MAIZE GRAIN YIELD IN ANIMAL-POWERED FARMING AS AFFECTED BY SOIL FERTILIZATION VARIANT: RESULTS FROM THE 2023 SEASON IN NORTH-EAST CROATIA

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Ranko Gantner[1], Igor DelVechio[2], Zvonimir Steiner[3], Bishal K. Sitaula[4], Krešimir Bošnjak[5], Vesna Gantner[6]

Abstract

The objective of this study was to investigate maize grain productivity in a low-input farming system as affected by the variant of soil fertilization. All the agrotechnical operations in this field research were powered solely by draft horses and by the use of traditional horse-drawn implements (plow, tine-harrow, seeding machine and inter-row cultivator), except the modern horse-drawn roller-cutter made for green-manures and cover crops management prior to establishment of cash crops, and a small reconstructed (halved) disc-harrow (initally made for a small tractor). Tested soil fertilization variants were: Zero fertilization, horse farmyard manure application (FYM), green manuring with crimson clover (Trifolium incarnatum L.) (GMC), FYM + GMC, and full dose mineral NPK fertilization. Maize grain yields in this research were lower than in previous field trials in the north-east Croatia, most likely because of later seeding term, but not due to source of powering. The highest yielding was NPK variant (7.60 t/ha) which was significantly higher than the lowest Zero variant (2.01 t/ha). FYM (6.67 t/ha), FYM+GMC (6.24 t/ha) and GMC (4.60 t/ha) were intermedium but not significantly different from the NPK.

Key words: *maize, yield, soil fertilization, animal power, sustainability.*

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Introduction

Modern crop farming is characterized by using powerful diesel-powered tractors with implements that have raised the human work efficiency to the levels never seen before. Slow but continuous growth of crops yields is achieved thanks to the broad use of agrochemicals (mineral fertilizers and pesticides). Though, the sustainability of current intensive practices is questionable due to several major issues: excessive soil compaction induced by heavy machinery (Hamza and Anderson, 2005), soil structure and microbiome degradation due to excessive use of mineral fertilizers and lack of organic fertilizers (Singh et al., 2020), reliance on exhaustive fossil energy resources for powering the farm operations (Gantner et al., 2014) and fertilizers production (Lal, 2004) associated with adverse effect to climate, and excessive emissions of toxic compounds from the pesticides applications and consequential loss of biodiversity (Demeneix, 2020) in broad areas of arable countryside, as well as negative impacts to human health. With aim to mitigate these negative consequences of modern intensive farming there advented some more sustainable options in last few decades, like ecological farming, organic farming, integrated farming, conservation farming, precision farming, regenerative farming and low-input farming. Currently the low-input farming option appears to receives the least attention and is mainly unknown to the general public and even to the majority of farmers. According to Poux (2007), low input farming systems should be considered as a core option for Europe. Low input farming systems seek to optimize the management and use of on-farm resources and to minimize the use of production inputs as off-farm resources, such as purchased fossil fuels, chemical fertilizers, and pesticides (Parr et al., 1990; cit. Poux, 2007). Thereafter low-input farming systems have the potential to fit into organic farming regulations. The main advantages of low input farming systems over the high input ones are the potentially higher efficiency at the farm level, reduction of pollution risks and beneficial effects to biodiversity and landscape (Poux, 2007). According to Garré (2022), the inclusion of work horses in sustainable transitions, can help increase the farm autonomy and sustainability of European smallholdings. Since the animal-drawn agronomy relies on the on-farm produced fodder as a source of clean and carbon-neutral bioenergy (Gantner et al., 2014), it perfectly fits into concepts of low-input farming and circular economy as well.

Aim of this research is to test the maize grain productivity in a low-input farming system as affected by the variant of soil fertilization. Maize crop is chosen for the study since maize is the most important crop in Croatia (about third of Croatian arable area is occupied by it).

Material and Methods

The field trial was set up near Požega town in the Slavonia province, the north-east part of Croatia. At the trial site the terrain was slightly sloped and generally well drained. Forecrop was spring oats harvested in July 2022. After the oats harvest, the soil was plowed shallowly (about 10 cm in depth) by traditional single-bottom horse plow with bottom width of 0.25 m. Before commencing the operations for the trial, the soil was levelled by tine harrowing with a traditional horse-drawn tine-harrow.

Basic parcel area was 42 m^2 (= 4.2 m × 10 m) and consisted of 6 maize rows with interrow distance of 0.7 m and length of 10 m. In the trial there were tested 5 variants of soil fertilization, each with specific sequence of agrotechnical operations (Table 1). All variants were repeated in two replications (in two basic parcels), spatially randomized in a complete random block arrangement.

Table 1. Tested variants of soil fertilization with specific sequences of agrotechnical measures

Trial variant	Soil fertilization	Agrotechnical operations
# 1	No fertilization (ZERO)	Autumn plowing (2022), spring plowing (2023), discing, tine-harrowing, seeding, inter-row cultivation, hand harvesting
# 2	Farmyard manure (FYM)	Everything like in #1, but horse farmyard manure was added by broadcasting before autumn plowing, 24 t/ha (170 kg/ha of N, 53 kg/ha P_2O_5, 119 kg/ha K_2O)
# 3	Green manuring with crimson clover (GMC)	Crimson clover wass hand-seeded in August 26th 2022 (20 kg/ha), covered by soil by tine-harrowing, and plowed-under in spring 2023. Than followed operations like in #1
# 4	Farmyard manure + crimson-clover cover crop (FYM+GMC)	Everything like in #2, but after plowing-under the FYM, the soil was harrowed and crimson clover seeded in September 24th 2022 (20 kg/ha), and covered with soil by tine-harrowing. Than followed operations like in #1
# 5	Mineral fertilization (NPK)	Everything like in #1, but 567 kg/ha of PK 20:30 + 369 kg/ha of urea 46%N were spread before spring discing (170 kg/ha of N, 113 kg/ha P_2O_5, 170 kg/ha K_2O)

Soil quality (texture and chemical properties) was analysed upon sampling the layer of top 30 cm before commencing the trial. Soil was appraised as a silty loam (Table 2), whilst the chemical traits indicated medium acidic soil with good levels of plant available P and K, and medium humus content.

Table 2. Soil texture and chemical parameters of soil fertility at the trial site before commencing the trial (average sample of the top 30 cm layer)

Particle class (and dimension)	Coarse sand (2 to 0.2 mm)	Fine sand (0.2 to 0.063 mm)	Coarse silt (0.063 to 0.02 mm)	Fine silt (0.02 to 0.002 mm)	Clay (< 0.002 mm)
Fraction (weight %)	1.82	7.37	43.96	30.18	16.67
Soil texture appraisal based on weight fractions of particle classes is silty loam.					
Chemical parameter	pH (H_2O)	pH (KCl)	Humus (%)	AL-P_2O_5 (mg/100 g of soil)	AL-K_2O (mg/100 g of soil)
Value	5.30	4.15	2.48	21.21	22.12

Nitrogen fertilization was limited to 170 kg/ha of N, according to the Nitrate directive by the Croatian authority. In the NPK variant, nitrogen was given in the form of granulated urea (369 kg/ha of urea 46 %), together with 113 kg/ha of P_2O_5 plus 170 kg of K_2O in the form of granulated PK 20:30 (567 kg/ha PK 20:30). Mineral fertilizers were hand-spread before discing operation. In the variants with FYM there were added 24 t/ha (2.4 kg/m^2) of FYM, also to adhere to the Nitrate directive. FYM was about 6 months old and content of plant nutrition minerals (Table 3) was analysed at the agrochemical laboratory of the Faculty of agrobiotechnical sciences Osijek. Nutrients content was similar to average of Croatian farming operations (Cvjetković et al., 2014). FYM was broadcasted by hand fork prior to the autumnal plowing with traditional front-wheeled single-bottom horse-drawn plow with furrow width of 25 cm. Plowing depth in autumn was about 15 cm.

Table 2. Characteristics of the farmyard manure (FYM) collected from horses and used after about 6 months of deposition (fermentation)

pH (1:5 v/v)	Dry matter content (%)	Total carbon in fresh-weight (%)	Total nitrogen in fresh-weight (%)	Total P (P_2O_5) in freshweight (%)	Total K (K_2O) in freshweight (%)
8.39	48.5	8.821	0.721	0.221	0.497

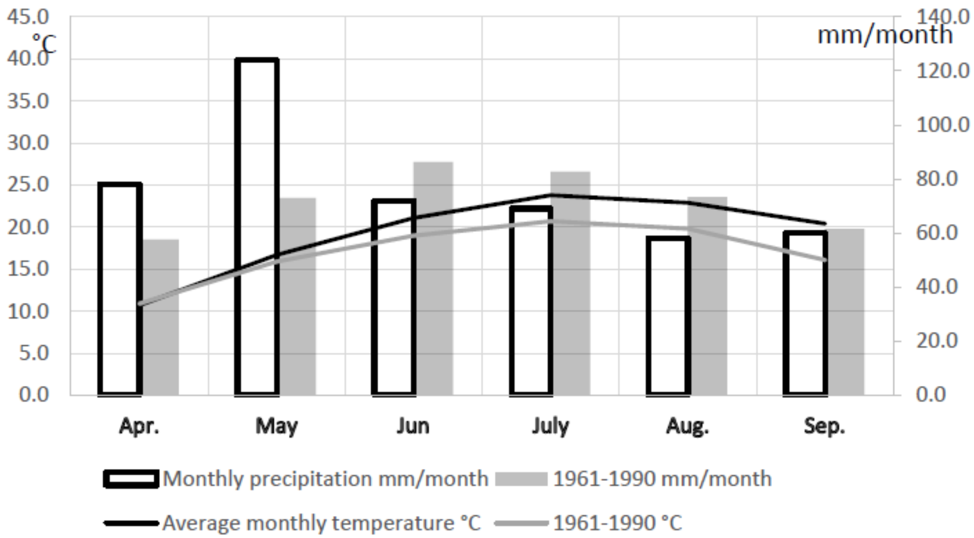
Despite the seeding term was intended for the beginning of May 2023, seedbed preparation and seeding were postponed to mid of June due to extraordinary excessive and frequent rains during the spring 2023. Previous winter was extraordinary mild so the volunteering spring oats survived the winter and produced a considerable oats herbage growth, thus acting as a cover crop on every trial variant. In order to enable the required operations, the oats herbage was chopped by a modern horse-drawn roller-cutter (“Rolcut V” of the Italian manufacturer Equi Idea of Verona) few days before plowing. Plowing with traditional front-wheeled single-bottom horse-drawn plow to depth of about 10 cm was done on June 14th 2023. Subsequent discing was done the next day by using small disc-harrow containing two gangs, each with five discs, of total working width of 1.5 m. Tine-harrowing was done immediately after disc-harrowing with the traditional tine-harrow composed of three wings, with total working width of 1.8 m. Seeding was done also on June 15th 2023, with traditional mechanical two-row seeding machine at the interrow distance of 0.7 m. The established crop stand was denser than recommended for the seeded maize hybrid (8/m^2) because there was no feature to adjust the seeding machine. Seeded hybrid was Bc-344 (FAO 300 of the Bc-Institute, Croatian plant breeding and seed company). When maize plants were about 20 cm tall inter-row cultivation was performed with a traditional horse-drawn single-row inter-row cultivator. There was no additional weeding done. Harvest was done on October 16th 2023 by hand-picking of maize ears from the two inner rows of each basic parcel, and solely from the mid two meters, thus the harvested area per each plot was 2 m × 1.4 m = 2.8 m^2. Ears were weighed and separated into kernels and cobs which were weighed again to get the freshweights. Subsamples of harvested kernels and cobs were air-dried for two weeks and then oven-dried at 70°C for 4 hours in order to get the dry-weights. Based on the ratio of dryweight/freshweight there were calculated dry matter content and moisture at harvest for each variant and replication. Dry kernel yields were recalculated to yields of standard quality kernel (14 % of moisture) in tons per hectare (t/ha). Statistics were calculated by using MS-Excel (arithmetic averages, analysis of variance and LSD for comparison of means).

All the draft power for doing the agrotechnical operations in this research was from two mares of the Croatian heavy draft horse breed. They were harnessed with traditional leather harnesses and hitched to the traditional implements (plow, disc-harrow, tine-harrow, seeding machine and inter-row cultivator).

Results and discussion

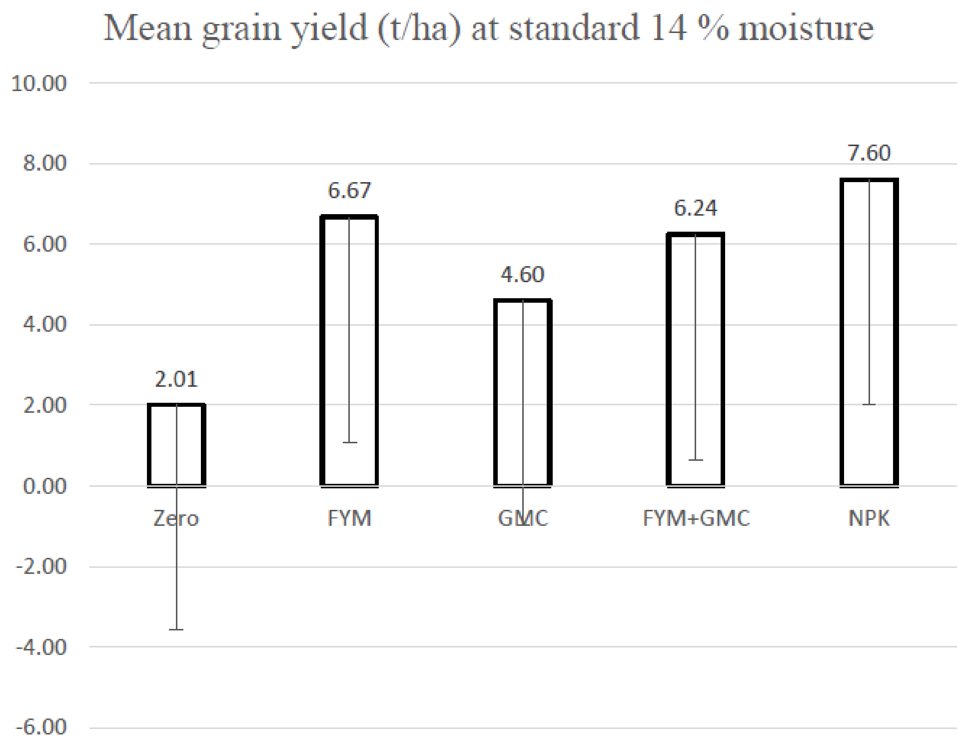
Considering the weather during the maize vegetation in north-east Croatia (DHMZ, 2023), it was about 3°C warmer than in the reference 30-year period (1961-1990) recorded at the nearest meteorological station in Slavonski Brod (Figure 1), with excessive precipitation in April and May and lack of rainfall from July till the September indicating droughty conditions.

Figure 1. Weather conditions during the spring and summer 2023, period that was critical for maize crop development, along with the 30-year reference period average.



Results of the field experiment showed that only NPK variant significantly (α=0.95) outyielded the Zero control variant (Figure 2). However, grain yields of organic fertilization variants didn't differ significantly from the NPK variant which was the highest yielding. Average yields of tested variants varied between 2.01 (Zero fertilization) and 7.60 t/ha (NPK fertilization), and were much lower than yields in the previous research of Ambrušec et al. (2021) in north-east Croatia, who also obtained the lowest yield in zero fertilization (about 5 t/ha) and highest yields in NPK fertilization (11 and 14 t/ha on lower- and higher-quality soil). Generally lower yields in this trial can be attributed to the much later seeding term in this research (mid-June 2023) than in Ambrušec et al. (2021) research (May 2019). Among the organic fertilization variants in this trial, green manuring (GMC) appeared inferior to NPK as well as to the farmyard manure (FYM) variant. Similarly, in the previous research in north-east Croatia (Ambrušec et al., 2021), maize grain yield on lower-quality soil was significantly lower upon green manuring with crimson clover than upon full NPK variant (8 vs. 11 t/ha), but only slightly lower at higher-quality soil (13 vs. 14 t/ha). Yields in this research were also lower than in previous Marković et al. (2017) research in north-east Croatia, probably also because of late seeding term in this trial. Poor performance of GMC variant in this trial was the consequence of poor overwintering of crimson clover. Namely, crimson clover plants were overdeveloped (too tall and too lush) due to unusually long, warm and moist autumn, and they come to rotting at arrival of cooler winter temperatures. Better overwintering was at the FYM + GMC variant due to later seeding term of crimson clover.

Figure 2. Average grain yields of each tested variant (columns), recalculated to the standard moisture content of 14 %. LSD(α=0.95) is presented as vertical bar, and equals to 5.58 t/ha.



Average maize grain moisture varied among tested variants (Table 3) and the respective cob yield associated to the grain yield. Cob/grain ratio of about 0.16 was similar to the ration in previous research of Marković et al. (2017) near Osijek in their Zero fertilization variant where they obtained average maize grain yield of only 5.7 t/ha despite the maize was seeded much earlier, in beginning of May 2010 and 2013. Cob/grain ratio in their NPK variants was about 0.11 thus indicating the high share of grain in the total ears yield.

Table 3. Average maize grain moisture content (%) and ratio of cobb/grain dry matter yield

Fertilization variant	Zero	FYM	GMC	FYM+GMC	NPK
Grain moisture content (%)	32.9	24.3	22.8	31.2	25.7
Ratio cob/grain yield	0.18	0.16	0.19	0.16	0.16

Obtained maize grain yields in this solely animal-powered agronomy were quite satisfactory (NPK variant 7.6 t/ha) when the very late seeding term (mid-June) is regarded, thus supporting the thesis that considering the yield, this way of powering the farming operations is not inferior to tractorized one. Completely low-input farming variants FYM and FYM + GMC (with no chemical inputs) have shown about 16 % lower yields (6.67 and 6.24 t/ha) than the NPK variant thus indicating either slight inferiority of organic soil fertilization when compared to NPK, or the need for greater doses of FYM, or the need for application of FYM timely closer to the maize crop establishment (prior to the spring plowing). However, expected losses of plant nutrients from autumn applied FYM are minimal due to very quick establishment of volunteering oats that acted as a winter cover/catch crop. There might be beneficially to rethink the annual nitrogen limit of 170 kg/ha from the farmyard manures since not all nutrients comprised in FYM are readily available, i.e. there is always a fraction of organically-bound nutrients that require time to be released for plant nutrition (Eghball et al., 2002), unless the FYM is applied every year in the rate of 170 kg/ha, thus forming the stock of organic nitrogen in soil for the sufficient crop nutrition in a long run. The inter-row cultivation, efficiently controlled the weeds in the inter-row space in this trial since there was no perennial weeds in the field and almost no weed emergence after the operation. The most abundant weed was annual grass *Setaria viridis* L. which virtually did no harm to the maize crop.

Animal-powered and human-handled operations in this trial required a lot of physical effort. Human operators were much more tyred than when driving a tractor. Work efficiency was much smaller than it would be if the operations were done by tractor with implements. These realizations could lead to the reluctance of completely animal-powered farming despite the many advantages it offers (as mentioned in the Introduction chapter). If the low-input farming is to be a significant contributor to the sustainable development of agriculture and societies, along with other more sustainable farming options, there would be needed personal inner transformation of farmers and potential new farmers to accept such labor-intensive farming (Gantner et al., 2023). In line with this are the findings of Woiwode et al. (2021) who stated that, besides the technological solutions, inner transformation would be required for system change towards sustainability. In this context, the inner transformation relates to consciousness, mindsets, values, worldviews, beliefs, spirituality and human–nature connectedness. Research should be continued with addition of tractorized agronomy as a control variant, and the economics should be investigated too.

Conclusion

Maize grain yields in this research were lower than in previous field trials in the north-east Croatia, most likely because of later seeding term, but not due to source of powering. There sims that completely animal-powered agronomy can give maize grain yields competitive to the fully tractorized agronomy. However, FYM and FYM + GMC organic soil fertilization variants have given slightly (insignificantly) lower yields than the NPK variant thus indicating the need for improvement of their application (either application of FYM timely closer to the maize crop establishment or increase of FYM rate since not all nutrients from the FYM are readily available, i.e. there is always a fraction of organically-bound nutrients). Solely animal-powered operations were associated with extraordinary physical efforts of human operators and low work efficiency, which could cause the reluctance to this way of farming. Personal inner transformation might improve the acceptance of such the way.

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