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Macronutrient Applications and Irrigation Regimes Impact Weed Dynamics and Weed Seedbank Augmentation in *Solanum melongena* L. Fields

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Abstract: Weeds are a major yield-limiting factor bedeviling eggplant (*Solanum melongena* L.) production in Russia. This study aimed to determine the influence of macronutrient rates and drip irrigation regimes on weed flora composition and potential soil contamination by weed seedbanks in the eggplant field. Three field experiments were conducted during the 2019–2021 cropping calendar. Two-factorial field experiments were designed in four blocks whereby the composition of weed flora in eggplants was examined under the influence of different macronutrient rates (40 tons manure and $N_{140}P_{30}$, 40 tons manure and $N_{320}P_{120}K_{210}$, and control without fertilization), and three thresholds of pre-irrigation soil moisture % least moisture capacity (LMC) (in particular, 70, 80 and 90% LMC). The results demonstrated that nutrient rates contributed to a significant increase in weed density of 27.1 to 37.6%, due to an increase in the number of annual weeds (annual winter weeds and annual early spring weeds), and an increase in soil moisture threshold from 70 to 90%. Nevertheless, low moisture availability between the rows as a result of drip irrigation utilization led to a decrease in weed populations by 10.8 to 15.9%. Potential contamination of the arable soil layer with weed seed was desirably decreased, ranging from 19.8 to 21.7% with the application of fertilizers, compared with the control. Furthermore, the soil weed seedbank was considerably reduced by an increase in the pre-irrigation threshold of soil moisture.

Keywords: macronutrient; irrigation; species composition of weeds; weed seedbank; eggplant

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1. Introduction

Vegetable production occupies a place of eminent importance in Russia's agricultural sector. Eggplant (*Solanum melongena* L.) [1] is an important vegetable crop grown globally. As eggplant can be harvested and sold weekly, it plays an important role in the livelihood of farmers [1]. Currently, because of higher market prices and increasing per capita consumption, vegetable production has grown in leaps and bounds in Russia, especially during the off-season. Hence, vegetable cultivation poses a lucrative enterprise for farmers. Due to the continuous monoculture of vegetable crops and intensified production off-season, high pressure from plant diseases and weeds has caused significant crop losses, particularly by weeds [2,3]. To date, few papers have been published concerning weed management approaches in eggplant fields. Weeds are a biological component of all farmland ecosystems. Weed species, numbers, and biomass have vital roles in maintaining the diversity of ecosystems. Therefore, high weed density can give weeds a competitive edge against crops for water, nutrients, and light [4]. According to the Russian Agricultural Academy (www.ras.ru), crop losses due to weed infestation in the Russian Federation are reported as 40 million tons annually [5].

Nutrient and irrigation regimes can alter the ecological succession in the weed community by directly changing the soil nutrient conditions, and affecting yield and yield components of the crops [6,7]. Reducing weed competitive ability in cropping systems through modified fertilizer application practices and irrigation regimes might enable effective weed control [4]. Water deficit is a major yield-limiting factor in crop production across various regions [8]. Accordingly, understanding the crop response to different environmental stresses forms the basis of enhanced crop water-use efficiency (WUE) for better yield, even under drought stress conditions [9].

Weed management is one of the most important farming practices for improving crop yield and yield components, and can be successful based on a systematic approach. Weed control is indispensable in crop production due to the negative impact weeds have on the balance of nutrients, physical and biological indicators of soil fertility, water–air ratio, and other agrocenosis regimes. Reducing the adverse effects of chemicals in the environment, such as contamination of water sources [10], and focusing on improving various factors for properly utilizing nutrients in farming systems, is vital. Thus, the efficacy of agricultural fertilization on weed–crop competition can be relevant to integrated weed control practices and fertility–water management [11]. Fertilization efficacy on weed–crop competition can vary regarding the timing, placement, concentrations, and source of nutrients. According to Little et al. [12] and Dudkin and Dudkina [13], banded application or deep placement significantly diminishes weed populations compared with broadcasting. These findings were deduced from various studies in which banded or deep applications of inorganic or organic fertilizer were preferable to broadcast applications for weed management purposes [14,15].

Numerous weed species in farming systems are more responsive to fertilizers than main crops [12,16]. Increasing nutrition rates may enhance the competitive ability of weeds, potentially decreasing the positive effects of nutrients in crops [14,17]. For this reason, fertilization methods (rate, source, placement, and timing of nutrients supplied) should ensure that crops have more access to nutrients than weeds [18,19]. Both the weed and the crop have a direct efficacy on the resources available in their immediate environment and unique responses to the quantity of resources available within that environment [20]. However, evidence of weed competition with crops for resources such as soil nitrogen and phosphorous [21] must include documentation of nitrogen depletion associated with weeds and the dependence of crop growth on nitrogen availability [22,23].

More recently, Little et al. [12] investigated the efficacy of both water and fertilizer availability on weed–crop competition, and described that the effects of fertilizer rate on weed–crop competition, weed growth, and yield are extremely variable. Nitrogen application can stimulate seed germination and the emergence of numerous weed species, such as false chamomile (*Matricaria perforata*) [24,25], redroot pigweed (*Amaranthus retroflexus*) [26], and common lambsquarters (*Chenopodium album*) [26]. The efficacy of nitrogen addition on seed germination can also be related to the maternal environment of the seed [26]. Moreover, nutrient conditions in the environment can affect weed seedling growth after germination through effects on seed resources [12].

The relationship between nutrient availability and crop yield is associated with direct fertility effects and indirect effects mediated by weed–crop competition changes. Smirnov et al. [27] stated that the negative correlations between fertilization and crop yield might be attributed to the enhanced competitive ability of weed populations. The interaction of weeds–fertilizers–water is a complex topic that needs further comprehensive study [12]. The risk of enhanced weed competition with crops reflects that weed populations may be highly responsive to nitrogen, phosphorus, and potassium in agricultural systems [12,28]. The objective of our study was to evaluate the effectiveness of fertility management at different composition and field rates, and also different thresholds of pre-irrigation soil moisture on weed infestation and weed seedbank augmentation in eggplant (*Solanum melonagena* L.) cultivation in Daghestan, southern Russia.

2. Materials and Methods

2.1. Experimental Site Description

The study was carried out in temperate semi-arid climatic conditions. The meteorological data showed average precipitation, humidity, and temperature range in the experimental field. In June, the temperatures increased to a range of 25.1–30.2 °C; in July, 30.5–34.4 °C, and in August, 31.1–33.5 °C. Precipitation was 17.7–25.7 mm (June), 12.2–32.5 mm (July), and 19.0–35.5 mm (August) (Meteorological Organization of Dagestan State, Russia, https://www.meteorf.gov.ru) (accessed on 28 September 2022). Although precipitation was low, it was relatively evenly distributed throughout the year, with more precipitation in the hot season (hottest months of the year). Three field experiments were conducted at the educational and experimental farm of the Dagestan State Agrarian University (40°55′ N, 46°28′ E, and 139 m altitude) during 2019–2021. Soil samples, i.e., 35 cm deep soil cores, were collected randomly in the field from each replication plot before transplanting eggplant seedlings. The soil samples were dried at 60 °C and analyzed using standard methods by Clemson University Agricultural Service Laboratory (Clemson, SC, U.S.A.). The soil of the experimental field was classified as loamy sand (fine loamy), with a pH of 7.1 and organic matter of 1.9%.

2.2. Design of Experiments

Two-factor field experiments were designed whereby the composition of weed species phytocenosis and population characteristics in eggplants were observed under the influence of different macronutrient rates including 40 tons manure and $N_{140}P_{30}$, 40 tons manure and $N_{320}P_{120}K_{210}$, and control without fertilization, and thresholds of pre-irrigation soil moisture '% least moisture capacity (LMC)' of 70, 80 and 90% LMC. The experimental design used for the field experiments was a randomized complete block design (RCBD) of four blocks with in-row spacing of 60 cm and 80 cm inter-row spacing. Each year, thirty-day-old seedlings of eggplant 'Almaz,' a widely grown cultivar in Daghestan, raised in 60-celled polystyrol trays, were transplanted in the field in single rows at the beginning of April.

Field and laboratory observations were carried out according to the generally accepted standard methods proposed by Kuriata et al. [1].

Drip irrigation was used to supply water to the crop, and CJSC Musharaka (Republic of Dagestan) drip tubes were used. Irrigation took place in the evenings at around sunset. The distance between the emitters was 30 cm with a water drip rate of 2 L/h. Irrigation was carried out based on the evapotranspiration rates prevailing in each experimental year and the different levels of LMC (70, 80, and 90%), namely, about 15–21, 24–32 and 52–66 times, with the norm of 219 m^3 ha^{-1}, 146 m^3 ha^{-1} and 73 m^3 ha^{-1} for the threshold of 70%, 80% and 90% LMC, respectively.

2.3. Least Moisture Capacity % (LMC)

Initially, using the 'flooded area method,' we determined the LMC of loamy sand (in the percentage of arid soil). The method was based on the rationale that the soil was saturated with water when all the pores were filled, and the excess moisture was allowed to drain under gravity. The established equilibrium moisture corresponded to the LMC. A site size of 2 m^2 was selected to determine the slightest moisture capacity. A protective border was created, enveloped with a double ring of compacted earth rollers 25–30 cm high. Using the envelope method with a soil drill, soil samples were taken at 5 points of the site from a depth of 10 cm to 1 m, for moisture estimation. After six hours of drying, the soil moisture was determined, which characterized the pre-irrigation threshold of soil moisture or LMC.

Depending on different experimental treatments, the LMC at 70, 80, and 90% was maintained. The onset of the pre-irrigation threshold of soil moisture was controlled by the tensiometric method using a TR-46908 tensiometer–hygrometer (www.terraagro.ru) (accessed on 14 October 2021).

2.4. Soil Seed Bank Sampling

Weed seed assessment was performed after each experiment. In each experiment, 36 reference points were fixed using a 3 × 7 m grid, with 7-point samples in each experimental plot. This method of sampling was applied for the whole three years of experiments. In each sample, two soil cores (7 cm diameter and 15 cm depth) with a soil bulk density ranging from 1.4 to 1.6 g cm^{-3}, were taken from each plot using parallel grids; these grids divided each plot to systematically distribute the sampling locations. Therefore, 108 soil samples per year were conducted in each trial for three years.

Soil from the same layer of each plot was pooled and mixed thoroughly to form composite samples. The soil samples were air-dried and pulverized. Three sub-samples were taken from each of the three layers, with each subsample being the gross weight of the whole sample. Each subsample was put into a small bag made of nylon mesh (pore diameter of 0.1 mm) and washed with tap water to remove the soil. The residue containing the weed seeds was air-dried and sieved through increasingly finer meshes (20-, 40-, 60-, 80-, 100-, 120-mesh sizes). The residue from each sifting was placed into Petri dishes and tested under a binocular microscope (maximum magnification of ×400) for weed seed identification.

Viable seeds were assessed by applying slight pressure with fingers [26]. The total number of viable seeds in each subsample was determined, and seed density was expressed as the number of seeds per square meter based on the surface area of the cores and the weight of the whole sample.

2.5. Weed Sampling

Analysis of the weed species composition at the beginning of the study before treatment was performed. Weed suppression was considered at 20 and 40 days after planting in all experiments. Weed populations were randomly chosen from two sampling areas (2 rows by 1 m) based on the method of the European Weed Research Society (EWRS) (https://www.ewrs.org) (accessed on 9 May 2019) in each experimental plot. Weed density per m^2 in these areas was determined each year at 20 and 40 days after planting. In addition, all annual and perennial weed seed samples were dried at 60 °C in the oven for dry weight (biomass) assessment.

2.6. Data Analysis

Due to normality and constant variance, all the collected data were examined before analysis was performed. SAS version 9.2 (SAS Institute Inc., Cary, NC, USA) was used to analyze data from all three field studies, using the mixed procedure with replication as the random factor. Each year was analyzed individually. The least-squares mean statement in SAS, with Tukey's post-hoc at $p = 0.05$, was used for means comparison. Data from the different sampling dates, including weed density, weed dry weight, and weed seed numbers, were analyzed using repeated measures. There was significant interaction between the year and experimental treatments.

3. Results and Discussion

Weed management in vegetable crops remains challenging in Russia due to long-term monoculture cultivation systems, intensive off-season farming, and a lack of integrated weed control tools. The determination of the weed phytocenosis indicated that the most common annuals were *Amaranthus retroflexus* [26], *Chenopodium album* [26], *Abutilon teophrasti* [19], *Portulaca oleracea* [21], *Setaria viridis* [23], *Echinochloa crus-galli* [23], and *Tripleurospermum inodorum* [19]. Perennials consisted of *Convolvulus arvensis* [24], *Equisetum* *arvense* [26], and *Cirsium arvense* [4]. In total, 23 various weed species were observed in eggplant fields, and annual dicotyledons were the most dominant species. Of the perennial weeds, *Equisetum arvense* and *Cirsium arvense* [4] were the most dominant.

The majority of the weed species were annuals (65.2%), of which late spring, early spring, and winter annuals accounted for 34%, 17.4%, and 13.0%, respectively. The species composition of dominant perennial weeds in the agro-phytocenosis of eggplants was represented by different biological groups as simple perennials and creeping perennials with values of 7.8% and 5.3%, respectively. According to the weed biology data pooled from the eggplant field, monocotyledons comprised 26.1% and dicotyledons 73.9% during experiments. Data analysis revealed that the eggplant field was heavily infested (68 weeds m^2) with various weed species. In tandem, similar results on weed investigation in eggplant cultivations were released by Pohl et al. [29].

Weed community investigation at the beginning of the study showed a difference in the species composition of weeds (Figure 1).

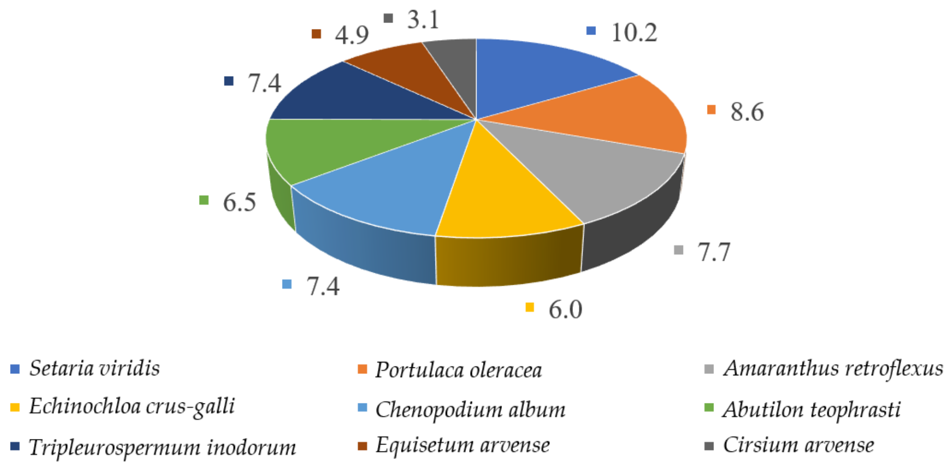

Figure 1. Floral composition of weeds (%) at the beginning of the study.

It is known that the use of fertilizers leads not only to an increase in crop yield [30,31] viz. eggplant yield [32,33] but also a change in the species composition of weeds and their harmfulness due to the enhanced development of those species that use nutrients better [34,35].

Twenty days after transplanting seedlings, the results showed that weed populations in the eggplant field significantly increased by 23.7 and 32.5% with the application of 40 tons manure and $N_{140}P_{30}$, and 40 tons manure and $N_{320}P_{120}K_{210}$, respectively. An increase in weed density is associated with an increase in the number of annual weeds by 35.2–47.7% and a decrease in the number of perennials. On the other hand, the results obtained from the experiments also indicated a significant reduction in total weed populations of 9.2–12.2% as an increase in the threshold of pre-irrigation soil moisture from 70 to 90% LMC with non-fertilization treatment 20 days after transplanting seedlings (Table 1). At the same time, the number of annual weeds also diminished by 8.3% to 10.1%, and perennial weeds by 18.4–34.2% (Table 1). These findings were consistent with those of Sokolov et al. [36] and Voronov et al. [37]. We deduced that maintaining a moisture threshold of 70% LMC at an irrigation rate of 219 m^3. ha^{-1} was almost two times higher than the duration of irrigating eggplants when applying an irrigation rate of 73 m^3. ha^{-1} (90% LMC). Weed dry biomass increased, ranging from 89.3 to 109.4 g m^2 due to improvements in soil nutrition and irrigation regime. Jiang et al. [4] stated that proper fertilizer management can improve crop competitiveness, thus, decreasing weed density and altering the species composition of the weed community.

Table 1. The number of weeds in the eggplant crop depending on the rates of mineral fertilizers and the levels of pre-irrigation moisture of the soil.

Fertilizer Rates (Kg ha^{-1}) NPK	Pre-Irrigation Threshold of Soil Moisture (% Least Moisture Capacity) (LMC)	Weed Density (Number m^{-2})			Total Weed Dry Weight (g m^{-2})
		Total	Annuals	Perennials	
20 days after planting					
Control 'Nontreated'	70 80 90	73.2 e 66.4 f 63.7 fg	62.4 d 56.8 e 55.6 e	10.8 a 9.6 ab 8.1 bc	74.5 d 68.3 de 66.7 e
40 tons manure and $N_{140}P_{30}$	70 80 90	90.8 b 82.3 c 79.0 d	84.3 b 77.2 c 74.8 c	6.5 d 5.1 e 4.2 f	101.1 a 91.8 b 89.3 bc
40 tons manure and $N_{320}P_{120}K_{210}$	70 80 90	96.5 a 87.7 bc 85.9 bc	91.1 a 83.9 b 83.2 b	5.4 e 3.8 f 2.7 g	109.4 a 101.2 a 99.7 ab
LSD_{05}		3.8	3.1	2.6 g	4.4
40 days after planting					
Control 'Nontreated'	70 80 90	59.3 d 53.4 e 49.8 f	50.1 d 45.8 e 43.3 e	9.2 a 7.6 b 6.5 c	42.1 cd 38.4 d 36.3 e
40 tons manure and $N_{140}P_{30}$	70 80 90	76.3 b 66.8 cd 63.6 cd	70.2 ab 62.4 c 60.1 c	6.1 c 4.4 d 3.5 e	58.7 b 52.1 bc 49.6 c
40 tons manure and $N_{320}P_{120}K_{210}$	70 80 90	81.2 a 73.5 bc 69.1 c	76.3 a 69.8 b 66.4 bc	4.9 d 3.7 e 2.7 f	65.0 a 59.5 b 56.7 b
LSD_{05}		3.3	1.9	5.3	2.4

Means followed by different letters are significantly different by Tukey-adjusted means comparisons at $p \leq 0.05$.

Determination of the number of weeds 40 days after transplantation of seedlings (before the reproduction stage) showed that weed populations in the eggplant field were favorably enhanced by the application of 40 tons manure and $N_{140}P_{30}$, and 40 tons manure and $N_{320}P_{120}K_{210}$, compared with the control plots. The highest annual weed number (76.3/m^2), total weed density (81.2/m^2) and dry weight (65 g/m^2) were attained with the application of 40 tons manure and $N_{320}P_{120}K_{210}$, and 70% LMC. On the other hand, the population of perennial weeds 6.1/m^2 increased with 40 tons manure and $N_{140}P_{30}$, and 70% LMC. On the other hand, perennial weed populations were significantly reduced (2.7 number/m^2) by the application of 40 tons manure and $N_{320}P_{120}K_{210}$, and increasing the pre-irrigation moisture threshold to 90% LMC (Table 1).

Studies have proposed a set of multiple regression dependencies that allow prediction, with a high degree of reliability, of the growth and development of weeds based on water supply and soil nutrient availability. Dependence includes the determination of a set of indicators that characterize the weed infestation of the eggplant crop under irrigation conditions. The general form of dependencies is represented by a regression equation herein provided [38]:

$$N1, N21, M = a + \frac{b}{I_{NPK}} + \frac{c}{W} + \frac{d}{(I_{NPK})^2} + \frac{e}{W^2} + \frac{f}{I_{NPK} \cdot W}$$

where $N1, N2, M$, respectively, denote the number of annual weeds on the 20th day of the growing season of the crop/m^2; $N1$, the number of perennial weeds/m^2; $N2$, the total weed dry weight on the 20th day of the growing season of the crop, g/m^2; W, the threshold of pre-irrigated soil moisture in the zone of soil moisture during drip irrigation, LMC %; I_{NPK}, the collective dimensionless index of soil nutrient provision; and a, b, c, d, e, f, the empirical coefficients determined by the method of multiple regression analysis (Table 2).

Table 2. Parameters of the regression equation for forecasting weed growth depending on water supply and soil nutrient availability.

Measured Traits	**Variables**						**R2**
	a	***b***	***c***	***d***	***e***	***f***	
Annual weeds N1 (plant m^{-2})	178	891	−18,548	−23,760	845,040	−11,163	0.97
perennial weeds N2 (plant m^{-2})	−7.56	−182	1266	5280	−17,640	−313	0.93
Total dry weed mass M (g m^{-2})	206	1012	−20,940	−26,760	970,200	−18,684	0.95

The index I_{NPK} is determined by the ratio of the total available amount of nitrogen, phosphorus, and potassium contained in the soil or introduced with fertilizers to the standard of removal for the production of 1 ton of crop biomass, relative to which the calculation is:

$$I_N = \frac{\sum N}{N_{RATE}},\ I_P = \frac{\sum P}{P_{RATE}} I_K = \frac{\sum K}{K_{RATE}}$$

where, $\sum N, \sum P, \sum K,$ respectively, designate available forms of nitrogen, phosphorus, and potassium contained in the soil and applied fertilizers, kg/ha; and $N_{RATE},\ P_{RATE},\ K_{RATE}$ are, respectively, the standards for the removal of elements nitrogen, phosphorus, and potassium with the yield of the calculated crop, kg/t. Calculations were carried out relative to the eggplant crop.

The generalized index is taken to be numerically equal to the lowest value of $I_{NPK} I_N I_P I_K$ as for the yield-limiting nutrient element.

Graphs exhibiting dependencies on the abundance of annual and perennial weeds, and total weed dry weight, are presented in Figure 2. In addition to the general patterns of development of processes depending on the conditions of water supply and the availability of nutrients in the soil, the graphs highlight the areas of influence of factors, the thresholds of saturation of factors, and the areas of optimal and most unfavorable combinations of factors. In particular, the pattern of increasing total weed dry weight coupled with the increase in the provision of soil nutrients through the use of manure and mineral fertilizers was well traced. Moreover, the enhancement of weed biomass could be attributed to an increase in annual weeds, since the shape of the graphs was maximally correlated. On the contrary, the number of perennial weeds reduced with an increase in the generalized index of soil nutrient availability. Appropriate fertilizer application methods help crop producers to control weed populations by increasing the competitive ability of crops [4,39,40]. Hence, the application of mineral fertilizers can significantly affect weed–crop competition in farming systems [41,42].

In weed populations with strong growth responses to soil nutrition, addition of fertilizer can enhance competitiveness relative to crops [12]. Blackshaw and Brandt [14] reported that weed competitiveness against wheat significantly increased by increasing rates of phosphorus. On the other hand, the competitiveness of less phosphorus-responsive weed species *Bassia scoparia* and *Lolium persicum* diminished by the increasing field rates of phosphorus [14]. In some cases, weeds that are strong competitors for nutrient and water uptake might significantly interfere with crops when nutrients are limited. Santos et al. [43] reported that interference of common purslane (*Portulaca oleracea*) decreased lettuce shoot biomass by more than 80% at a phosphorus rate of 0 g L^{-1} soil and 70% at 0.8 g L^{-1} soil.

The joint solution of the proposed dependencies allows us to find areas of mutual influence of factors that ensure minimal development of weeds, thus, taking into account changes in the phytosanitary situation with an improvement in irrigation and mineral nutrition conditions, and also optimize farming techniques to suppress weeds.

Our three-year studies of the species composition of weeds did not show changes under the influence of the investigated rates of mineral fertilizers, apparently due to the short period of their use. At the same time, the floral composition of weedy phytocenosis under the influence of fertilizers altered somewhat (Figures 3 and 4).

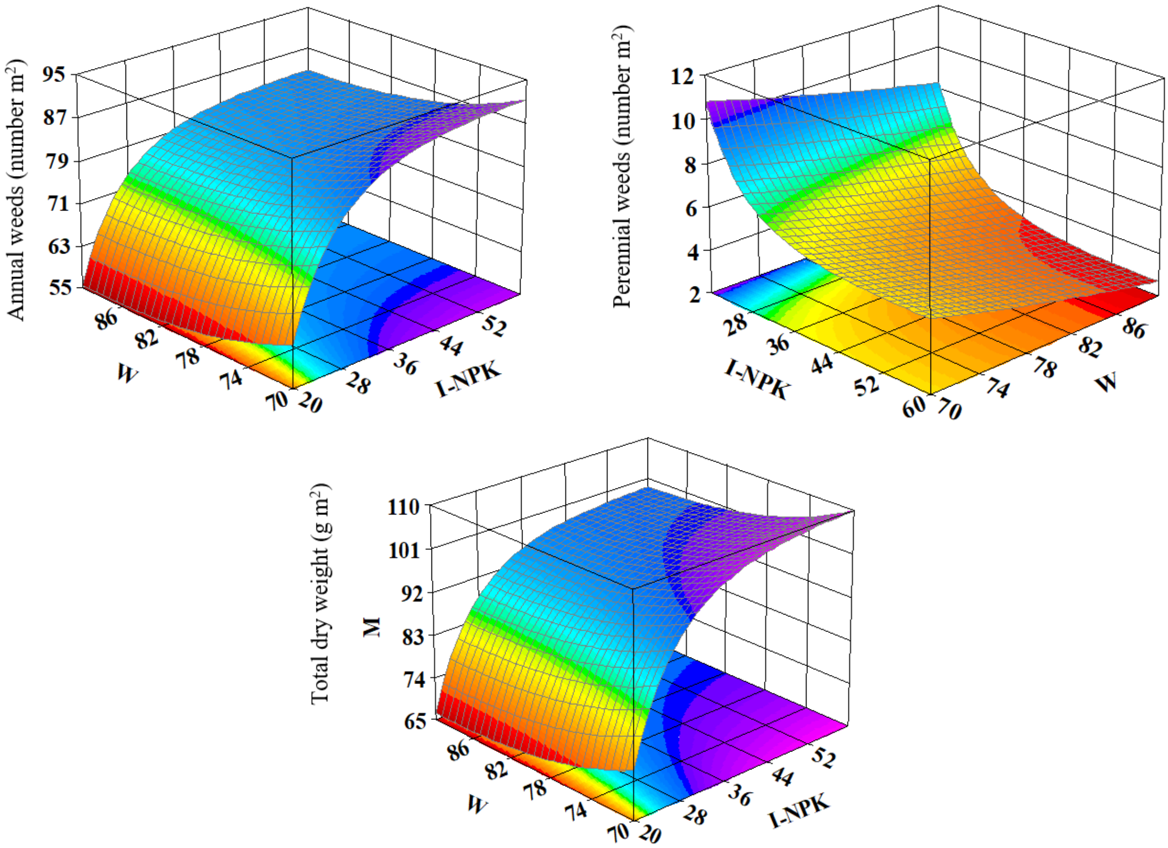

Figure 2. Distribution of annual and perennial weeds, and total dry weight, depending on water supply conditions (W) and soil nutrient availability.

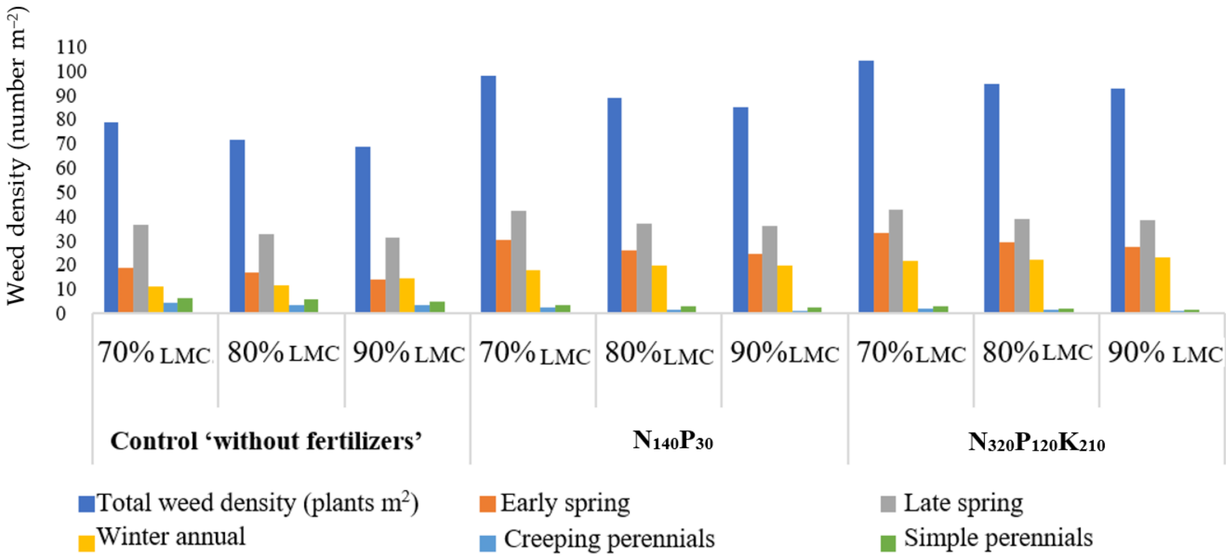

Figure 3. Weed dynamic affected by different treatments 20 days after planting.

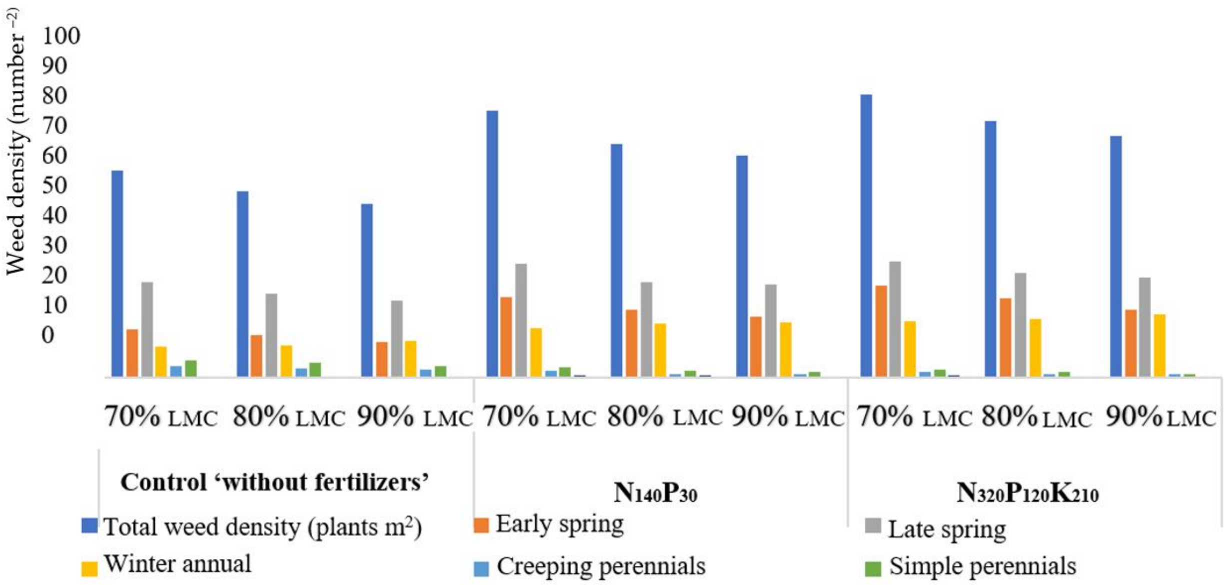

Figure 4. Weed dynamic affected by different treatments 40 days after planting.

Despite an increase in the total weed number of 23.9%, the population of late spring weeds decreased, and in contrast, the number of winter annual weeds increased from 17.2% to 21.3% with the use of 40 tons manure and $N_{140}P_{30}$ at 20 days after transplanting eggplants. The number of perennial weeds generally diminished by applying fertilizers, such that the population of creeping weeds and simple weeds were reduced by 5.2 and 7.2%, respectively, compared with the control.

An increase in the rates of $N_{320}P_{120}K_{210}$ mineral fertilizers applied contributed to a further reduction in the proportion of late spring annuals, early spring annuals, and winter annual weeds. On average, compared with the control, the number of early spring and winter weeds increased by 8.1 and 5.3%, respectively, due to a reduction in the density of late spring weeds. Appropriate fertilizer application approaches play an important role in weed management systems [44], however, mentioned approaches may also enhance control complexity and do not eliminate nutrient uptake by weeds [19]. Hence, species-specific information about the effect of fertilization on weed–crop competition can assist farmers in developing fertilization practices and weed control approaches tailored to their operations.

Changes in pre-irrigation soil moisture thresholds also impacted the relationship between biological groups of weed phytocenosis. By increasing the antecedent moisture threshold from 70 to 90% LMC, the number of early spring weeds diminished, ranging from 26.9% to 29.4, whilst winter annual weed density increased from 18.3% to 23.5%, and the population of late spring weeds remained constant. For perennial weeds, there was a tendency of reduced weed density associated with an increase in the threshold of pre-irrigation soil moisture (Figure 3).

Weed suppression assessment 40 days after transplanting seedlings under the influence of fertilizer application and thresholds of pre-irrigated soil moisture revealed no changes in the ratio between different weed groups. The patterns noted in the previous observation period recurred. At the same time, a study of the floral composition of weedy phytocenosis showed an increase in the relationship between the biological groups. The patterns noted in the previous observation period persisted. At the same time, the study of the floral composition of weeds showed an increase in the relationship between the weed groups.

The study of weed seed banks at the beginning and end of the growing season in the arable layer showed that fertilizer rates and pre-irrigation thresholds of soil moisture affected potential weed seed banks in different ways.

An analysis of the data presented in Table 3 showed that by increasing fertilizer rates, the weed seeds in the soil decreased, ranging from 19.8 to 21.7%, compared with the nontreated plots. The most significant reduction in the weed seedbank was obtained with the application of 40 t manure and $N_{140}P_{30}$, and 40 t manure and $N_{320}P_{120}K_{210}$, where weeds decreased at a value of 193–197 million seeds ha^{-1} with antecedent moisture of 70% as the least moisture capacity. Data analysis processing by dispersion computation confirmed the reliability of differences in the number of weed seeds depending on the crop-forming factors studied.

Table 3. Investigation of soil weed seedbank depending on the combination of fertilizers and pre-irrigation soil moisture levels.

Fertilizer Rates ($Kg\ ha^{-1}$) NPK	Pre-Irrigation Soil Moisture Threshold (% Least Moisture Capacity) (LMC)	Million Seeds ha^{-1}		Compared to Control	
		Beginning of Growing Season	End of the Growing Season	Million Seeds ha^{-1}	%
Control 'Nontreated'	70	264	212	-	-
	80	261	231	−33	−12.5
	90	265	240	−24	−9.1
40 tons manure $N_{140}P_{30}$	70	259	197	−67	−25.4
	80	266	215	−49	−18.6
	90	263	222	−42	−15.9
40 tons manure $N_{320}P_{120}K_{210}$	70	262	193	−71	−26.9
	80	258	211	−53	−20.1
	90	260	215	−49	−18.6
LSD_{05}		16	13		
Coefficient of variation (%)		11.34	4.49		

The transition from antecedent moisture threshold of 70% LMC to focal moisture LMC led to a decrease in weed seedbank by an average of 14.1%, while at the control plots, weed seedbank reduced by 23.3%. The least reduction in the weed seedbank in the arable layer was attained at 240 million seeds ha^{-1} or 9.1% with a combination of 90% LMC and non-fertilization treatment.

Eggplant yield. Data analysis indicated that there was significant interaction between fertilizer application and LMC. In all cases, fertilizer application led to an increase in the eggplant yield at all levels of LMC. All treatments significantly ($p < 0.05$) increased eggplant yield, ranging from 32.5 to 44.1 tons per hectare in comparison with the control, showing a low coefficient of variation (3.9 to 9.1%).

The yield increase caused by the application of $N_{140}P_{30}$ under the irrigation regimes 70–90% LCM ranged from 10.4 to 15.8 t ha^{-1}, and for $N_{320}P_{120}K_{210}$ under the irrigation regimes 70–90% LCM ranged from 18.7–22 t ha^{-1}, respectively. At all levels of LMC, the application of different macronutrients led to the attainment of desirable yields, with yield increases ranging from 47 to 99.5%, compared with the nontreated control.

The best eggplant yield of 44.1 t ha^{-1} was attained with the application of macronutrient composition $N_{320}P_{120}K_{210}$ under the irrigation regime of 90% LMC which ensured an economically justified eggplant yield. The lowest eggplant yield of 22.1 t ha^{-1} was achieved with the irrigation regime of 70% LMC without fertilizer application as control (Table 4). The yield serves as the main indicator of eggplant response to the applied experimental treatments. The application of macronutrients led to a significant increase in eggplant yield at all levels of pre-irrigation soil moisture.

Table 4. Eggplant yield response to the level of pre-irrigation soil moisture and fertilizer application rates.

Fertilizer Rates ($Kg\ ha^{-1}$) NPK	Pre-Irrigation Threshold of Soil Moisture (% Least Moisture Capacity) (LMC)	Eggplant Yield	Yield Increase	
		($t\ h^{-1}$)	($t\ h^{-1}$)	%
Control 'Nontreated'	70	22.1 ef	-	-
	80	24.9 e	2.8	12.7
	90	25.3 e	3.2	14.5

Table 4. *Cont.*

Fertilizer Rates ($Kg\ ha^{-1}$) NPK	Pre-Irrigation Threshold of Soil Moisture (% Least Moisture Capacity) (LMC)	Eggplant Yield	Yield Increase	
		($t\ h^{-1}$)	($t\ h^{-1}$)	%
40 tons manure $N_{140}P_{30}$	70	32.5 cd	10.4	47.0
	80	36.7 c	14.6	66.0
	90	37.9 c	15.8	71.4
40 tons manure $N_{320}P_{120}K_{210}$	70	40.8 b	18.7	84.6
	80	42.3 a	20.2	91.4
	90	44.1 a	22.0	99.5
LSD $_{05}$	-	0.0102	0.029	0.0050
Coefficient of variation (%)	-	6.60	9.11	3.99

Means followed by different letters are significantly different by Tukey-adjusted means comparisons at $p \leq 0.05$.

4. Conclusions

The study of the weed species composition in eggplant cropping showed that fertilizer rates contributed to an increase in weed infestation levels of 27.1% to 37.6% in the field, due to an increment in the number of different annual weeds, as well as an increase in the pre-irrigation threshold of soil moisture from 70% to 90% LMC. Conversely, due to less moisture between the rows as a result of using drip irrigation, a decrease in weed density, ranging from 10.8% to 15.9%, was observed. Potential contamination of the arable soil layer with weed seed was significantly reduced by 19.8–21.7% with the application of fertilizers compared with the control, and an increase in the pre-irrigation threshold caused the least reduction in soil weed seedbank. The highest eggplant yield, with a value of 44.1 t ha^{-1}, was achieved by the application of fertilizer composition $N_{320}P_{120}K_{210}$ under the irrigation regime of 90% LMC, which ensured economically justified eggplant yield in southern Russia.

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