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Assessment of agricultural ecosystem benzo(a)pyrene pollution on a wheat field model

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Abstract. The represented research aims to assess the pollution of agricultural ecosystems with benzo(a)pyrene. The study considers the exhaust gases of heavy farming machinery as a primary source of pollution. This dangerous carcinogen entering air with internal combustion engines exhausts goes to the water and soil, and then, through the trophic chains, in a human body. Alongside the obvious negative impacts on human health, the benzo(a)pyrene exposure manifests through the decline in the agricultural ecosystems' productivity, soil fertility, etc. The assessment was implemented on a wheat field model during harvest using the direct combining method. The model doesn't consider the ambient pollution sources. The performed simulations allow disclosing the correlations between the harvesting machine's velocity and pollutant's emission mass on the model field, identifying the most environmentally dangerous engine's operation mode, and pointing out the possible ways to decrease the benzo(a)pyrene impacts on agricultural ecosystems.

1 Introduction

The rapid growth and development of the technosphere result in an annual decrease in territories that are not affected by anthropogenic influence. Pollutants, which are by-products of almost any economic branches [1-4], enter the environment and then into the human body through the respiratory organs or digestive tract, causing various pathologies and lesions [5, 6]. Therefore, ensuring the environmental safety of food products, and consequently, agroecosystems is a relevant problem.

The 3,4-benzo(a)pyrene ($C_{20}H_{12}$) is one of the most dangerous pollutants entering ecosystems, both natural and technogenic ways. It has a carcinogenic, mutagenic, embryotoxic, and hematotoxic effect on living organisms [7]. Thermally and chemically stable molecules of benzo(a)pyrene enter the body through the respiratory and digestive systems and accumulate in cells, penetrating the DNA structure and causing irreversible mutations of the body and its descendants [8].

To examine the benzo(a)pyrene emissions in the agricultural ecosystems, it is necessary first to understand the anthropogenic mechanism of this pollutant formation. C20H12

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generates during the incomplete combustion of hydrocarbon fuels, including those used by agricultural machinery. The carcinogen content in the exhaust gases of the internal combustion engines depends upon the type of fuel, the quality of the formation of the fuel-air mixture, the design parameters of the combustion chamber, etc. In the combustion chambers and exhaust systems of internal combustion engines, $C_{20}H_{12}$ can be in three states: in the form of steam, the smallest resinous aerosol, and also adsorbed on soot particles. With insufficient air content in the fuel-air mixture (with an excess air coefficient of less than 0.6), as well as with the introduction of aromatic and especially polycyclic aromatic hydrocarbons into the homogeneous fuel mixture, it leads to a sharp increase in the concentration of benzo(a)pyrene in the exhaust gases [9].

The solid suspended particles emitted into the atmospheric air by vehicles and agricultural machinery pass along with the rain into the soil, roots, and aerial plant parts. Further on, these substances get into the human body through the trophic chains.

Prolonged exposure to benzo(a)pyrene on the human body leads to a weakening of the immune system, which, in turn, can cause the development of some chronic diseases of the respiratory, nervous, and digestive systems. Carrying out productive activities while exposed to the carcinogen can contribute to the appearance of the skin and upper respiratory tract irritation, stomach ulcers and increase the risk of cardiovascular diseases, chronic pulmonary pathologies, and other respiratory disorders [10].

The introduction of benzo(a)pyrene into the soil reduces its biological productivity. Among the pollution impacts, there are the deterioration of the water-air regime, a sharp decrease in the concentrations of mobile nitrogen and phosphorus compounds, the development of saline processes, changes in microbiota, etc. [10, 11].

Thus, the assessment of contamination of agroecosystems with benzo(a)pyrene is an urgent task of agricultural and environmental protection services. The obtained results will allow assessing the ecological safety and increase the productivity of agricultural ecosystems.

2 Methods

The suggested model examines the contamination of agroecosystem during grain-harvesting with the direct combining method [12]. The input data are:

• The field size is 1 ha (100 m on a side);
• Average crop yield is 3.5 tons per hectare;
• The number of exploited machinery $N = 1$;
• The pollution source is farming machinery utilized directly in the field, in particular, Vector 410 grain-harvesting combine (table 1 represents its technical features taken from Rostselmash Plant agricultural equipment catalogue).

The model doesn't consider the impact of ambient $C_{20}H_{12}$ emission sources.

Table 1. Vector 410 grain-harvesting combine technical features.

Engine	Engine pover, kW	Mass[1], kg	Header's constructive width[2], m	Grain bunker volume, m^3
Diesel	154	14383	6	6

Notes. 1. Considering the header, stacker, and fuel masses (with the fuel tank filled up to 75 percent and diesel fuel density 855 kg/m^3). 2. With a constructive width utilization ratio of 0.96, the model uses for calculations the header's working width of 5.76 m.

The model field harvesting implements the circular method most suited for the small (with run-length less than 400 m) or irregularly shaped fields [12]. The use of graphic methods applied through the KOMPAS-3D CAD software system allows determining the route of harvesting combine (fig. 1). With the known quantities of grain bunker volume (see table 1) and apparent density of wheat (780 kg/m^3), the grain bunker mass capacity is 4.68 tons. Therefore, with the assumed value of crop yield (see model inputs), the grain unload during harvesting is unnecessary, as well as an accounting of environmental pollution with heavy-duty vehicles' emissions.

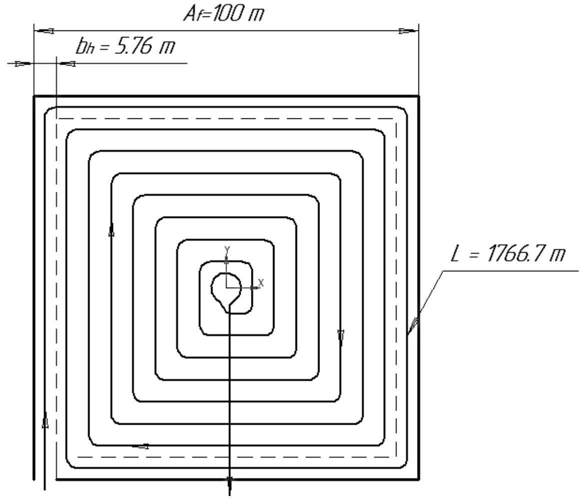

Fig. 1. The combine harvester route on the wheat field model (A_f is the side of the square-shaped field, m; b_h is the header working width, m; *L* is the combine route length, m).

To calculate the emissions of benzo(a)pyrene, the method [13] is proposed to use. Its foundation is a scientifically based model of the vehicle's operation. According to the used method, the following algorithm of the polluting component of vehicle exhausts mass implements.

1. The volume flow rate of the exhaust gases [14] correlates with the relative engine power, a quantifiable transportation work feature [15].
2. The pollutant concentration in the exhaust gases is a function of transportation activity characteristics, such as relative engine power or relative air excess ratio.
3. The pollutant mass flow rate is the multiplication of the volume flow rate and the pollutant concentration.
4. Calculation of the total pollutant emission for the investigated period.

The main input parameter for calculating the $C_{20}H_{12}$ mass flow rate with the applied method is the average harvester speed. This parameter depends on many factors, including engine power, ear flatness (when harvesting flat ears, the combine speed cannot exceed 1 km/h), the header width, crop yield, grain ripeness, etc. [12]. In this regard, the contamination assessment of the model agroecosystem takes into account the speed range of 1 – 8 km/h.

The method [13] allows considering the change in the pollutants emission in correlation with the engine operating modes. Table 2 represents the approximate time fractions of the engine operation in the unsteady and steady states.

Table 2. Engine modes time ratio for grain-harvesting machine.

Acceleration	Steady velocity	Deceleration and idle mode
0.1	0.75	0.15

The benzo(a)pyrene emissions calculations in the model agricultural ecosystem implement through the Mathcad software.

3 Results and Discussion

Fig. 2 represents the harvesting machine $C_{20}H_{12}$ emissions on the wheat field model in the speed range of 1 – 8 km/h. The columns illustrate the calculated emission values, and the dotted line depicts the trend approximated in Microsoft Excel.

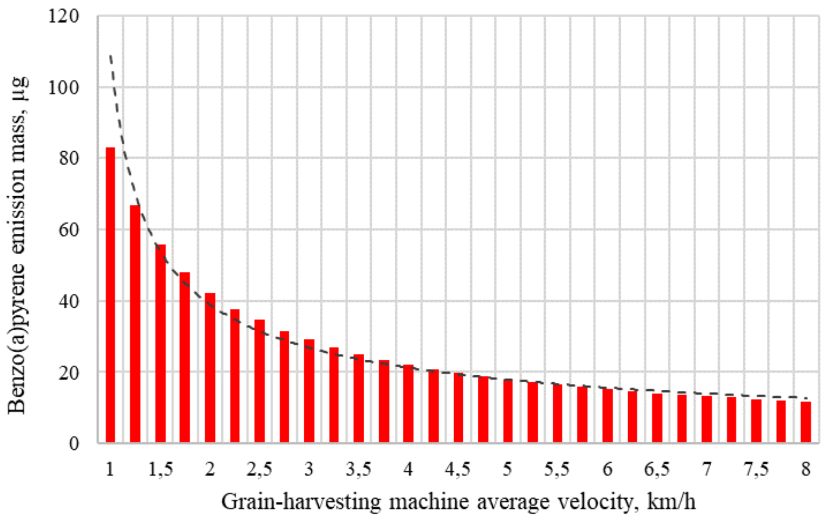

Fig. 2. Benzo(a)pyrene emission mass during harvest period in correlation with Vector 410 harvesting combine average velocity

The chart (see fig. 2) shows the pollutant mass reduction with the speed increase tendency described with a sufficiently high confidence rate (R^2 = 0.9805) by a power function.

$$M = 108.68v^{-0.637}, \quad (1)$$

M is benzo(a)pyrene emission mass, µg; *v* is the harvesting combine average velocity on the model field, km/h.

In the thresholds of the examined velocity range, the $C_{20}H_{12}$ emissions differ by about seven times. This fact allows suggesting that the optimal speed from an ergonomic point of view of 6.5 – 8 km/h is also the safest for the agroecosystem environmentally.

Analysis of the benzo(a)pyrene mass flow rate at steady and non-steady engine operating modes (at v = 5.5 km/h) showed that the most ecologically unfavorable is the idle mode of the combine (table 3).

Table 3. Benzo(a)pyrene emission flow rate, µg/s, for Vector 410 in relation to the engine’s operation modes.

Acceleration	Steady velocity	Deceleration and idle mode
0.008	0.002	0.067

The analysis of table 3 shows that the possible way to negate the environmental impacts of grain harvesting is to reduce the downtime of a combine. Optimal preparation of the combine for work, its pre-setup, and rational organization of harvesting operations can significantly reduce the emission of $C_{20}H_{12}$.

4 Conclusion

The performed research recognizes the emissions of heavy farming equipment and the transport moving along the nearby highways as the primary sources of benzo(a)pyrene pollution of agroecosystems. Emitting into the atmospheric air by internal combustion engines, this dangerous carcinogen permeates the hydrosphere and soil and then through trophic chains into the human body. In addition to the obvious health impacts, exposure to benzo(a)pyrene also reduces the productivity of agroecosystems, soil fertility, etc.

The conducted studies revealed the correlation between the harvester speed and the mass of the pollutant emission. Analysis of $C_{20}H_{12}$ mass flow rate in steady and non-steady operating modes of harvesting combine engine showed that the braking and idling are the most dangerous modes environmentally. The possible ways to reduce the pollution are preliminary adjustment of the combine's settings, selection of the harvester's optimal speed based on its power characteristics, the crop yield, grain ripeness, hydrometeorological conditions, etc.

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