Intensification of nitrification processes in soil by ultraviolet (UV) irradiation

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Abstract. This study highlights the application of UV radiation for soil treatment with regard to agricultural plant growth intensification. The influence of the parameters of ultraviolet radiation (intensity and wavelength) on the value of the redox potential in the soil was quantified. The experimental tests carried out in soils, plants, seeds with ultraviolet radiation lamps for changing the accumulation of the most mobile nitrate forms of nitrogen were defined.

1. Introduction

At present, despite numerous studies of the total nitrogen balance of fertilizers in the soil-plant system, the processes of transformation of the products of the metabolism of nitrogen compounds in soils as a result of nitrification and denitrification have been insufficiently studied [1-3].

It is known that under artificial ultraviolet irradiation of the upper arable layers of the soil, active oxidation of molecules of humic substances occurs, in addition, the redox potential of the soil increases, which has a positive effect on the processes of nitrification-denitrification in the soil [4-6}.

At the same time, it is known that an increase in soil temperature and pH increases the intensity of both processes. At [7], the obtained results determined the effect of treatment modes with ultraviolet radiation at the following exposure values: 24; 48; 72; 96; 120 W·s/m^2 with wavelengths of 248, 280, 302, 313, 334 and 365 nm. Analyzing of the experimental data (Fig. 1) given in [8] made it possible to determine that irradiation of fulvic acid solutions contained in soils in the range of 280 - 390 nm led to the fact that after 24 min of irradiation (dose 120 W·s / m^2), the number of fulvic acid molecules decomposed with the formation was one and a half times higher than their number when irradiated with light for 12 minutes. (E_0' = +0.40 V), i.e. there was an increase in the redox potential. Experiments conducted at wavelengths of 248 and 280 nm revealed findings that were lower than those obtained at 365 nm in the control. It has been demonstrated that a variation of 21.84 nm from the optimal wavelength and 28.77 W•s/m^2 from the optimal exposure level can result in a 5% reduction in the efficacy of electro-treatment with UV radiation, especially for seed shoots.

Table 1. The processes of oxidation of nitrate nitrogen in the soil [9]

The highest stage of reaction	$+\boldsymbol{n} \cdot \boldsymbol{e}^-$	The lowest stage of the reaction	*E*, V
$\boldsymbol{NO_3^-}$ + $3H^+$	$+2 \cdot e^-$	$HNO_2 + H_2O$	+0.94
$\boldsymbol{NO_3^-}$+ H_2O	$+2 \cdot e^-$	$NO_2^- + OH^-$	+0.01
$\boldsymbol{NO_3^-}$+ H_2O	$+\boldsymbol{e}^-$	$NO_2\uparrow + \boldsymbol{OH}^-$	-0.86

It is necessary to quantitatively determine the influence of the parameters of ultraviolet radiation (intensity and wavelength) on the value of the redox potential in the soil. Nitrification takes place in the soil under oxidizing conditions, when the oxidation potentials E are close to 0.4 ÷ 0.5 V. If the aeration of the soil is difficult, and the redox potentials fall below 0.35 V, then the denitrification processes proceed intensively.
In particular, the redox potential is a complex combination of the activities of the various reduced and oxidized forms of substances involved in a reaction [9]. The decrease in normal potentials during reduction reactions during nitrogen denitrification occurs as follows is shown in Table 1.

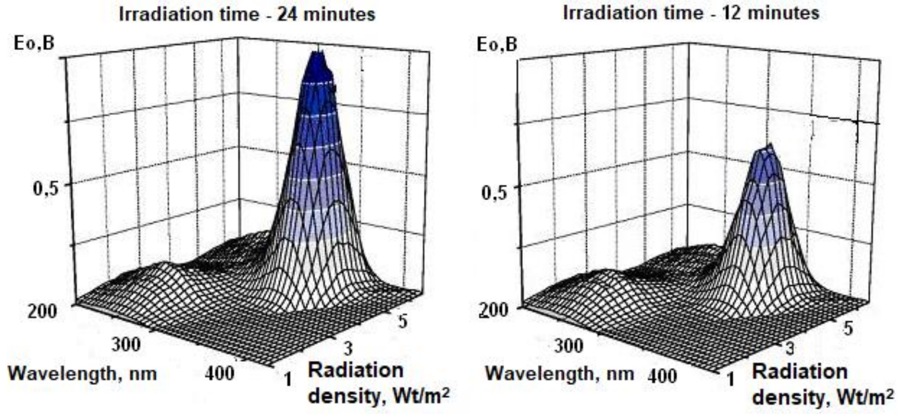

Figure 1. Graphs of the dependence of the change in the redox potential of soil substances on the wavelength and dose of ultraviolet radiation

2. Research Methods

Characterizing the elemental composition of soil organic matter, as a rule, the total (gross) carbon content is determined. According to the amount of carbon that is part of the organic matter, the humus content is calculated, since there are no reliable methods for the direct determination of humus in soils.
The humus-accumulative horizon is the richest in organic matter, containing from 1.0 ÷ 1.5 (under ash, desert soils) [10]. Down the profile, the amount of organic matter decreases. In sedimentary soil-forming rocks (loess), organic matter is evenly distributed throughout the entire thickness in an amount of 0.2÷0.4% [11].
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The light exposure to UV radiation can be calculated as follows [12].
The UV radiation's direct penetration zone into the soil is restricted (5÷10 mm). As a result, the influence of light on soil processes is complicated. Humic compounds, which coat solid phase particles with films, are among the components in the upper layer of the arable layer that might be damaged by UV light. Colored organic compounds can attach oxygen even in molecule form when exposed to ultraviolet light. The composition of humus includes amino acids [13] capable of inhibiting the activity of soil enzymes, which affects its colloidal-chemical properties.
When calculating soil processes, they try to use models [14] based on thermodynamic equations of equilibrium reactions, which do not require the determination of parameters, which, for example, the density of soils of various types changes by 2–3 times, thermal conductivity by 5÷10 times, the speed of propagation of light waves - 10÷12 times.
For the composition of the studied soil (see Table 1), the ionic strength [15] (kmol / m^2) equal

$$I = \frac{1}{2 \cdot M} \cdot \sum_{i=1}^{M} |z_i| \cdot c_i = \frac{1}{2 \cdot 10000} \cdot (2 \cdot 0{,}5 + 2 \cdot 0{,}25 + 1 \cdot 0{,}14 + 1 \cdot 0{,}024 + 2 \cdot 0{,}42 + +1 \times 0{,}08) = 0{,}000129 \text{ or } 0.129 \text{ mol / m}^2$$

here M - the total number of ions; $c_i -$ the concentration; z_i - charge of the ion.
For gray soils, it is determined by the formula

$pH = 7{,}6 + 0{,}12 \cdot \sqrt{N_1} \approx 7{,}6$, here N_1 - the Na content, 0.003% (Table 1).
Formulas for the initial reaction of the denitrification process [16]

$$NO_3^- + H_2O + 2e^- = NO_2^- + 2OH^- \quad (1)$$

For the initial soil data in the Tashkent region

$$E = 0{,}656 + 0{,}038 \cdot \sqrt{I} - 0{,}076 \cdot pH - 0{,}019 \cdot lg[NO_3^-] = 0.01 \quad (2)$$

here the equation includes $[NO_3^-]$- the content of nitrate nitrogen in the soil.
Due to an additional quantum of energy, in formula (1), UV irradiation allows $h\nu$ bringing an additional electron e^- into an excited state and thereby increase the value of the potential E to the required values.

3. Results

The goal of the field tests conducted at the "BMKB-Agromash" experimental field base (Tashkent region) was to discover changes in soil processes under the impact of periodic ultraviolet irradiation under various experimental variables. In this case, the site was divided into experimental maps [17]. The soils of the experimental site are typical gray soil of old irrigation, formed on the loess accumulations of the Tashkent cycle. In terms of texture, they are medium loamy, with a heavier depth, non-saline.

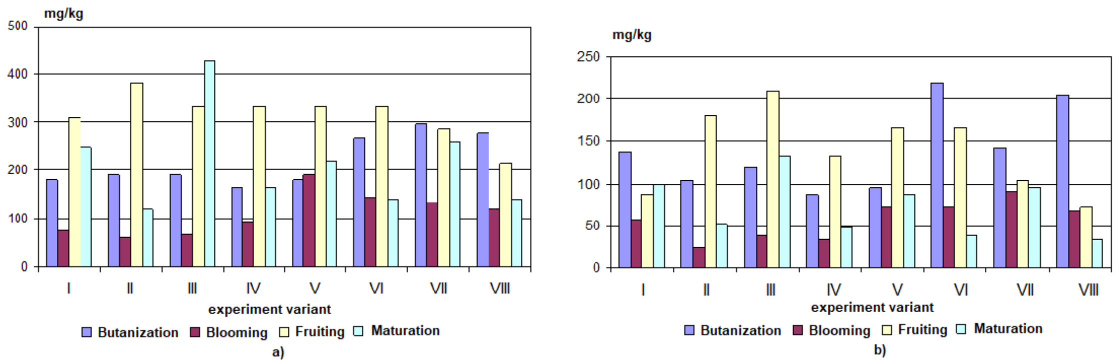

Figure 2. The effect of electrical treatment with UV radiation on the nitrogen compound content (mg / kg) of the soil by development phase (in mg per kg of soil): a) arable layer depth 0 ÷ 30 cm, b) soil horizon depth 30÷50 cm, I - control (soil without plants and UV treatment), II - control (soil with a plant and without UV treatment), III - UV treatment of soil without plants, IV - UV treatment of soil and cotton seeds, V – pre-sowing UV treatment of soil and cotton seeds, soil during sowing, VI - UV treatment of soil and plants during their growing season, VII - UV treatment of soil during plant growing, VIII - pre-sowing UV treatment of cotton seeds + UV treatment of soil and plants during the growing season of plants

Figure 2 shows the results of the experiments in the form of a histogram. The graph shows that at the time of flowering and ripening of the plant, there is a decrease in nitrogenous compounds in the soil, which may indicate its intensive selection by plants.
At the first stage, we will single out the arable zone (0÷30 cm), which is actively influenced by ultraviolet radiation.
Treatment with ultraviolet radiation lamps, according to the findings, can greatly increase the accumulation of the most mobile nitrate forms of nitrogen (Fig. 2), resulting in an extra rise in plant production. Comparison of soil layers shows that it is characterized by the movement of matter with ascending streams of soil moisture, which is usually observed in arid regions, when, during the period of hot dry weather, moisture begins to intensively evaporate from the soil surface.
Comparison of variants of experiments I and III with ultraviolet soil treatment without a plant shows a significant increase in nitrogen compounds in the time period corresponding to the final phases (fruiting and ripening) of cotton development, which may be caused by the intensification of the process of decomposition of humic substances into nitrogen compounds. This is of particular importance because it is known [18] that nitrates are the form of nitrogen compounds that are most easily lost by the soil; the

phenomenon of denitrification occurs, i.e., transition from nitrate back to ammonium form of nitrogen [19, 20].

Cotton plants in variations V, VI, VII, and VIII were exposed to UV irradiation three times before watering during the growing season: the emergence of 3-4 leaves, budding, and flowering (Figure 2). Plant nitrogen consumption increases throughout the flowering phase, according to a comparison of research findings. With the transition of cotton to the flowering phase, the leaf surface increases, the root system develops powerfully and deepens to1mand more. With the further growth of vegetative organs, the formation of fruit organs occurs. The evaporating activity of the bush increases. Water consumption from the cotton field at this time increases to 70 ÷ 90 m^3/ha per day and more. As a result, a large amount of water and nutrients is required.

4. Conclusions

Since nitrification takes place in the soil under oxidizing conditions, when the value of the redox potential E consists in the range > 0.35 V. This indicates that UV irradiation provides favorable conditions for enhancing nitrification processes, i.e. oxidation of ammonium nitrogen NH_4. Nitrate nitrogen NO_3 is readily soluble in water, is not absorbed or retained by the soil, which ensures its good availability for plants. Optimal conditions for the formation of nitrates are soil moisture 40 ÷ 70% of the irrigation rate, pH = 6 ÷ 8, soil temperature 30 ÷ 35^0C.

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