in the autumn (10–12 cm deep). The CT treatment consisted of shallow ploughing (15 cm deep) immediately after wheat harvesting, autumn ploughing (25 cm deep) and seedbed preparation with Rau-combi (composed of a harrow, cultivator and rollers). The fertilizer treatments included: control - without fertilization (Ø), incorporation of 330 kg ha^{-1} of N:P:K (F1) and 660 kg ha^{-1} of N:P:K (F2). The fertilizers were spread on the soil surface in the autumn.

Statistical analysis included regression analysis for the meteorological data, as well as for dependence of grain yield on meteorological conditions (sum of precipitations and mean temperature during vegetative period, April-September).

Differences between applied treatments in grain yield were presented with Weibull analysis (Dodson, 2006):

$$F(x) = 1 - e^{-\left[\frac{x}{\alpha}\right]^{\beta}}, \text{ for } x > 0$$

where β is a shape parameter and α is a measure of the scale (characteristic life), which were used for the calculation of the survival probability, to predict a parameter reaching a reliability of 0.10, 0.25, 0.50, 0.75 and 0.99.

Meteorological conditions

The observed 20 year period was characterized by increasing trends of both, sum of precipitation and the average temperature (Figure 1), but only temperature had significant increase in function of time.

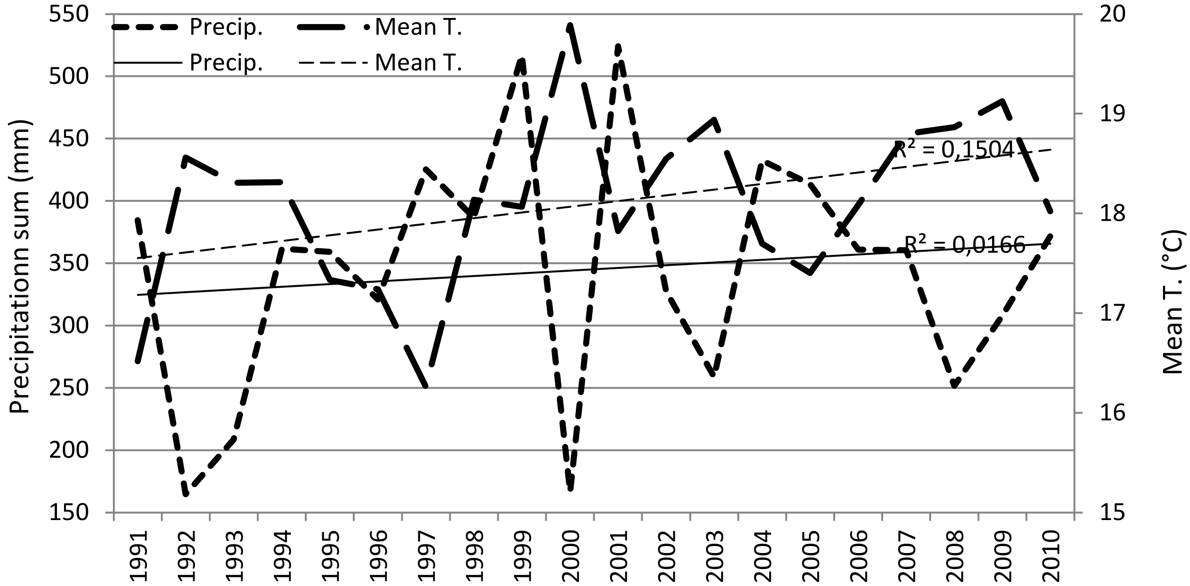

Figure 1. Precipitation sum and mean temperature during the examined period of 1991-2010

Regarding the sum of precipitation in the vegetative period, years 1992, 2000, 2003 and 2008 were unfavourable with ≤ 250 mm. The same years, together with 2002 and 2007 were also characterised with high average temperatures (≥ 18.5 °C), which were highlighted during 2000. Periods with lower temperature extremes were present during 1991, 1997-1999 and 2005, as well as high precipitation amount was present during 1999 and 2001.

Results and Discussion

Present variations of meteorological conditions induced variations of maize grain yield (Figures 2 and 3), which averaged 3.0-11.6 t ha^{-1} in no-till, 5.1-12.5 t ha^{-1} in reduced tillage and 7.5-13.9 t ha^{-1} in conventional tillage treatments; 5.1-11.5 t ha^{-1} in control, 6.2-12.5 t ha^{-1} in F1 and 6.5-13.7 t ha^{-1} in F2 treatments.

Regression function between grain yield and amount of precipitation (Figure 2) indicated positive and significant dependence of all three tillage systems on amount of precipitation (particularly in no-till, R^2 = 0.411), as well as positive and significant dependence of applied fertilization regimes on amount of precipitation (particularly F1, R^2 = 0.312).

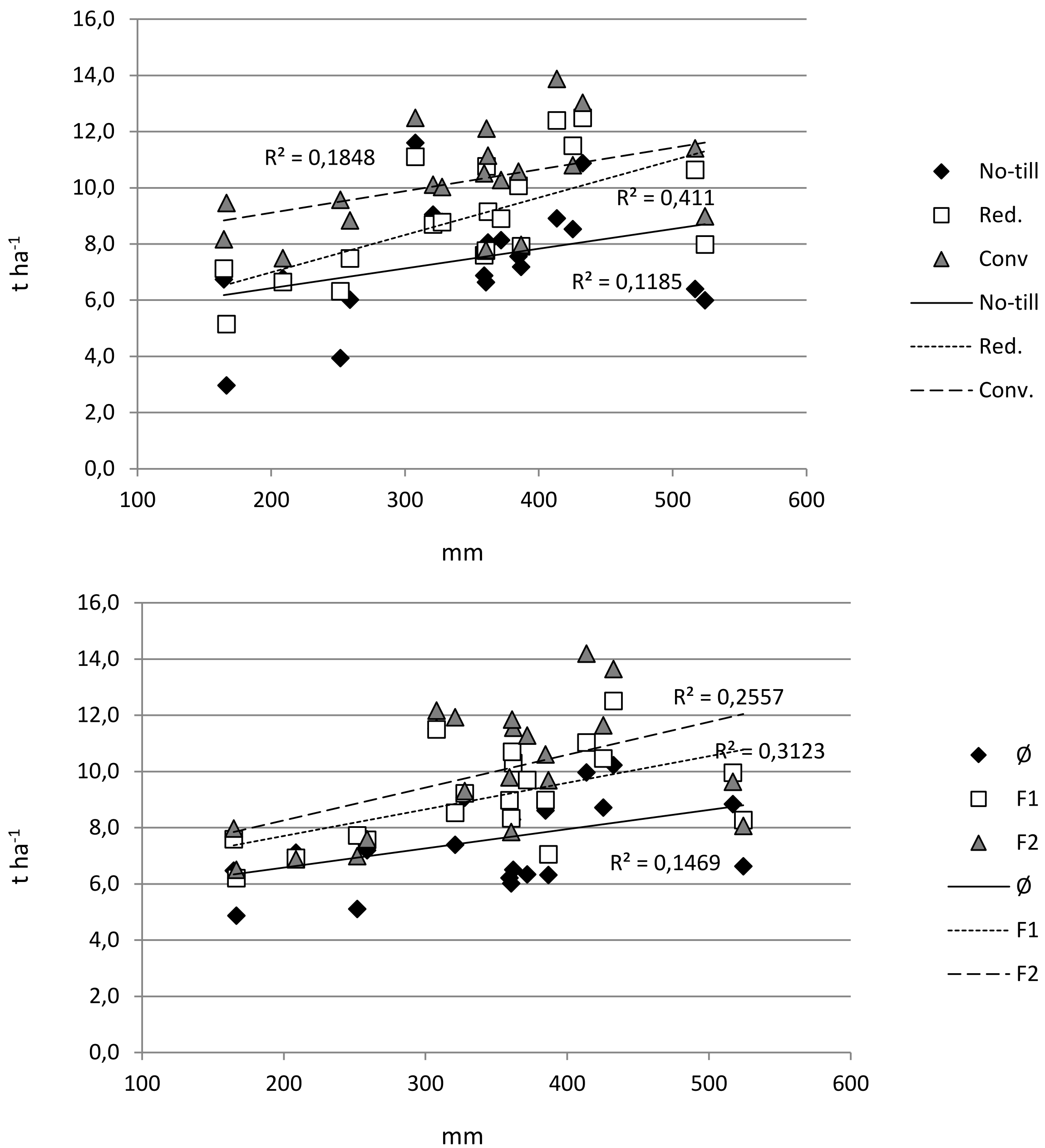

Figure 2. Dependence of average maize grain yield on precipitation in different tillage systems (no-till, reduced and conventional tillage) and fertilization levels (Ø, T1 - 330 kg ha^{-1} of N:P:K, T2 - 660 kg ha^{-1} of N:P:K)

On the other hand, the regression function between grain yield and mean temperature during vegetation (Figure 3) pointed to negative and significant dependence of no-till and reduced tillage on mean temperature (R^2 = 0.152 and R^2 = 0.306, respectively), as well as negative and significant dependence of F1 and F2 on mean temperature (R^2 = 0.151 and R^2 = 0.301, respectively). Observed results are in accordance with results of Schlenker et al. (2002) who underlined economic effect of climate change and importance of different cropping measures on agriculture production for dryland areas, which could contribute to yield increase in extreme meteorological conditions.

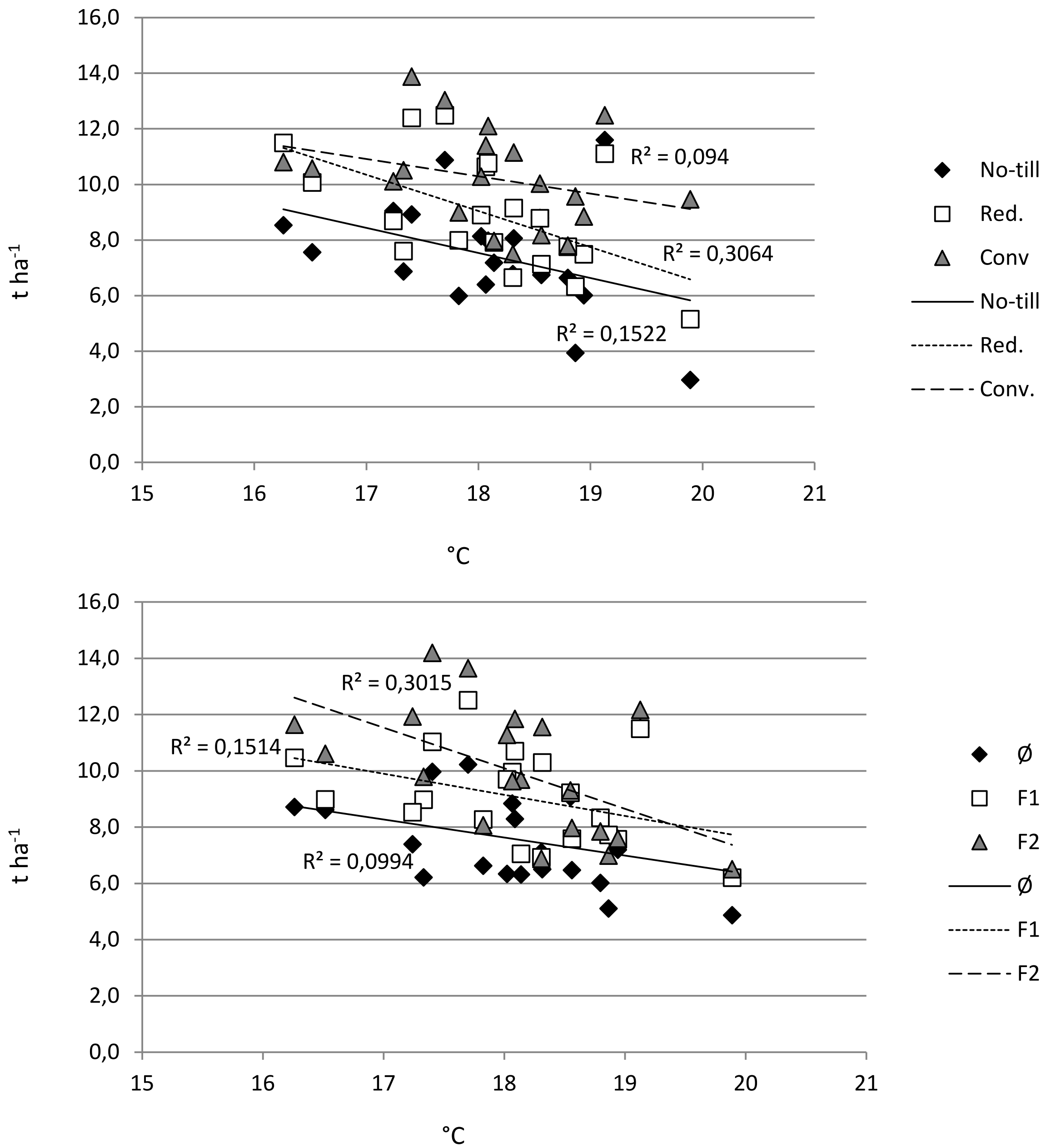

Figure 3. Dependence of average maize grain yield on mean temperature in different tillage systems (no-till, reduced and conventional tillage) and fertilization levels (Ø, T1 - 330 kg ha^{-1} of N:P:K, T2 - 660 kg ha^{-1} of N:P:K)

Aikins et al. (2012) and Gwenzi et al. (2008) indicated that ploughing and other tillage practices that conserves soil moisture could increase maize productivity in significant. That could be one of the reasons why temperature variations (as limiting factor for maize yield) insignificantly affects achieved yield under conventional tillage.

Prediction of grain yield depends on genotype and includes tolerance to many stress factors, including amount of precipitation and temperature, which also reflects to plant development. In this 20-year period, variations in meteorological factors induced variations in grain yield of examined maize hybrid. If a reliability of 0.10 is considered as the level with lowest environmental impact (sum of precipitation and temperature) and 0.99 as the reliability level with the highest environmental impact (Table 1), it could be assumed that the highest average variations between reliability of 0.10 and 099 were obtained in conventional tillage (2.33 t ha^{-1}), as well as in F1 fertilization regime (2.32 t ha^{-1}), irrespective to the fact that maximal variation did not exceed 2.46 t ha^{-1} (conventional tillage without fertilization).

At reliability level of 0.10, the potentially highest yield in the control could be achieved with conventional tillage. With the increase of environment impact (reliability level over 0.50), application of fertilizers induced yield increases, indicating that F1 had the highest impact in treatments with no-till and reduced tillage and F2 in treatment with conventional tillage. Videnović et al. (1986) and Tolimir et al. (2001) also found that increased amounts of fertilizer could compensate the yield deprivations caused by reduction in tillage intensity.

Table 1. Prediction of maize grain yield (t ha^{-1}) for different reliability levels (according to Weibull analysis), with three levels of fertilization and three tillage systems

Tillage	No-till			Reduced			Conventional		
Fertilization level	Ø	F1	F2	Ø	F1	F2	Ø	F1	F2
0.10	3.04	4.75	3.48	3.48	5.65	4.70	5.86	6.04	5.99
0.25	2.82	4.46	3.31	3.28	5.38	4.49	5.57	5.77	5.74
0.50	2.54	4.10	3.09	3.02	5.02	4.21	5.20	5.43	5.41
0.75	2.23	3.68	2.83	2.72	4.61	3.88	4.76	5.02	5.02
0.99	1.36	2.44	2.03	1.82	3.31	2.84	3.40	3.74	3.77

Greater environmental impact (increase in reliability levels) decreased differences between fertilization levels in treatment with reduced tillage, indicating that increased inputs of fertilizers could be unfounded practice during unfavourable meteorological conditions. The same tillage practice had the highest difference between fertilization levels among all three tillage practices. The lowest differences between applied fertilization levels in conventional tillage highlighted it as practice which enables better utilization of present conditions that could increase yields. In parallel, Videnović et al. (2011) also revealed the benefits of conventional tillage under rain-fed conditions, irrespective of the level of applied fertilizer.

Conclusions

According to the obtained results, it could be concluded that in rain-fed cropping conventional tillage could diminish impact of meteorological factors to some extent, while the higher fertilizer inputs could increase grain yield up to some level, but they are highly dependable on meteorological factors, particularly temperature. Environmental impact emphasized F1 as expedient fertilization regime in systems with reduced tillage, as well as F2 as expedient regime in combination with conventional tillage, which enables better utilization of present conditions that could increase yields.

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