POLLUTION

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STRESS RESISTANCE OF AGRICULTURAL PLANTS IN RELATION TO POLLUTANTS OF EXHAUST GASES

Research article

Abstract

One of the tasks of crop production at the present time is to eliminate stress factors that worsen the condition of agricultural structures. The rate of photosynthetic processes, and hence the productivity of agricultural crops decreases by the action of a stress factor. The influence of pollutants of exhaust gases of automobile engines on five types of crops such as sunflower, soybeans, oats, peas, and wheat has been investigated. It was established that the contamination of the exhaust gases of vehicles results in a reduction in the content of chlorophyll a (up to 40%), chlorophyll b (up to 60%) and carotenoids (up to 70%) in crops grown in the immediate vicinity of the highway, as compared to the section of the field located at a considerable distance from the road. The sensitivity of the photosynthetic apparatus of the studied crops to pollution is highest in sunflower and oats. Soybeans have the lowest sensitivity. The maximum decrease in the ratio of chlorophylls a and b was recorded for oats, which indicates its low stress resistance. The best defense mechanism in relation to the effects of exhaust gas pollutants is observed in soybeans. The use of biodiesel fuel is proposed as a way to reduce the stress impact of exhaust gases on agricultural crops. An improvement in the environmental performance of the MTZ-80 tractor engine has been registered when it is running on a fuel mixture containing 60% (vol.) of commercial petroleum diesel fuel and 40% of biodiesel fuel. When using fuel compositions, smokiness of the exhaust gases is 10-21% lower, the content of carbon monoxide (II) in them is reduced by 12-24%, and the content of unburned hydrocarbons is 12-32% less compared to oil fuel.

Keywords: biodiesel fuel, photosynthetic pigments, plant stress resistance.

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СТРЕССОУСТОЙЧИВОСТЬ СЕЛЬСКОХОЗЯЙСТВЕННЫХ РАСТЕНИЙ ПО ОТНОШЕНИЮ К ПОЛЛЮТАНТАМ ОТРАБОТАВШИХ ГАЗОВ

Научная статья

Аннотация

Одной из задач растениеводства в настоящее время является устранение стрессовых факторов, ухудшающих состояние сельскохозяйственных структур. При действии стрессового фактора снижается скорость фотосинтетических процессов, а значит, и урожайность сельскохозяйственных культур. Исследовано влияние поллютантов отработавших газов автомобильных двигателей на пять видов сельскохозяйственных растений: подсолнечник, соя, овес, горох, пшеница. Установлено, что загрязнение от отработавших газов автомобилей приводит к снижению содержания хлорофилла a (до 40%), хлорофилла b (до 60%) и каротиноидов (до 70%) в сельскохозяйственных растениях, произрастающих в непосредственной близости от автомагистрали по сравнению с участком поля, расположенном на значительном удалении от дороги. Чувствительность фотосинтетического аппарата изученных сельскохозяйственных культур по отношению наиболее высока у подсолнечника и овса. Самой низкой чувствительностью характеризуется соя. Максимальное снижение соотношения хлорофиллов a и b было зарегистрировано для овса, что говорит о его низкой стрессоустойчивости. Наилучший защитный механизм по

отношению к воздействию поллютантов отработавших газов наблюдается у сои. Предложено применение биодизельного топлива как способ снижения стрессового воздействия отработавших газов на сельскохозяйственные культуры. Зарегистрировано улучшение экологических показателей работы двигателя трактора МТЗ-80 при его работе на топливной смеси, содержащей 60% (об.) товарного нефтяного дизельного топлива и 40% биодизельного топлива. При использовании топливных композиций дымность отработавших газов на 10-21% ниже, содержание в них оксида углерода (II) снижается на 12-24%, а содержание несгоревших углеводородов на 12-32% по сравнению с нефтяным топливом.

Ключевые слова: биодизельное топливо, фотосинтетические пигменты, стрессоустойчивость растений.

1. Introduction

Crop production is one of the important agricultural industries. Crop products are the basis of our nutrition; they are the most important and irreplaceable source of food for mankind. This branch of agriculture is currently facing a number of important tasks. First of all, crop production must be of high quality and environmentally friendly. Industry workers are expected to maximize product yields with minimal costs. The base of high productivity of agricultural crops is the intensive process of photosynthesis. The inorganic compounds and the energy of the sun's rays are converted into nutritious organic compounds (proteins, fats, carbohydrates) due to this process. Workers in the industry create new energy and resource-saving technologies for intensive crop production, improve agricultural machinery and increase the intensity of its operation, take measures to prevent losses when growing field crops. One of the directions of this work is the elimination of stress factors that worsen the condition of plants and reduce yields.

Stress can be defined as a general non-specific adaptive response of a plant when exposed to various unfavorable factors. The result of the action of stress factors is the slowing down of metabolic processes in the plant organism [1]. In this case, the energy of the plant organism is spent on counteracting stress, which damages the formation of the crop.

Stress factors can be physical, biological, and chemical. Chemical factors are extremely varied. These include soil salinization, oil spills, the use of pesticides and herbicides, the ingress of salts and oxides of heavy metals into the soil, etc. Their effect on the plant organism has been fairly well studied [1], [2], [3].

Another important stress factor is various gaseous pollutants [1], [4]. Gaseous substances penetrate into plant tissues quite easily; the main way is gas exchange through the stomata. Toxic gases dissolve in water that is part of cell walls, and then can enter into various chemical interactions, changing the pH of the medium, what entails a change in the activity of protein molecules in general and enzymes in particular. For example, the activity of transport proteins changes, which affects the permeability of cell membranes. Gaseous substances destroy various molecules in the cytoplasm, for instance, chlorophyll. This stress factor leads to the destruction of photosynthetic pigments and a decrease in the intensity of photosynthesis, and therefore, reduces the yield of agricultural crops.

Therefore, the content of the main photosynthetic pigments (chlorophylls and carotenoids) can be used as a marker of plant response to a stress factor [5], [6], [7], [8], [9].

Quite a lot of data have been published on the effect of gaseous emissions from various industrial enterprises, thermal power plants, various types of transport, etc. on the state of plants. Most often, the published data characterize the degree of air pollution and the stress level of plants growing in cities and industrial zones. However, there is practically no data on the actual effect of exhaust gas components on crops. But vehicles can be attributed to one of the main non-stationary sources of environmental pollution.

The aim of this work is to determine the effect of vehicle exhaust gases on the level of chemical stress of crops grown in the Tambov region and to find ways to reduce this stress.

2. Methods

Leaves of annual sunflower (*Helianthus annuus*), soybean (*Glycine max*), oats (*Avena sativa*), peas (*Pisum sativum*), and wheat (*Triticum aestivum)* were used as objects of research.

The collection of material for research was carried out during the growing season (June 2021) in the Tambov region. Sampling points are located on the main highways of the regional center in roadside zones (up to 5 m from the roadbed) and in the depths of the field (at a distance of 300 m from the highway).

The concentration of photosynthetic pigments (chlorophyll a and b and carotenoids) was determined spectrophotometrically [4]; acetone (analytical grade) was used as the solvent for obtaining extracts from plants. The absorption of acetone extracts of these pigments was determined using СФ-2000 spectrophotometer.

The methods of fine organic synthesis were used for the synthesis of biodiesel fuel by the transesterification reaction under conditions of homogeneous alkaline catalysis. The raw material for the synthesis of samples of biodiesel fuel was oil of crambe and oilseed radish. To measure the environmental characteristics, two fuel compositions (FC1 and FC2) were prepared. They consisted of 60% (vol.) of commercial petroleum diesel fuel and 40% (vol.) of biodiesel fuel synthesized from crambe oil (FC1) and oilseed radish oil (FC2). The physicochemical characteristics of the fuel compositions were determined using the methods enshrined in GOST P 52368-2005 “EURO diesel fuel. Technical conditions".

Measurement of the smokeness of the exhaust gases and the proportion of carbon monoxide and unburned hydrocarbons in the fuel compositions were carried out using the “Инфракар Д” and ”Инфракар М” instruments, respectively.

3. Results

Chemical stress factors, including exhaust gas pollutants, lead to a decrease in the rate of accumulation of photosynthetic pigments and affect the ratio of the spectral forms of chlorophyll.

To determine the degree of impact of vehicle exhaust gases on the state of agricultural plants, we selected the crops most common in the Tambov region: sunflower, soybeans, oats, peas, wheat. The leaves of plants, in which, mainly, the processes of photosynthesis take place, were taken in the summer, during the growing season, at sites located at different distances from highways.

For sampling of plant materials, 6 sampling points were selected in the Tambov region (Table 1).

Table 1 – Objects of research and points of selection of plant material material

1	Sunflower	road “Tambov-Kotovsk”
2	Soybean	road “Tambov-Kotovsk”
3	Oats	road “Tambov-Kotovsk”
4	Sunflower	road "Tambov-Penza", Northern bypass
5	Peas	road "Tambov-Penza", Northern bypass
6	Wheat	road "Tambov-Penza", Northern bypass

Table 2 shows the results of photometric determination of the content of chlorophylls a and b, as well as carotenoids in the studied agricultural plants. The numerator is the pigment content in plants growing along the highway; the denominator is the pigment content in plants located in the depth of the field and far from the stress factor for each point of material sampling.

Table 2 – Concentrations of chlorophyll a, b and carotenoids in the leaves of agricultural crops

Sampling points	C_a, mg/l	C_b, mg/l	C_k, mg/l
1	2.711	2.221	0.930
	3.316	2.602	1.223
2	5.892	4.674	1.909
	6.856	5.301	2.460
3	2.352	2.354	0.657
	4.655	3.768	1.459
4	1.596	1.371	0.589
	4.328	3.737	2.013
5	5.134	4.947	1.023
	6.135	5.409	1.466
6	8.459	7.578	1.488
	9.868	8.765	2.724

The content of chlorophylls a, b and carotenoids was lower in all samples from the surveyed areas collected along the highway, compared to the material collected in the depth of the field, where the influence of the exhaust gases has practically no effect. It can be concluded that plants growing near highway are under stress caused by a chemical factor - toxic substances of exhaust gases. The action of the stress factor leads to a decrease in the content of photosynthetic enzymes and, as a consequence, to the suppression of the process of photosynthesis, the accumulation of nutrients, and a decrease in yield.

The content of chlorophyll b in the cells of higher plants, as a rule, decreases in response to stress factors. Reducing the amount of pigment depends on both the point of sampling and the type of plant. Thus, the greatest decrease in pigment content (by 63%) was found for sunflower (point 4). Oats have almost the same high sensitivity (point 3, decrease by 40%). Soybeans and peas were found to be the least sensitive to the effects of exhaust gas components (a decrease in the concentration of pigments by 11% and 9%, respectively).

Markers of technogenic impact on environmental pollution are the ratios "C_a:C_b" and "(C_{a+b}):Ck" [5], where C_a, C_b, C_{a+b} are the concentration of chlorophyll a, b and their sum, respectively, mg/l; C_k is the total concentration of carotenoids, mg/l.

If the plant is under chemical stress, the ratio of chlorophyll a and b concentrations naturally decreases (the accumulation of chlorophyll b is a response to stress). The ratio of chlorophyll concentration to carotenoid concentration increases under stress. Figures 1 and 2 show the values of these biomarkers.

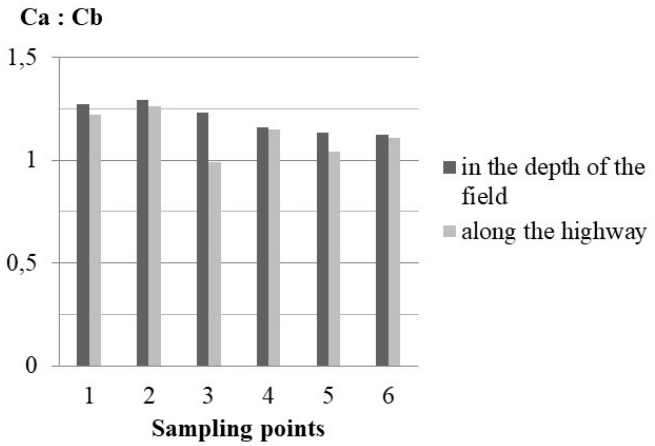

Figure 1 – The ratio of chlorophyll a and b concentrations (mg/l) in the leaves of the studied plants

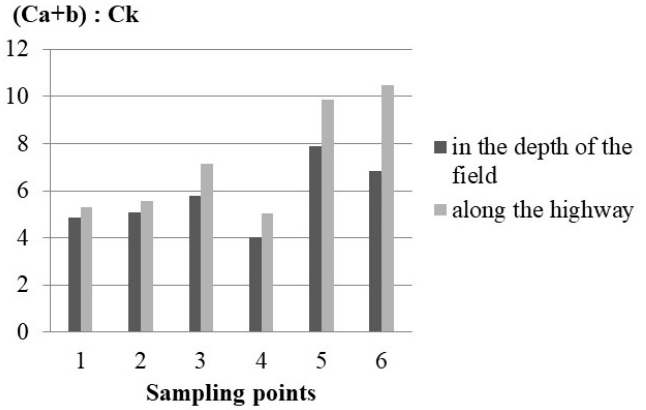

Figure 2 – The ratio of the concentrations of chlorophylls and carotenoids in the leaves of the studied plants

A decrease in the chlorophyll a:chlorophyll b ratio is considered an indicator of plant stress [8], [9], [10]. The Ca:Cb ratio decreased at all sampling points where plants were exposed to the influence of exhaust gases. Moreover, the maximum decrease in the value (up to 20%) was observed for the point 3. This indicates that oats is the least stress-resistant, and more sensitive to the influence of automobile pollutants than other studied crops.

The study clearly shows that the components of the exhaust gases of road transport are a chemical stress factor for agricultural plants. Consequently, reducing the toxicity of exhaust gases will contribute to the production of not only cleaner crop production, but will also contribute to higher yields.

We propose the use of biodiesel fuel as a way to reduce the concentration of harmful substances in the exhaust gases. Biodiesel is meant fatty acid methyl esters synthesized from a variety of plant materials. It is known from bench tests, that when a diesel engine runs on biodiesel fuel, the content of polycyclic aromatic and unburned hydrocarbons, carbon monoxide (II), and soot in the exhaust gases is noticeably reduced [11], [12], [13]. Operational tests were carried out on the MT3-80 tractor as part of this study.

Two samples of biodiesel fuel were synthesized. The synthesis was carried out by the transesterification reaction with methyl alcohols in the presence of a homogeneous alkaline catalyst. The raw materials for the synthesis were crambe and oilseed radish oils. It should be noted that edible vegetable oil was not used for the synthesis of biodiesel. Oilseed radish was grown as a green manure, which helps to restore soil fertility (as a green fertilizer and a means of weed control). To approximate the real conditions of agricultural production, the oil from the oilseed radish was squeezed out before the synthesis process on a small-sized oil press for farms, produced by LLC "Research Center TEAC-MO". The crambe oil was stored for several years and was identified as “substandard” due to increased acidic numbers (24.3 mg KOH/g).

The resulting biodiesel was blended with commercial petroleum diesel fuel. Two fuel compositions were prepared. The fuel composition FC1 contained 60% (vol.) of commercial petroleum diesel fuel and 40% (vol.) of biodiesel fuel obtained from crambe oil. The fuel composition FC2 contained 60% (vol.) of commercial petroleum diesel fuel and 40% (vol.) of biodiesel fuel synthesized from oilseed radish oil. The physicochemical characteristics of the obtained fuel compositions are shown in Table 3. All characteristics correspond to the requirements of GOST, therefore, the fuel compositions can be used to operate the diesel engine of the MT3-80 tractor.

Table 3 – Physical and chemical characteristics of fuel compositions

Parameters	FC1	FC2
Density, kg/m^3, at 15 °C	898	887
Viscosity, 40 °C, mm^2/s	4.2	4.1
Pour point, °C	–11	–11
Flash point, °C	152	149
Sulfur content, mg/kg	173	167
Water content, mg/kg	105	97
Mechanical impurities content, mg/kg	absent	absent
Acidity, mgKOH/100 cm^3	1.3	1.3
Monoacylglycerol content, %	0.500	0.500
Diacylglycerol content, %	0.100	0,.105
Triacylglycerol content, %	0.002	0.002
Iodine number, g I_2/100g	111	110
Ash content, %	0.01	0.01

Field tests were carried out on an MTЗ-80 tractor. Commercial petroleum diesel fuel (DF) and fuel compositions with a biofuel component based on crambe oil (FC1) and based on oilseed radish oil (FC2) were used as the test fuel.

Measurements of smokiness and toxicity of exhaust gases were carried out (Figure 3).

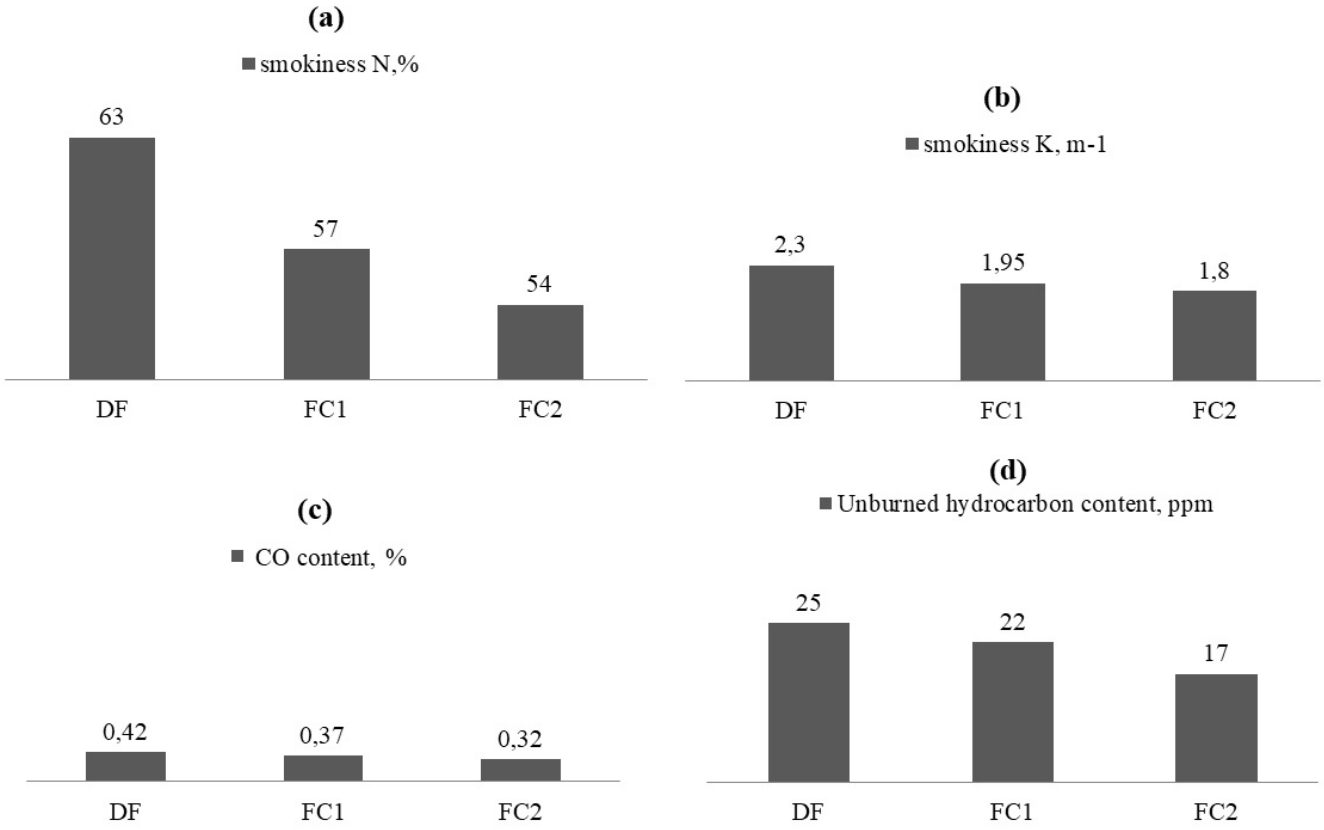

Figure 3 – Environmental indicators of the MTЗ-80 tractor on different types of fuels

When compared to the obtained results with the environmental characteristics of commercial petroleum diesel fuel, it is seen that the content of carbon monoxide (II) in the exhaust gases of an engine operating on a fuel composition FC1 is 12% lower, and that operating on a fuel composition FC2 is 24% lower. A similar decrease in the content of unburned hydrocarbons in the exhaust gases is 12% and 32% correspondingly. The smokiness of the exhaust gases of the MTЗ-80 engine, operating on fuel compositions containing 40% of biodiesel fuel, is also lower than when operating on commercial oil fuel, by 15-21% in terms of the main indicator - the light absorption coefficient *K*, and by 10-14% in the auxiliary indicator - the light attenuation coefficient *N*. Biodiesel fuel synthesized from oilseed radish oil has shown the best results from an environmental point of view.

4. Conclusion

The influence of pollutants of exhaust gases of automobile engines on five types of widespread agricultural plants (sunflower, soya, oats, peas, and wheat) has been investigated. It was found that pollution from exhaust gases of cars leads to a decrease in the content of chlorophyll a (up to 40%), chlorophyll b (up to 60%) and carotenoids (up to 70%) in agricultural

plants growing in the immediate vicinity of the highway as compared to the field located at a considerable distance from the road.

The sensitivity of the photosynthetic apparatus of the studied crops in relation to pollution by components of exhaust gases is not the same. They can be arranged in the following row in descending order of sensitivity: sunflower > oats > wheat > peas > soybean. The maximum decrease in the ratio of chlorophylls a and b was recorded for oats (20%), which indicates its low stress resistance. Sunflower, soya and wheat are more resistant to chemical stress; their chlorophyll ratio varies to a lesser extent (1-4%). The best defense mechanism in relation to the effects of exhaust gas pollutants is observed in soya.

One of the ways to mitigate the stressful effect of toxic components of exhaust gases on agricultural crops could be the wider use of biodiesel, primarily for the operation of agricultural machinery.

An improvement in the environmental performance of the MTZ-80 tractor engine when operating on a fuel mixture containing 60% (vol.) of commercial petroleum diesel fuel and 40% of biodiesel fuel has been recorded. Smokiness of exhaust gases when using fuel compositions is 10-21% lower than that of exhaust gases of an engine running on petroleum fuel. The content of carbon monoxide (II) also decreases with the transition to fuel compositions by 12-24%, and the content of unburned hydrocarbons in the exhaust gases decreases by 12-32% compared to oil fuel. The best environmental characteristics are observed for a fuel composition based on oilseed radish.

Conflict of Interest **Конфликт интересов**

None declared. Не указан.

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