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Volodymyr Kramar

POSSIBLE UTILIZATION DIRECTIONS OF ASH FROM BIOMASS COMBUSTION. BIOMASS ASH AS FERTILIZER IN AGRICULTURE

The present position paper №27 of the Bioenergy Association of Ukraine belongs to the planned series of publications on the main issues of bioenergy development in Ukraine.

The purpose of this *Position Paper* is to observe the rational ways of biomass ash utilization, in particular, to analyse the possibilities and summarise the experience of its use as fertilizer in agriculture. In recent years, the use of biomass fuel in Ukraine has increased significantly, as well as the formation of ash from its combustion. Currently in Ukraine there is no established practice of handling this ash, which would comply with the principles of circular economy. Basically, the ash is taken to landfills, which causes additional costs for businesses and increases the anthropogenic impact on the ecosystem. From the sustainable development point of view, the reuse of this resource is important because such ash contains a number of valuable minerals that could be used as fertilizers and return to their natural cycle.

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Volodymyr Kramar
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For feedback and comments: kramar@secbiomass.com
Bioenergy Association of Ukraine
2-A Maria Kapnist Street, office 116,
03057, Kyiv, Ukraine
+38 (044) 453-28-56
info@uabio.org
www.uabio.org

GRATITUDE

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Content

Introduction

The problems of ensuring the sustainable development of nature and society are becoming increasingly important in today's world. One of the most popular definitions of sustainable development is "development that meets the needs of today without compromising the ability of future generations to meet their own needs [1]".

One of the basic principles of rational use in the context of sustainable development is the "zero level" of consumption of natural resources, preservation of the natural cycle of substances in the process of anthropogenic activities and the priority of environmental optimality in the long run.

The principles of sustainable development and resource management have formed the basis of the "circular economy" concept as a new economic model based on reduction, reuse and utilization of energy, transition from fossil fuels to RES, resource recovery, recycling secondary raw materials.

On December 2015, the EU Commission adopted the EU action plan for the Circular Economy and the Economy Package, which includes measures to stimulate Europe's transition to a circular economy. The goals of the circular economy are reflected in the European Green Deal strategy presented by the European Commission in December 2019 [2], which aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use.

In 2017, the Ministry of Economic Development and Trade of Ukraine prepared the National Report "Sustainable Development Goals: Ukraine" [3], which defines the basic indicators for achieving the Sustainable Development Goals (SDGs). The report presents the results of adaptation of 17 global SDGs taking into account the specifics of national development. Goal 12 of the National Report "Responsible Consumption and Production" notes the need to create legal and institutional preconditions for the formation of green economy in Ukraine, which will significantly reduce the dependence of economic growth on the use of natural resources and energy. At the same time***, the circular economy concept should serve as a basis for rethinking the role of waste as a resource***. Tasks under Goal 12 include ensuring the sustainable use of chemicals, as well as reducing waste generation and increasing their recycling and reuse based on innovative technologies and industries.

In recent years, the use of biomass fuel in Ukraine has increased significantly, as well as the formation of ash from its combustion. Currently in Ukraine there is no established practice of handling this ash, which would comply with the principles of circular economy. Basically, the ash is taken to landfills, which causes additional costs for businesses and increases the anthropogenic impact on the ecosystem. From the sustainable development point of view, the reuse of this resource is important because such ash contains a number of valuable minerals that could be used as fertilizers and return to their natural cycle.

The purpose of this Position Paper is to observe the rational ways of biomass ash utilization, in particular, to analyse the possibilities and summarise the experience of its use as fertilizer in agriculture.

1. General overview of kinds of ash from biomass combustion and its properties

1.1. Physico-chemical properties, elemental composition

According to the definitions of the current State Standard DSTU EN 14588:2013 "Solid biofuels. Terms and definitions":

- ash is a mineral residue obtained by fuel combustion.
- ash content – the mass of inorganic residue formed after fuel combustion under standard conditions, usually expressed as a percentage by weight of dry matter.
- internal ash – the total ash content of the biofuel itself.
- external ash – total biofuel ash together with contaminants obtained during harvesting, logging, processing, transportation, storage, etc.

The amount and elemental composition of the formed ash, as well as its other properties depend on the following main factors:

- **types of burned biomass** (types and origins of plants; parts of burned plants; ways and technologies of biomass storage for combustion);
- **combustion technologies** (combustion on the grate or in the fluidized bed; the design of the combustion chamber and boilers; the parameters of the combustion process: combustion temperature, air flow, as well as other parameters);
- **technologies for capturing ash** from flue gases (cyclones, various filters);
- **use of additional technologies** to prevent excessive emissions of harmful substances into the atmosphere, used in the combustion of biomass (additive of ammonia water or dolomite into the combustion layer).

Usually there are three fractions of ash at the biomass combustion plants (**Fig. 1.1**):

- ash residue (**bottom ash**);
- fly ash from the cyclone (**cyclone ash**);
- fly ash from the filters (**filtration ash**).

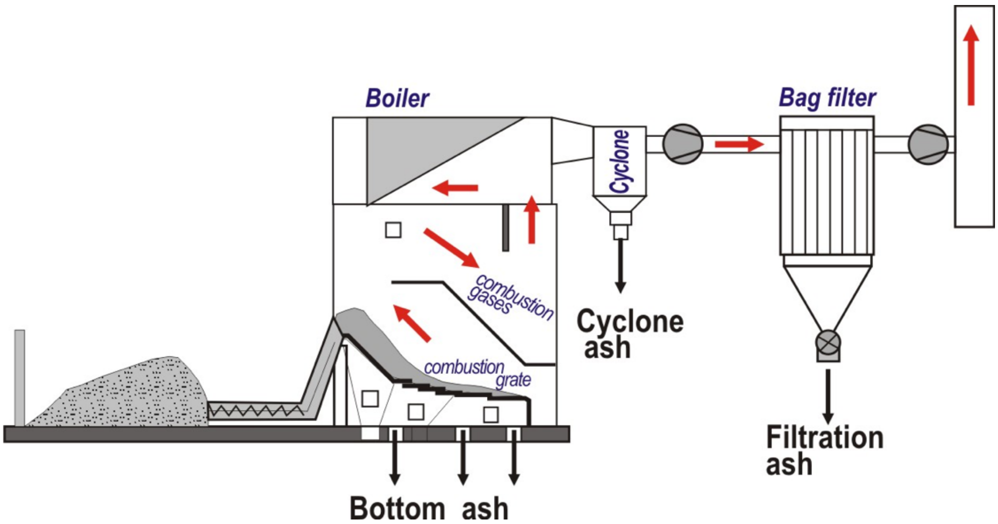


Fig. 1.1. Classification of ash from biomass combustion

The bottom ash is formed on the grate in the furnace. This ash fraction is often mixed with mineral impurities contained in biofuels, such as sand, stones and earth.

Cyclone ash includes small, mostly inorganic, ash particles that are carried out together with the flue gases from the furnace and deposited mainly in multicyclones located behind the furnace. This ash fraction mainly contains large particles of fly ash.

Filtration fly ash is the second, smaller fraction, deposited in electrostatic precipitators, fabric filters or in the form of condensation sludge in the condensation units of flue gases (usually located behind the multicyclones). This ash fraction mainly includes aerosols.

The mass distribution of ash fractions depends on the type of biomass combustion (***Table 1.1, Table 1.2***). The average particle density and bulk density of biomass ash depends on its fraction (***Table 1.3***). In addition to the type of fuel, they depend on the particle size of ash (***Table 1.4***).

Table 1.1. Distribution of ash fractions for different boilers and biomass combustion methods

Combustion type	Bottom ash (%)	Fly ash (%)
Grate combustion	60-90	10-40
Spread stoker	40-50	50-60
Pulverized fuel combustion	10	90
Circulating fluidized bed (CFB)	10-20	80-90

Table 1.2. Distribution of ash fractions for the grate combustion of some fuels (%)

Ash fraction	Bark	Wood chips	Sawdust
Bottom ash	65-85	60-90	20-30
Cyclone ash	10-25	10-30	50-70
Filtration ash	2-10	2-10	10-20

Table 1.3. Average particle density and bulk density of biomass ash [4]

Ash fraction	Average particle density	Bulk density	
		Average	Std. deviation
	kg/m³	kg/m³	kg/m³
Bottom ash	2600 – 3000	950	200
Cyclone ash	2400 – 2700	650	120
Filtration ash	2300 – 2600	350	120

Table 1.4. Influence of ash particle size on its bulk density [5]

Fuel	Ash fraction	Particle size, µm	Bulk density, kg/m³
Sawdust	Bottom ash	10-30 000	662
	Cyclone ash	2-100	283
Shredded wood	Bottom ash	15-15 000	960
	Cyclone ash	2-160	430

In general, the particle size depends on the type of fuel used, the ash content, the chemical composition of the ash and the amount of mineral impurities in the fuel. The particle size of bottom ash depends on its sintering (**Fig. 1.2**), while the particle size of fly ash depends on the technology used to separate fly ash, as well as on the chemical composition of biofuels.

The particle density decreases from bottom to filtration ash.

One of the main physical characteristics of ash is its melting point. The melting temperature affects the final composition and physical state of the ash after burning biomass or any fuel. The calorific value of fuel is also one of the important physical characteristics that affect the final state of the ash.

The total mass yield of ash during biomass combustion depends on its ash content, which in turn depends on the type of biomass. In addition, the ash content may differ even for one type of biomass. For example, oak trunk wood gives 0.35%, leaves – 3.5% and bark – 7.2% ash. The wood of branches contains more ash than the trunk wood; for example, birch and spruce branches gives 0.64 and 0.32%, and trunk wood – 0.16 and 0.17% ash.

Fig. 1.2. Classification of ash from biomass combustion

The abovementioned characteristics of some types of biomass are given below (**Table 1.5**).

Table 1.5. Average physical characteristics of ash for some biomass types (on dry basis)

Biomass type	NCV, MJ/kg	Ash content, %	Ash melting temperature, °C
Deciduous wood	18.8	chips with bark: 1.0-2.5 chips without bark: 0.8-1.4 sawdust: 0.5-1.1	1426
Softwood	18.4		1340
Bark	19.2	5.0-8.0	1440
Cerial straw	17.2	4.0-7.0	998
Sunflower husk	16.8	3.0-4.0	960
Miscanthus	17.6	2.0-5.0	973
Energy willow	18.4	1.0-2.5	1283
Grape chips	19.8	2.0-3.0	1450

The **Table 1.6** below shows the average content of basic chemical elements in the ash of different types of biomass [6],[7], taking into account the total ash.

Table 1.6. Typical chemical composition of ash after combustion of some types of biomass (% of dry matter weight)

Chemical element	Softwood chips	Softwood bark	Cereal straw (wheat, rye, barley)	Sunflower husk
Ca	26.0–38.0	24.0–36.0	4.5–8.0	3.7
K	4.9–6.3	5.0–9.9	10.0–16.0	28.8
Mg	2.2–3.6	2.4–5.6	1.1–2.7	1.2
Na	0.3–0.5	0.5–0.7	0.2–1.0	0.8
P	0.8–1.9	1.0–1.9	0.2–6.7	0.3
Si	4.0–11.0	7.0–17.0	16.0–30.0	21.3
C_{org}	0.2–3.1	0.2–1.1	9.0–16.6	n/a

The main factor influencing the elemental composition of ash is the type of combustible material. Incineration technology is a secondary factor that affects the quality of ash. Depending on various factors (type of biomass, combustion technology), the elementary composition of different types of biomass ash varies within very wide limits (**Fig. 1.3** and Annex 1).

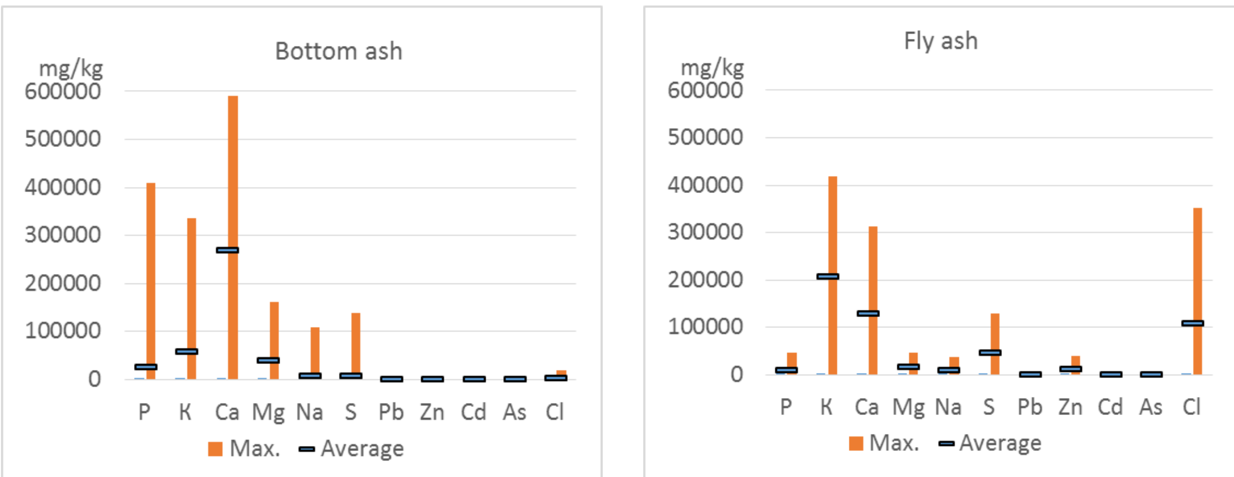


Fig. 1.3. The limit and average contents of chemical elements in the biomass ash [8]

Compared to the chemical composition of coal ash, biomass ash contains less iron, silicates, sodium and sulfur, but more potassium, manganese and barium [9].

Typically, the most environmentally important heavy metals (Zn and Cd) are mainly contained in volatile ash (***Table 1.7***), while nutrients (K, Mg and P) and lime components (Ca) are mainly found in bottom ash. Wood ash is the richest in calcium, and herbaceous ash is high in potassium. The reason for the higher content of zinc and cadmium in volatile ash compared to bottom ash is that these elements in the combustion process evaporate and settle on the volatile ash particles in the form of aerosols.

Table 1.7. An example of heavy metals content distribution in the ash fractions [10]

Element content, mg/kg of dry matter	**Cd**	**Pb**	**Zn**	**Cr**	**Cu**	**Ni**	**Hg**	**As**
Bottom ash	1	22	500	40	100	45	0.03	3
Fly ash	9	85	1150	70	130	62	0.23	4

Potassium, phosphorus and calcium, which are the most important compounds in terms of ash use as fertilizer, are contained in it mainly as oxides K_2O, P_2O_5, CaO.

1.2. Estimation of ash quantities from energy use of biomass in Ukraine

As of the end of 2019 – beginning of 2020, the total installed thermal capacity of biomass heat generating equipment in Ukraine was approximately 4 GW, excluding individual boilers installed in the family houses. The total ash quantities generated by energy use of biomass can be estimated based on the quantity of biomass used and the average ash contents of its kinds.

Fig. 1.4 shows the approximate amounts of bottom ash formation in the space heating boiler houses on different biomass fuels depending on their maximum required heat capacity, provided the heating season duration is 170 days.

Based on the analysis of data from the State Statistics Service on the use of different types of fuels in 2018 and taking into account assumptions about fuel characteristics, the total amount of ash from biomass combustion in Ukraine was estimated (***Table 1.8***). At the same time, the approximate distribution of used fuel between the population and enterprises and organizations was taken into account. The share of each type of fuel accounted as “final consumption” was accepted as the share of fuel biomass used by the population.

Table 1.8. Estimation of the ash generation from biomass combustion in Ukraine in 2018

Types of biomass fuels	Total used	Useful (except for non-energy purposes and losses)	The same in tons	Moisture, %	Ash, % of d.b.	Share of use,% by		Ash formation, taking into account 10% of fuel as unburnt, t		
						population	enterprises and organizations	Total	population	enterprises and organizations
Charcoal, t	908	905	905	10	1.5	22.1	77.9	12	3	10
Fuel briquettes and pellets from wood and other natural raw materials, t	424177	390748	390748	12	3.5	13.7	86.3	13 239	1 813	11 426
Firewood for heating, dense m^3	4187042	4163795	2914657	30	1.5	59.3	40.7	33 664	19 953	13 711
Wood shavings and wood chips, t	934442	932933	932933	40	1.5	8.4	91.6	9 236	775	8 461
Other solid biofuels of vegetable origin, t	1200001	1163490	1163490	15	5	6.7	93.3	54 393	3 639	50 754
TOTAL, t								110 544	26 183	**84 361**

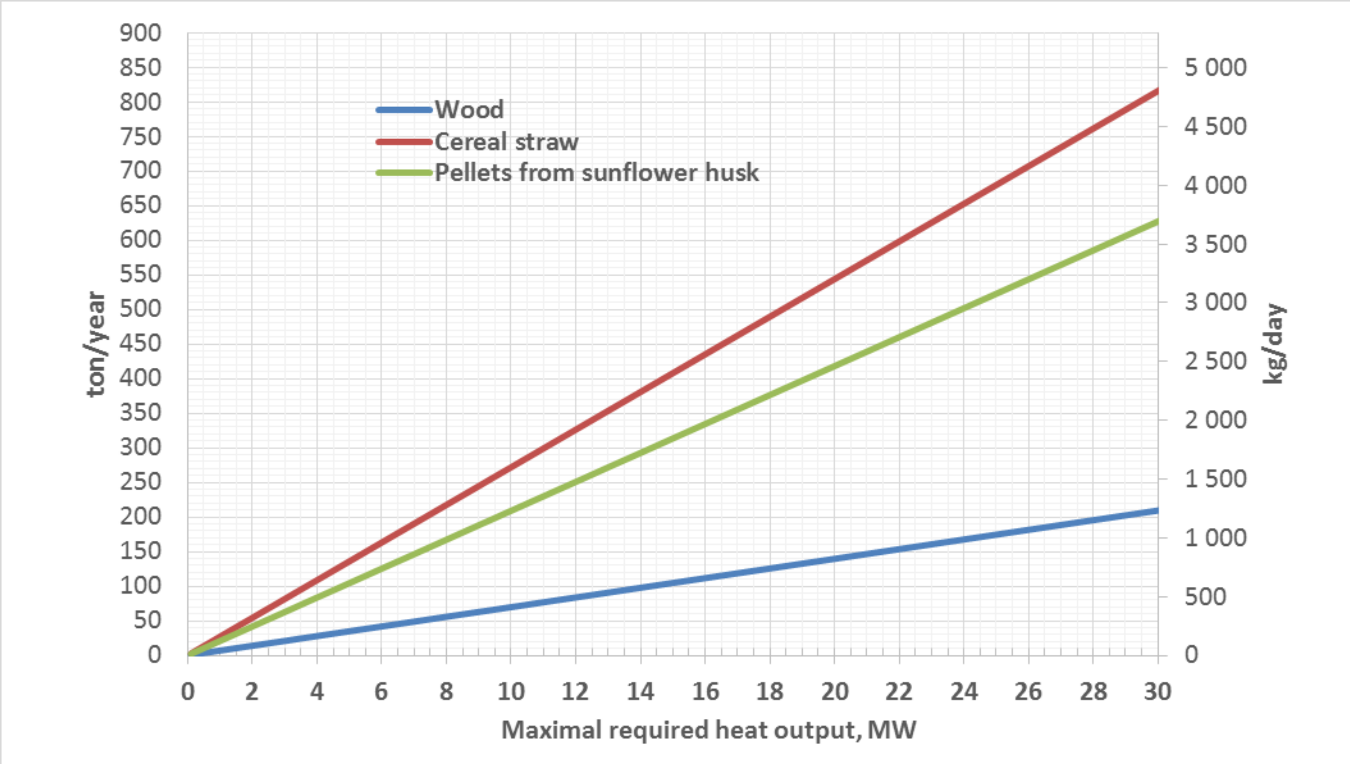


Fig. 1.4. Estimated formation of bottom ash in the boiler houses for space heating

Thus, based on the analysis, we can assume that various enterprises and organizations in Ukraine, consuming biomass fuels, generate about **84.4 thousand tons** of ash. Given that mainly grate combustion of biomass is used, it can be expected that 75% is bottom ash and 25% is fly ash, with 3-5% of ash being captured by cyclones and other flue gas cleaning systems, as only large installations are equipped by such systems. Thus, about 80% of total amount of biomass ash needs to be recycled or placed in landfills.

Based on this, we can assume that in 2018 **about 67.5 thousand tons** of biomass ash required the recycling or landfilling, not taking into account the ash generated by individual heating of population.

According to various estimates, from 6 to 15 million tons of ash and slag waste are generated annually in Ukraine by thermal power plants. According to the State Statistics Service, in 2018 the total amount of waste under the names "fuel slag" and "coal ash dust" was **6.2 million tons** [11]. Thus, currently the annual amount of biomass ash is about 1% of the annual amount of ash and slag waste from coal thermal power plants.

In the future, as the ratios of biomass and coal use in thermal and electrical generation change, so will the ratios of biomass and coal ash formation. If we take into account the prospects for bioenergy development in Ukraine until 2035 [12], for the period from 2018 to 2035 the consumption of solid biofuels should increase from 2.8 to 9.9 million t.o.e., ie 3.5 times. Given that the main reserve for the growth of energy use of biomass is straw and other agricultural residues, as well as energy crops, the average ash content of fuel biomass will increase by 1.5-2 times. In addition, due to the increase in the technical level of biomass energy plants and the strengthening of environmental requirements, the share of fly biomass ash captured by cyclones and filters may increase. Thus, the amount of ash compared to 2018 may increase 5-8 times, and in 2035 in industry and energy will be generated and required the recycling or disposal of **up to 550 thousand tons of biomass ash**. Given the prospects of reducing coal heat and power generation, in particular its possible cessation in the electricity sector by 2050 [13], biomass ash in the future may become one of the main sources of solid waste in the energy sector.

2. Current practice of biomass ash management in Ukraine and abroad

2.1. Legislative requirements in Ukraine for the ash handling

2.1.1. General terms

At present, there are no mandatory requirements in Ukrainian legislation for the reuse of ash from biomass heat generating plants.

According to the Law of Ukraine "On Waste" of 05.03.1998 № 187, "... **waste** – any substances, materials and objects formed in the process of production or consumption, as well as goods (products) that have completely or partially lost their consumer properties and **do not have further use at the place of their formation or detection and from which their owner gets rid of**, intends or must get rid of by disposal or removal". This law also sets requirements for waste classification, certification, accounting and reporting. **All types of waste during certification and primary accounting should be classified** in accordance with the State Classification of Ukraine "DK 005-96. Waste classifier"[14]. According to this classifier, **wastes include** newly formed substances and their mixtures in thermal, chemical and other processes and which are not the purpose of this production (**slag, ash**, bottom residues, other solid and pasty formations, as well as liquids and aerosols).

According to the current practice, biomass ash is mainly classified as waste of group 90 (Secondary wastes from the provision of services for the collection, disposal and treatment of waste). In this case, the following codes are used for biomass ash according to the class:

- **9010.2.9.01 –** Non-volatile residue and slag
- **9010.2.9.04 –** Fly ash

There are also cases of assigning biomass ash to group 40 (wastes of production and distribution of electricity, gas, steam and hot water) and assigning it the following codes:

- **4010.2.3.04 –** Solid wastes from the process of purification of other flue gases (ash captured by cyclones and filters at the boiler outlet)
- **4010.2.8.01 –** Fuel slag (actually ash from the boiler furnace – bottom ash)

According to the abovementioned law, hazardous waste is waste that has such physical, chemical, biological or other hazardous properties that create or may create a significant danger to the environment and human health and that require special methods and means of handling them. There are 4 classes of waste hazard. According to the existing practice[1], **bottom ash belongs to the 4th class** – "low-risk substances", **and fly ash – to the 4th or 3rd class** "moderately dangerous substances".

The **end result** of waste management can be:

- **utilization** – the use of waste as secondary material or energy resources;
- **disposal** – carrying out operations with waste that do not lead to their utilization;
- **landfilling** – the final placement of waste during its disposal in specially designated places or facilities so that the long-term harmful effects of waste on the environment and human health do not exceed the established standards.

[1] From January 1, 2019, the document GOST 12.1.007-76 "SSBT. Harmful substances. Classification and general safety requirements ", which determined the hazard classes, was cancelled, and there are no other document that would perform similar functions. Therefore, the uncertainty in this matter currently exists.

Depending on the amount of waste generated at the enterprise, business entities in the field of waste management, whose activities lead exclusively to waste generation, get **limits on waste generation and disposal**, may be required to obtain a **permit** for operations in the field of waste management and to submit **annual waste declarations**.

A special **passport** is issued for each place or object of waste storage or disposal, indicating the name and code of waste (according to the state classification of waste), their quantitative and qualitative composition, origin, as well as technical characteristics of places or objects of storage or disposal, and information on methods of control and safe operation of these places or facilities.

Article 40 of the Law of Ukraine on Waste provides **incentives for waste disposal and reduction of their generation to economic entities** that implement technologies aimed at reducing waste generation, dispose of waste in the production process (works, services), carry out its collection and procurement, construction of enterprises and shops, as well as organize the production of equipment for waste disposal, participate in the financing of measures for waste disposal and reduce the amount of their generation.

Incentives include: benefits for taxation of profits from the sale of products made using waste; priority government lending; special state subsidies to reduce interest on bank loans related to investments aimed at waste disposal and manufacture of relevant equipment; subsidies from the State Budget of Ukraine and local budgets for the transportation of waste (secondary raw materials) or semi-finished products obtained from this waste; informing about technological possibilities of waste utilization; grants from environmental protection funds and other sources; benefits for replenishment of working capital of enterprises engaged in the collection and procurement, treatment (processing) and disposal of waste as a secondary raw material, provided the targeted use of these funds for the purchase and processing of such waste.

However, the main way to treat ash in Ukraine is to bury it in landfills or to take it illegally to places not intended for it.

2.1.2. Ash storage requirements

According to the standard DSTU 4462.3.01: 2006 "Nature protection. Waste management. The order of operation", storage of waste, as its temporary placement on the territory of enterprises, institutions, organizations may be as follows:

- **technologically caused** – storage in production premises (shops, sections, auxiliary facilities, etc.), which is associated with its initial collection and accumulation;
- **intermediate** (before final removal or disposal) storage – on industrial sites, in stationary and non-stationary warehouses, under temporary cover, etc.

Moderately hazardous waste (class III) is collected in containers that ensure its localization, in particular open (unless otherwise agreed in the prescribed manner), which allows for loading and unloading and transport work, prevents adverse effects on human health, spread of harmful substances in the environment. Such waste is stored in open or closed containers (boxes, bags, packages, etc.).

Low-hazardous waste (class IV) is collected in open containers or in the form of a cone-shaped pile in conditions that allow to perform loading, unloading and transport works. These wastes can be **combined with municipal** (household) wastes at the placement sites or used as insulating material, as well as for various purposes in the case of land use planning without adverse effects on the environment and human health. **Such waste can be stored openly in bulk**.

For **collection and temporary accumulation of waste** at enterprises, shops, the **appropriate sites** should be allocated and equipped, marked containers, compartments, bins, etc. installed with clear indication of the type of waste, group, degree (class) of hazard, (including toxicity), brands. The design and dimensions of the container should ensure **easy filling and shipment of waste and prevent their mixing, as well as pollution and spoilage of waste** that can be used as secondary raw materials.

Storage of moderate and low-hazardous waste (III-IV classes) on the territory of industrial sites **in the open** (in bulk, in open containers, etc.) is allowed if the following requirements are met:

- **concentration of harmful substances** in the air up to 2 meters height from the ground, in the soil of the sanitary protection zone, due to the migration of toxic waste ingredients, as well as in surface waters should not exceed the established standards;
- **the territory** of industrial site must be located on the leeward side, **to have a cover** made of material impermeable to toxic substances and be equipped with an autonomous drainage system. The penetration of surface runoff from the site into the general drainage system must be prevented by **embankment** and other measures. Special **treatment facilities** providing catching and neutralization of toxic substances are necessary for the specified drain;
- store waste in **protected conditions from precipitation and wind**.

These requirements do not apply to specially equipped waste disposal sites (sludge accumulators, slag dumps, etc.), built according to the relevant projects. **Long-term (more than 2 years) waste storage facilities** are equated to their disposal sites and are subject to the relevant requirements for monitoring, control and certification of waste disposal sites.

According to the current norms DBN B.2.2-12:2019 "Planning and development of territories", the conditions of placement of ash dumps and determining the size of sites for them should be provided for the norms for boiler plants. In turn, the norms DBN B.2.5-77:2014 "Boiler houses" indicates that ash and slag dumps are allowed to be located outside the boiler room site. If it is impossible to use ash and slag for the needs of construction industry, **ash and slag dumps should be designed if the size of the site for slag dump allows to operate the boiler house for at least 25 years**, with allocation of the first construction stage for 10 years. For this purpose, ash and slag dumps are placed near the territory of the boiler house, using, if possible, land plots unsuitable for agriculture, lowlands, ravines, wetlands, developed quarries intended for remediation, taking into account future development of the construction area and protecting water bodies from possible ash and slag removal by rain or flood waters.

Thus, the **design of special places for permanent storage of ash and slag is necessary only in the case when it is not regularly removed for useful disposal**.

2.1.3. Possibilities of utilization

Utilization is aimed at full or partial replacement of traditional raw materials and fuel with waste; removal of other components from it; use of waste as charge materials, semi-finished products, etc.

At present, **Ukrainian legislation does not have mandatory requirements for the utilization of ash from heat generating plants**, including ash from biomass combustion. There is also no exact data on the level of practical application of ash in construction or other industries. Ukraine has developed a number of **state standards** that provide for the use of fly ash and hydraulic ash removal as a component of cement mixtures, concretes and paving materials (see Annex 2). But fly ash or hydraulic ash removal means **only ash from coal combustion at thermal power plants**. As result of the harmonization of Ukrainian legislation with EU legislation, some standards allow the use of ash according to the **EU standard**, but **it is also ash from dust combustion of coal or co-firing of coal with other materials**.

The **National Waste Management Strategy in Ukraine until 2030** [15], approved in 2017, could make a certain contribution to changing the situation regarding the use of ash. The strategy aims to introduce a systematic approach to waste management at the state and regional levels, reduce waste generation by increasing its recycling and reuse. Its implementation was planned in three stages: the first - 2017-2018, the second – 2019-2023, the third – 2024-2030. It is expected that the implementation of the Strategy will contribute to the implementation of a waste management system on an innovative basis; development of relevant legislation; improving the state of the environment, as well as the sanitary and epidemiological well-being of the population. It is also planned to attract investments in the field of waste management, and thus the creation of modern infrastructure, introduction of new technologies, reducing the amounts of its disposal in landfills, etc.

2.1.4. Removal of ash to landfills

Wastes that belong to hazard class 4 (including ash) can be stored openly on an industrial site in the form of a cone-shaped pile, from where they are reloaded into a dump truck and delivered to the place of disposal.

The relevant tax is paid for waste disposal (***Table 2.1***).

Table 2.1. Waste tax rates, set depending on the hazard class and level of hazard of the waste [16]

<table>
<tr><th>Waste hazard class</th><th>Waste hazard level</th><th colspan="2">Tax rate, UAH per 1 ton</th></tr>
<tr><td>I</td><td>extremely dangerous</td><td colspan="2">1405.65</td></tr>
<tr><td>II</td><td>highly dangerous</td><td colspan="2">51.2</td></tr>
<tr><td>III</td><td>moderately dangerous</td><td colspan="2">12.84</td></tr>
<tr><td>IV</td><td>low-risk</td><td colspan="2">5</td></tr>
<tr><td></td><td>low-hazardous non-toxic waste from the mining industry</td><td colspan="2">0.49</td></tr>
<tr><td colspan="4">Coefficient to tax rates, which is set depending on the place (zone) of waste disposal in the natural environment</td></tr>
<tr><td colspan="3">Waste location (zone)</td><td>Coefficient</td></tr>
<tr><td colspan="3">Within the settlement or at a distance of less than 3 km from such boundaries</td><td>3</td></tr>
<tr><td colspan="3">At a distance of 3 km and more from the boundaries of the settlement</td><td>1</td></tr>
</table>

It should be noted that for the disposal of waste for which no hazard class is established, the tax rate **set for the disposal of waste of hazard class I** is applied.

According to the standard DBN B.2.4.2-2005 "Landfills for solid waste. Basic design provisions", solid waste from residential and public buildings, institutions, trade and catering enterprises, as well as street, garden, construction waste and some types of solid inert waste on the basis of appropriate justification, as well **as industrial waste of III - IV classes of danger (including slag of boiler houses and CHP)** are accepted at landfills **with the permission of local bodies** of sanitary-epidemiological and ecological services and fire inspection. Industrial waste of hazard class IV **can be used at the landfill for solid waste as an insulating material**. Fine-grained industrial waste (hazard class IV) with a grain size of not more than 0.5 mm, **can be used at landfills to protect artificial waterproofing from mechanical damage**.

To what extent can the waste disposal fee affect the **economics of biomass heat production**? If we assume that 70% of 1 ton of ash is waste of the hazard class IV, and 30% of the class III, the fee for placing this ash at a distance of more than 3 km from the settlement border will be 7 UAH. Transportation of 1 ton of ash (for example, a truck of 3 tons, 15 km, at a price of 20 UAH/km), will cost 100 UAH, or almost 14 times more. If 1 ton of fuel biomass produces 50 kg of ash, the cost of its removal to the landfill in terms of fuel biomass is **equivalent to increasing the price of 1 ton of fuel by 5-6 UAH (or 0.15-1%)**.

2.2. Obtaining permission to use ash as fertilizer

According to the Law of Ukraine "On Licensing of Economic Activities" [17], the production of agrochemicals is not included in the list of licensed activities, ie their production **does not require a license**.

The **Law of Ukraine "On Pesticides and Agrochemicals"** defines the following basic requirements for these products:

- **high biological efficiency in relation to the intended purpose**;
- safety for human health and the environment, provided that the regulations of their application are observed;
- compliance with state standards, sanitary norms and other normative documents.

This law also sets requirements for the use of pesticides and agrochemicals, namely:

- **prohibition** of import into the customs territory of Ukraine, production, trade, use and advertising of pesticides and agrochemicals **before their state registration**, except for the cases established by this Law;
- the need for the Ministry of Environment to enter information on the registration of this agrochemical in the single state information web portal "Single Window for International Trade".
- the **possibility to use the agrochemical without state registration**, if it is specified in the **relevant list**, which is an appendix to the Law (biomass ash is not included in this list[2]).
- general procedure for conducting state tests of pesticides and agrochemicals.

State tests of pesticides and agrochemicals of domestic and foreign production are carried out for the purpose of biological, toxicological-hygienic and ecological assessment and development of regulations for their use. Enterprises and organizations authorized by the Ministry of Environment and included in the relevant **List** [18] have the right to conduct tests.

State tests of pesticides and agrochemicals are carried out in two stages: field and production.

The purpose of field tests is to **determine or confirm the biological effectiveness of new pesticides and agrochemicals compared to those used**, to develop temporary regulations for their use and in-depth study of formulations.

Production tests are conducted to **confirm the biological effectiveness** of pesticides and agrochemicals **in different areas of Ukraine**, clarification and justification of regulations and methods of their application, sanitary and environmental standards, development and modification of methods for determining residual amounts of these pesticides and agrochemicals.

The approved **Test Procedure** [19] defines the relevant procedure, the main stages of which are listed below:

- Development of **draft Technical Requirements (TR)** of the agrochemical and submission of a package of documents for its inclusion to the plan of state tests.
- **Examination** of the submitted documents in the State Food and Consumer Service, determination of the necessary research and organizations that will conduct tests.
- Inclusion of the agrochemical in the **state test plan**, approval of the test plan.
- Production of experimental batches of the agrochemical in the quantities required for testing.

[2] If it is possible to prove in any way that the obtained ash is one of the types of fertilizer listed in the list, then such ash can be used in agriculture without state tests, state registration and re-registration.

- Conducting state tests of agrochemical with a new active ingredient during **two full growing seasons**. Based on the results of field tests, the Ministry of Environment determines the scope of state tests, and **in case of non-establishment or non-confirmation of the biological effectiveness of a new agrochemical compared to those already used**, decides to withdraw the agrochemical from further state tests.
- During the state testing of agrochemicals, the Ministry of Health provides **toxicological and hygienic assessment** of the agrochemical and the conditions of its use, develops the necessary hygienic standards and regulations.
- Registration of the active substance in the Committee for Hygienic Regulation of the Ministry of Health.
- Submission of a package of documents for state registration of the agrochemical, including report on the results of state tests.
- Carrying out **sanitary and hygienic examination** (State Service of Ukraine on Food Safety and Consumer Protection), and ecological-expert assessment of materials submitted for registration of pesticides and agrochemicals (Ministry of Environment).
- Approval of the results of the state sanitary and hygienic examination and ecological expert assessment of the materials submitted for registration.
- Consideration of examination results and registration documents by independent experts of the scientific-expert council formed under the Ministry of Environment, development of proposals and recommendations on the possibility of state registration of the agrochemical.
- Recommendations for the registration of the agrochemical in connection with its biological and economic effectiveness are also provided by the institute – the executor of state tests and approved by its scientific council.
- In case of positive results of examinations and recommendations of the scientific-expert council, the Ministry of Environment **decides on the state registration of the agrochemical**. Negative conclusion of the state sanitary-epidemiological examination, negative ecological-expert assessment of the materials submitted for registration of pesticides and agrochemicals are the basis for the decision to refuse registration.
- The agrochemical is entered in the **State Register of Pesticides and Agrochemicals**.
- The decision on state registration of agrochemical takes effect from the moment the agrochemical is entered in the State Register of Agrochemicals and expires at the end of the year (December 31), determined by the registration deadline.

The payment for registration of agrochemicals is determined by the relevant Order [20].

In general, the **procedure for testing and registration of new pesticides and agrochemicals is quite long** (taking into account field tests – at least 2 years).

There are certain possibilities of using ash in **organic production**. Organic production is a holistic system of food management and production, which combines best practices in terms of environmental protection, biodiversity, conservation of natural resources, the application of high standards of proper maintenance (welfare) of animals and a method of production that meets certain requirements for products made using substances and processes of natural origin. Until recently, Ukraine did not have effective legislation on organic production, including requirements for its certification. The process of certification of lands and farms was carried out by non-governmental institutions in accordance with the requirements of EU Council Regulation 834/2007, which contains rules and requirements for organic production and operates throughout the EU. Recently, Ukraine has adopted the Law of Ukraine "On Basic Principles and Requirements for Organic Production, Circulation and Labeling of Organic Products" [21], and a number of bylaws have also been adopted and are being prepared for adoption.

A characteristic feature of organic production is **the restriction for use of chemicals of artificial origin**. Agriculture with the use of organic technologies aims to maintain the natural fertility of the soil. Plant nutrition should mainly pass through the soil ecosystem. Wastes and by-products of plant and animal origin must be processed for further plant nutrition. **The use of fertilizers and non-renewable plant nutrients should be minimized**. Appropriate fertilizers can only be used if these measures are insufficient. Its choice is clearly limited, and use must be documented.

According to the draft "**List of substances** (ingredients, components) that are allowed to be used in the organic production and which are allowed for use in maximum permitted quantities" [22], the use of wood ash is allowed if it has not been chemically treated after felling. However, the possibility of using ash from combustion **other types of vegetable raw materials** is not mentioned in the draft list.

But it should be mentioned that the Law of Ukraine "On Basic Principles and Requirements for Organic Production, Circulation and Labeling of Organic Products" states that the above list of substances allowed for use in organic production is formed **exclusively from substances (ingredients, components); the use of which is permitted in agriculture**. That is, the registration procedure according to provisions of the Law of Ukraine "**On Pesticides and Agrochemicals**" is still required.

2.3. The existing practice of ash treatment in Ukraine

In addition to the removal of solid waste to landfills, it is common use of ash from biomass combustion as fertilizer. **Basically, ash is used as fertilizer in home gardens**. Thepopulation use ash from biomass combustion in own stoves or boilers. There are also many cases when the population **has got biomass ash from nearby boiler houses, usually free of charge**.

There are also some **examples of commercialization of biomass ash use as fertilizer**. Some manufacturers offer biomass ash for sale, packaged in bags or big bags, sometimes in a mixture with other components, such as compost or lime.

Among such agrochemicals, to the State Register of Pesticides and Agrochemicals Permitted for Use in Ukraine [23] are included:

- "Ecoplant (sunflower ash)" from the company "ORIY", Ukraine, defined as a mineral fertilizer (composition: P2O5 – 7.66%, K2O – 49.29%, MgO – 10.03%, CaO – 12.26 %), for use in growing potatoes.
- "Ecosoil" from the company "Lignin", Ukraine, defined as a compound mineral fertilizer of plant origin (composition: potassium (K2O) – not less than 20.0%, phosphorus (P2O5) – not less than 5.0%, magnesium (Mg) – not less than 5.5%, calcium (Ca) – not less than 8.0%, total sulfur (S) – not less than 3.5% Main trace elements: iron (Fe) – not less than 1340 mg/kg; zinc (Zn) – not less than 300 mg/kg, copper (Cu) – not less than 240 mg/kg, manganese (Mn) – not less than 200 mg/kg, molybdenum (Mo) – not less than 1.5 mg/kg; cobalt (Co) – 0.37 mg/kg, mass fraction of water – not more than 9.0%, mass fraction of potassium in terms of (K2O) – 34.34%), for use in crop production, vegetable growing, horticulture, ornamental farming.

A number of manufacturers offer agrochemicals that are not included in the state register, for example:

- Wood ash "TM AGRO-X" [24] in packages of 1 kg, active substances: potassium, phosphorus, calcium, magnesium, iron, sulfur, zinc, boron. Purpose – fertilizer for vegetable growing.
- "Wood ash" [25] from the company "Wood Fuel", in packages of 0.5 kg, as a fertilizer for vegetable growing.

- "Wood ash" [26] from PE OVI, composition: phosphorus P – 7%, potassium K – 24%, calcium Ca – 18%, magnesium Mg – 12%, other trace elements as a fertilizer for vegetable growing and floriculture.
- "Sifted wood ash" [27] from TM OGOROD, in packages with Zip-lock, 1 liter each, as a fertilizer for vegetables and horticulture.
- "Buckwheat ash" [28] from PE Kharitonov, composition: P – 6.8%, K – 35%, Ca – 18%, Mg – 12%+ trace elements, in a package of 1 kg, as a fertilizer for vegetables and horticulture.
- PrimeEco fertilizer based on sunflower ash [29], in big-bag packages of 1 ton and plastic bags from 2.5 to 40 kg. Main components: potassium (K) – 28-38% *, calcium (Ca) – 11-13%, phosphorus (P) – 4-8% *, magnesium (Mg) – 6-9%, sulfur (S) – 3-6%. Used on any soil, for all crops and in horticulture.
- "Sunflower ash" [30], manufacturer PE Ostroverkhy, in packages of 1 kg, composition: phosphorus – 6-7%, potassium – 24-30%, calcium – 18-28%, as a fertilizer for vegetable growing.
- "Sunflower ash" [31], manufacturer "Agro World", in packages of 2 liters, as a universal organic and mineral fertilizer.
- "Sunflower ash" [32], manufacturer "Dim Sad Gorod", in packages of 1 liter, as a universal organic and mineral fertilizer.
- "Sunflower ash" [33], "Sunflower ash + lime" [34], manufacturer "Agroopt +", in packages of 2 kg (composition: phosphorus – 6-7%, potassium – 24-30%, calcium – 18- 28%, magnesium, iron, boron, manganese, sulfur, zinc, molybdenum) as a fertilizer for vegetable and fruit crops.
- Sunflower ash in big bags of 300 kg from Energospetsinvest Comfort LLC, at the price 800 UAH/ton. Composition: (P_2O_5) – 6.8%, (K_2O) – 35.2%. The company has built and operates DH **boiler house** in the city Zaporizhia of **12 MW** installed thermal capacity **on sunflower husk pellets**.
- "Sunflower ash" – other offers (up to 10 producers). There are offers at the price of 1000 UAH/t with delivery.
- Ash from burning wood [35] (coniferous, softwood and hardwoods), as well as from burning sunflower pellets – private advertisement. In stock 30-40 tons, the price is 2,2 UAH/kg.
- Nikaprom Group [36] (city Dnipro) buys ash from burning straw and other agricultural waste and sells it as fertilizer.
- Private advertisements for the purchase and sale of ash of various types of biomass. https://flagma.ua/zola-so253420-1.html.

The **large offer of fertilizers on the basis of sunflower ash** attracts the attention. Given that the by-products of sunflower cultivation (stems, baskets, etc.) are used as fuel very limited, it can be assumed that the source of raw materials for the production of such fertilizers is ash formed at sunflower oil production plants from burning sunflower husks. Due to the relatively high heat capacity of heat generating equipment and almost year-round operation of these plants, a large amount of sunflower husk is used and, accordingly, a significant amount of ash is formed and concentrated in one place, which facilitates logistics.

In the future, supply of sunflower ash as fertilizer may increase, as a number of oil companies are planning to build new thermal power plants (for example, oil plants of Kernel company). Also, the company "Potoky" began construction of its own thermal power plant at the oil extraction plant in the Dnipro city [37]. The planned fuel is sunflower husk, and the ash will be used as fertilizer.

But not only sunflower oil companies want to sell ash as fertilizer. So, the preparation of technical requirements for compound organomineral microfertilizer **"Popilogumat"** is carried out at the enterprise **"Smilaenergopromtrans"** (biomass CHP in Smila, Cherkasy region). It is noted that this microfertilizer is a highly effective humic fertilizer with trace elements in chelated form, which have the properties of plant growth stimulants and are antidepressants for almost all crops. The microfertilizer can be used for complex treatments of agricultural plants, starting from seed treatment and subsequent treatment of vegetative plants. It can be used in a mixture with most fertilizers, biologicals and growth regulators with a synergistic enhancement of their action. The conclusion of Cherkasy Regional State Design and Technology Center for Soil Fertility Protection and Product Quality on the quality of wood ash was obtained (see Annex 3). The conclusion indicates a high content of **phosphorus and potassium**. The ash has an alkaline reaction, the content of trace elements and heavy metals is within acceptable limits obtained by other researchers. Given the acidity of this sample (pH 14), the use of ash as fertilizer and chemical ameliorant can be recommended. It is necessary to pay attention to the **rather high content of heavy metals** (cadmium, manganese and lead).

Khmelnytsky Biofuel Power Plant LLC, which is planned in Khmelnytsky region, has a planned electric capacity around 40 MW and will use cereal straw as fuel. In 2018, the company prepared the Technical Requirements "Ash from plant residues" and received the conclusion of the sanitary-epidemiological examination, which states that the ash meets the established medical safety criteria, the parameters of toxicometry meets the 4th class of danger. The company plans to sell ash as fertilizer.

2.4. Foreign experience of ash application

The theory and practice of ash use, including biomass ash, indicates the possibility of its application in agriculture, construction, energy, metallurgy, etc. The main areas of its application are as follows:

Agriculture and forestry:

- raw materials (source of nutrients) for the production of fertilizers to be used in fields and forests;
- research sites for growing and cultivating new plant species.
- **Construction industry:**
- production of cement clinker, ash is used as an additive to increase the content of magnesium and sand;
- production of bricks, ash is used for sand replacement;
- production of alternative binders (polymers, etc.);
- production of synthetic units of cold gluing or sintering, ash is used as the sand substitute;
- production of non-reinforced precast concrete.

The main areas of ash use in some countries are shown below (***Table 2.2***).

Table 2.2. Directions of biomass ash utilization in some countries [38]

Country Utilization:	Austria	Canada	Denmark	Germany	Italy	Netherlands	Sweden
Landfill/disposal	**Yes (A)**	**Yes (A)**	Yes (A)	Yes (A)	Yes (A)	Yes (A)	**Yes (A)**
Cement raw meal additio	Yes (B)	Yes (B)			Yes (B)		No
Cement and concrete fill					Maybe (B)	Yes (B)	
Use in forestry	No		**Yes (A)**			Maybe (B/C)	Yes (A)
Soil amendment/fertilizer	Yes (C)	Yes (A)	**Yes (A/C)**	Yes (A)	Yes (A)	**Yes (C)**	No
Addition to Compost	Yes				Maybe	Maybe (B/C)	
Asphaltic filler	Maybe (B)	No			Yes (B)	Yes (B)	No

Underground mining				Yes (A)	No	Yes (A)	No
Civil engineering	Yes (A)	Yes (A)	Yes (A)	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Other building materials	Yes (B/C)				Maybe (B/C)	Yes (B/C)	No
Other uses undefined		Yes (B/C)					
Export, undefined					**Yes (A/C)**		Yes (A/C)

Yes = Is applied in a country
Bold = Major application in a country
Maybe = application in review/research
A = Final use
B = Depending on technical specifications
C = Depending on regulatory requirements

Ash can be used **as a building material** that increases the load-bearing capacity in road construction and an addditive to stabilize the soil in road construction, where it replaces lime as a binder. In energy, ash is rarely used at the experimental level as a backfill and auxiliary material in chemical and electrochemical treatment and as a filtration material. In the metallurgical industry, ash is used as a useful additive, due to the large amount in its composition of phosphorus, potassium, magnesium and other chemical elements used in the manufacture of cast iron and steel.

In the EU, the issue of **sustainable use of biomass**, which involves the **return of minerals contained in biomass ash, to their natural cycle**, is of great importance. On the other hand, the **safety of ash use** for humans and the environment is of paramount importance, so appropriate restrictions are imposed, in particular on the heavy metals content. The method of ash disposal should be cost-effective or at least the least expensive.

With regard to the use of biomass ash as fertilizer in agriculture or forestry, some countries have requirements not only for the maximum content of heavy metals, but also for the minimum content of essential nutrients such as potassium, calcium, magnesium, phosphorus and nitrogen (see Annex 4).

As a rule, **biomass filtration ash, as well as ash from combustion in the fluidized or circulating fluidized bed, cannot be used as fertilizer** (the latter due to the high content of ballast substances and, accordingly, low nutrient content).

The features of some countries regarding the ash application as fertilizer in agriculture or forestry are described below.

Austria

Austria has a **directive on the utilization of biomass ash in agriculture**. It is allowed to use ash obtained only by combustion of **chemically untreated biofuels**. The filtration ash is collected separately and disposed of after appropriate treatment. The maximum application rate of ash is up to 2 t/ha per year in fields and up to 1.5 t/ha in pastures and meadows. It is allowed **to add ash to the compost** (up to 2%). In general, the use of ash in agriculture is insignificant.

Denmark

The use of ash in agriculture as an auxiliary fertilizer meets the requirements of national legislation on biomass, as well as the general trend for the maximum possible utilization of secondary raw materials. The most common method is **to scatter in the field, followed by plowing into the ground**. There are certain **restrictions** on the application of ash into the soil: no more than 5 tons/ha for 5 years. The application of a number of substances into the soil, in particular cadmium and phosphorus, is also limited. As for phosphorus, there is a limit of 30 kg/ha for both agriculture and forestry.

Another use is to **add it to compost** to speed up composting. Subsequently, the resulting compost is plowed into the soil. It is believed that it helps to improve the condition of soils, increase the permeability of surface layer and for better use of the potential of compost as fertilizer.

The use of ash as a **fertilizer for forestry** is also allowed, but this method is rarely used, as Denmark is mainly an agricultural country where few forests are exploited for commercial timber harvesting, and therefore the loss of forest soil nutrients is negligible.

Germany

Wood ash is mainly used as **fertilizer and liming agent for the forest soils**. Only unprocessed wood ash is allowed, which must also comply with national legal requirements for fertilizers. There are restrictions on the content of heavy metals in accordance with the laws on soil protection and forestry. It is allowed to add ash to the compost (up to 5%) in order to regulate its acidity.

Bavaria has special rules for the use of ash. Thus, a mixture of ash and dolomites is used for liming of forest soils. At the same time, there is a two-level control: the quality of ash and the quality of ash-dolomite mixture.

Italy

Basically, biomass ash is considered as "special waste", the treatment of which is entrusted to authorized enterprises. Mainly the ash ends up in landfills or is used in the construction industry. It is allowed to be used in the chemical industry for the production of fertilizers, as well as the use of ash from the burning of untreated wood in organic farming as fertilizer and soil improver. As a rule, biomass bottom ash from large boilers or CHPs is used in industry or ends up in landfills. Ash from small boiler houses and private boilers can be taken to landfills or used as fertilizer directly or as a compost additive. Part of the ash is exported outside the country.

Netherlands

There is no special legislation in the country on the use of biomass ash or even wood ash as a fertilizer for forestry, so such use is not allowed. The use of biomass ash as a fertilizer in agriculture is permitted **provided that it complies with national legislation on fertilizers**, especially on the content of heavy metals. It is peculiarity because not only its absolute content is considered, but also relative to the main active component of the fertilizer. Since the ash usually does not have a main component, but has several with the higher content, the ratio of heavy metal content to one of the components is often greater than the established limit, and the use of ash is not allowed.

Sweden

Wood ash is recommended to be used as a **fertilizer in forestry** after cleaning from impurities. There are requirements for the minimum content of nutrients and the maximum content of harmful elements. Before use, the ash should be **stabilized** (by adding water, self-curing or granulation), and its dose should be determined according to the acidity of the soil. As a rule, apply a dose of 2-3 tons per hectare during the rotation period (70 years).

Finland

It is allowed to use wood ash, ash of agricultural plants and peat as **fertilizer in agriculture**. The use of filtration ash is not allowed. The content of certain trace elements and heavy metals, especially cadmium, is also limited. There are restrictions on the minimum content of nutrients: for agricultural use not less than 2% (P + K) and not less than 8% Ca; for forest fertilizer not less than 1% (P + K), not less than 6% Ca and not more than 2% chlorine.

Canada

Different provinces of Canada have different legal requirements for the use of biomass ash as fertilizer. Some of them consider such ash as waste of a certain degree of danger. In some provinces, **the use of ash as fertilizer or soil improver is permitted after appropriate analyzes** for macro- and micronutrients and heavy metals. In some cases, an environmental impact assessment is carried out. According to statistics, up to 18% of the ash produced in Canada's pulp and paper mills is used as a soil improver.

Generally there are no specific legislation on the use of biomass ash as fertilizer or soil improver in other European countries.

STRUBIAS project

In June 2019, the European Parliament adopted a new EU Fertilizing Products Regulation (EU) No 2019/1009 [39], which replaces the previous EU Fertilizer Regulation (EC) No 2003/2003. Now the provisions of the Regulation also apply to fertilizers for which various types of secondary raw materials are used.

The STRUBIAS project is managed by the Joint Research Center of the European Commission in Seville. **The purpose of this project is to make more attractive the use of fertilizers, soil improvers derived from secondary materials in European practice**. The roadmap for the introduction of the circular economy, adopted by the European Commission, considers the new Fertilizer Regulation to be key to expanding the secondary raw materials market.

Currently, the project has developed a possible legal framework for the production and marketing of safe and effective fertilizers derived from biogenic waste and other secondary raw materials. In particular, three categories of fertilizers were evaluated:

- precipitated phosphate salts and derivates;
- materials and derivates of thermal oxidation (**including biomass ash**);
- residues from pyrolysis and gasification processes (including biochar).

The report contains technical proposals for acceptable input materials, process conditions, quality requirements and quality management system.

Obviously, in the near future we should expect **the implementation in the EU legislation of new approaches to the use of secondary materials based on the circular economy principles**, including application of biomass ash as fertilizer in agriculture and forestry.

3. Basic concepts of fertilizer application system. Amounts and tendencies of its use

3.1. Types of fertilizers and their importance for increasing crop yields

Fertilizers are substances designed to improve plant nutrition and increase soil fertility. By applying fertilizers, the processes of plant nutrition, change the quality of the crop and soil fertility, physical, chemical and biological properties of the soil can be controlled,. Studies by Ukrainain scientists have shown that the **use of fertilizers provides an average of 40-50% increase in yields** of major crops, which is much higher than the share of yield growth from varietal seeds, plant protection products or tillage. Depending on soil, climatic and other conditions, the increase in yield from fertilizer application varies considerably. Thus, in the Polissya zone it is 60%, in the forest-steppe zone – 40%, in the humid steppe – 15%, in the dry steppe – 10% and in the irrigated steppe – 40%.

Fertilizers can be classified by **method of production** (local and industrial), by chemical composition (mineral, organic, organo-mineral), by **physical state** (solid and liquid), by the **action on the soil** (hydrolytic and hydrolytic alkaline) and plants (direct and indirect actions).

Mineral fertilizers are products of industrial or natural origin that contain nutrients in mineral form. They are sometimes called “tuks”, and the fertilizer industry is called the “tuk” industry. Mineral fertilizers are classified by chemical and physical condition, the nature of interaction with the soil, the method of production.

The fertilizers by its composition are divided into: **compound** (composition meets the requirements of individual crops); **universal** (used on several types of crops); **mono- and two-component** (to eliminate the lack of a single element). By **purpose**, fertilizers are for professional and farming, for horticulture, vegetable and greenhouse farming, for the private sector (hobby sector).

The **active substance of the fertilizer** is the main nutrient contained in it. Doses of fertilizers that are recommended for application to crops are usually expressed in kilograms of active substance per 1 ha: nitrogen – nitrogen (N), phosphorus – phosphoric anhydride (P2O5), potassium – potassium oxide (K2O). The fertilizers may be **simple**, if contain one nutrient (nitrogen, phosphorus, potassium – macronutrients; boron, manganese, molybdenum – trace elements), and **compound**, containing two or more nutrients.

The fertilizer application system includes:

- **Basic fertilizing** – application of complete fertilizer (NPK) in the form of organic and mineral fertilizers for plowing, as well as before planting and sowing crops.
- **Pre-sowing fertilizing** – application of fertilizers during pre-sowing tillage.
- **Sowing fertilizing** – fertilizing at the same time as sowing or planting crops, it improves the nutrition of young plants that still have a small root system. Sowing fertilizing is always applied locally, so it is also called row fertilizing.
- **Fertilization**, or post-sowing fertilizing – application of fertilizers during the growing season of plants, it is used for nitrogenous and nitrogenous-potassic fertilization and for the application of microfertilizers.

Fertilizers are applied to the soil in a certain amount, which is determined by the norms and doses of application. **Fertilizer norm** is the total amount of fertilizer applied to crops during the period of cultivation. It is expressed in kg/ha of active substance (a.s.) or in t/ha (for organic fertilizers). To convert the fertilizer norm in kilograms of active substance to the physical weight of the fertilizer, it is necessary to divide the specified proportion of N, P2O5 or K2O by the percentage of nutrient content in the fertilizer. **Fertilizer dose** – the amount of fertilizer applied to crops per one time.

When establishing norms and ratios of mineral fertilizers for individual crops the need to compensate for nutrients removed from the soil along with crops and by-products, plant nutrient needs, planned yield, natural soil properties, availability of mobile forms of nutrients, fertilizers predecessors and possible aftereffects of fertilizers, as well as the balance of humus and NPK are taken into account.

Liebig's law of the minimum, or the law of limiting factors: the yield depends on the nutrient, which amount is minimal. It means that under the optimal mineral nutrition by the complex of elements one of them is at a minimum, its amount determines the yield.

The concept of "4 rules of fertilizing" [40**]**:

- application of the best form of fertilizer
- in the optimal dose
- in due time
- in the most appropriate way

Indicative norms of fertilizer application for different crops are given in the Annex 5.

Also, when deciding on the establishment of fertilizer norms, it is necessary to calculate its **economic efficiency and feasibility of use**. Research has shown that each subsequent unit of increasing doses of fertilizer provides a smaller increase in yield than the previous one. This pattern is called the **law of diminishing returns**. Therefore, it is important to establish an economic equilibrium, after which further increase in fertilizer doses will be unprofitable. **Equilibrium occurs when the expenditure of funds per unit of fertilizer corresponds to the receipt of funds from the harvest obtained due to this unit**.

The effectiveness of mineral fertilizers **decreases sharply** when used on **acidic soils**. It is proved that the effectiveness of fertilizers depends on liming of acidic and gypsum of saline soils and the combination of agronomically competent and rational use of fertilizers with other factors of crop formation (varieties and hybrids, plant protection, irrigation, tillage, etc.). Soil liming, in particular, reduces by 20–40% leaching of potassium from the arable soil layer, increases the efficiency of nitrogenous fertilizers by 20–30% and significantly improves the phosphorus regime of the soil.

3.2. Requirements for the characteristics and composition of fertilizers and current trends in its application

An indicator of the quality of fertilizer is the **content of nutrients in the form accessible to plants**. To characterize fertilizers, the mass fraction of nitrogen, phosphorus and potassium in terms of N, P2O5, K2O is determined. Fertilizers containing more than 33% of active substances are concentrated, and more than 60% – highly concentrated.

The list of most important mineral fertilizers and their chemical composition is given in the appendices (**Appendix 6**).

Analysis of the chemical composition of these fertilizers shows that the minimum and maximum content of active substances in it is as following (***Table 3.1***).

Table 3.1. Minimum and maximum content of active substances in the most common fertilizers

Fertilizers:	N,%	P_2O_5,%	K_2O,%
Compound	1.5-25.0	8.0-80.0	10.0-46.5
Nitrogenous	13.0-82.3	-	-
Phosphatic	-	14.0-52.0	-
Potassic	-	-	30.0-62.0

In addition, there are physical properties of different types of fertilizers, important for the choice of methods of storage, transportation, dosing and application to the soil: density, size and strength of granules, particle size distribution, flowability, dispersion, caking, hygroscopicity, critical speed, metal friction coefficient, etc.

Recently, more attention is paid to **highly concentrated fertilizers**, both unilateral and compound, especially their mixtures, which best meet the needs of the plant [41]. These fertilizers have good physicochemical properties (low hygroscopicity, non-caking, high flowability, solubility, physiological neutrality) and require significantly lower costs for transportation, storage and application.

By adjusting the ratio of nutrients in mineral fertilizers, the high yield without reducing its quality can be obtained. Recently, the so-called **"tuk" mixtures** have become very popular, in which the amount of nutrients is not fixed, but **varies depending on the size of the planned harvest**, biological characteristics of plants, climatic conditions and nutrient content in the soil.

Mineral fertilizer market analysts [42] note an increase in demand for **liquid compound fertilizers**. This is required by climate change, which is reflected in Ukraine in the growth of drought, especially in the spring. In addition, experts note that the application of liquid fertilizers at the rate of 50 kg/ha in efficiency is equal to 100 kg/ha of granular ones, applied by scatter.

The same trend is observed, for example, in the United States: according to the director of the American company AgriGuardian, in the USA liquid fertilizers already occupy 30% of the market. At the same time, granular fertilizers are traditionally applied to the main tillage, and liquid fertilizers are added to the row during sowing. In addition, the extent of foliar fertilization is increasing, which can be done only with liquid fertilizers.

Also, much attention is paid to the development of new **organo-mineral fertilizers (OMF)**. OMF is the fertilizers consisting of organic substances and related mineral and chemical compounds. Some researchers believe that OMF is a higher form, the next stage in the development of mineral fertilizers [43]. OMF improve physical properties of the soil, activate its chemical composition, increase the digestibility of nutrients, increase yields, retain moisture, reduce salinity, provide optimal water-air regime. Today there are various methods of production of organo-mineral mixtures, composts based on peat, coal, lignin and other organic materials. A special type of organo-mineral fertilizers are humic fertilizers, the active substance of which are salts of humic acids.

3.3. Techniques and technologies of fertilizer application

A set of successive production operations for the application of fertilizers is called **fertilizer application technology**. The choice of methods of fertilizer application to the soil in accordance with the biological characteristics of plants is of great importance for its efficient and rational use. There are following methods of fertilizing the soil:

- **entire** (or spreading) application ensures uniform distribution of fertilizers on the soil surface;
- **local** method provides placement of fertilizers in the soil by cells of different shapes directly in the root layers;
- **surface** method involves the application of fertilizers to the soil surface, followed by plowing into the soil, can lead to gaseous losses from fertilizers;
- **deep** method involves the application of fertilizers in pits or ditches to a certain depth.

Uneven application of mineral fertilizers reduces their efficiency by 35-45%, compound – by 28-35%; phosphorus and potassium – by 15-20%.

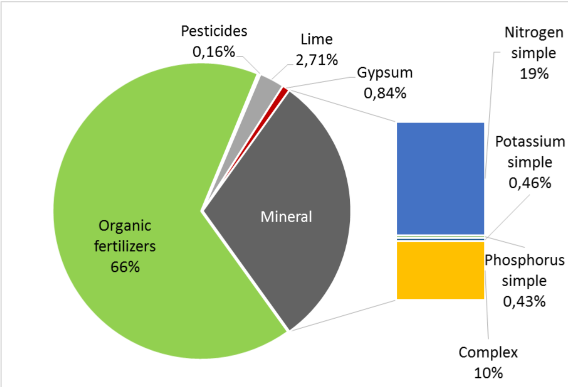
3.4. Fertilizer quantities used in Ukraine

According to the State Statistics Service, in 2018, 4.87 million tons of mineral fertilizers were used in Ukraine (2.15 million tons in the active substance – see ***Table 3.2***).

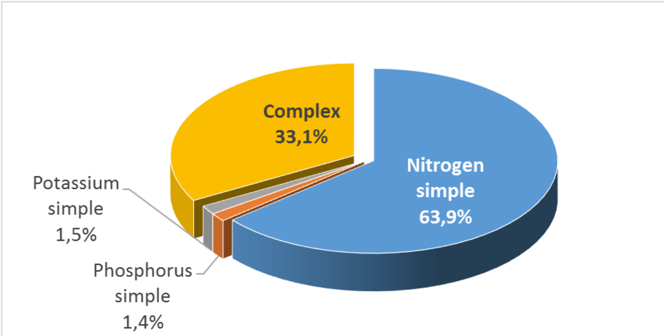
In addition, 10 675 thousand tons of various types of organic fertilizers, 25 thousand tons of pesticides, 438 thousand tons of lime, 135 thousand tons of gypsum were applied (**Fig. 3.1**).

Table 3.2. Application of mineral fertilizers in Ukraine in 2018

Type of mineral fertilizers:	Appliedd fertilizers, ths. t	Active substance applied, ths. t
Mineral nitrogenous simple	3109.4	1107.3
Mineral phosphatic simple	69.9	21.0
Mineral potassic simple	75.0	35.3
Mineral compound	1611.1	987.0
Total	**4865.4**	**2150.6**



a) application structure of fertilizers and other soil treatments



b) application structure of mineral fertilizers

Fig. 3.1. The application structure of fertilizers and other soil treatments in Ukraine

At the same time, an average of 133 kg of mineral fertilizers per hectare (in the active substance) was applied to crops. The total area of fertilizer application was 16.1 million hectares (about 39% of the total area of agricultural land). The amount of nutrients applied in 2018 was, in thousand tons:

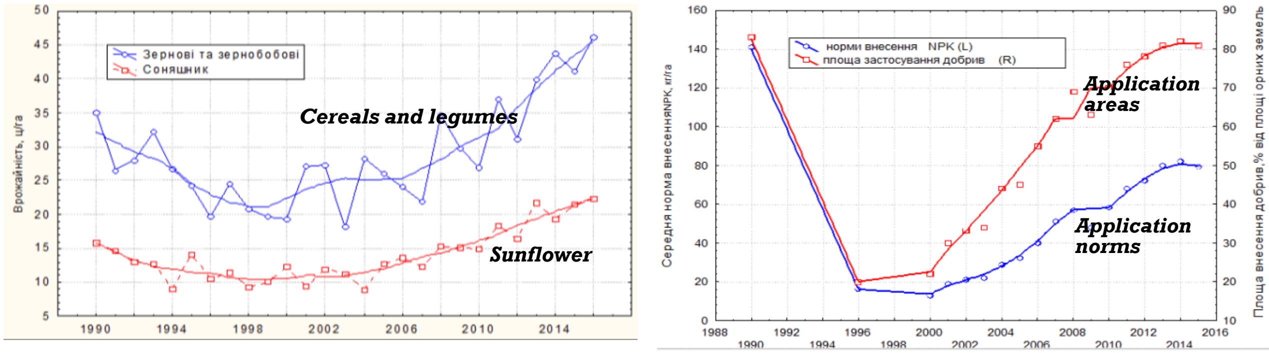
- nitrogen (N) 1404.9
- phosphorus (P) 410.35
- potassium (K) 335.4

The data in

Fig. 3.*2* shows that since the early 2000s, the **trend of increasing** both the mineral fertilizers specific application norms and areas, which was accompanied by an **increase in yields** of sunflower, cereals and legumes [40].

Fig. 3.*3* shows the amount and ratio of different types of mineral fertilizers applied for the main crops.

According to scientists [44], there are concerns about **significant imbalances in the application of nutrients in favor of nitrogen**. If in 1990 in Ukraine the ratio of N: P: K was 1: 0.8: 0.9, then according to 2018 it is on average 1: 0.29: 0.24.



a) change in crop yields b) change in fertilizer application norms

Fig. 3.2. Dynamics of yield and application of fertilizers in Ukraine

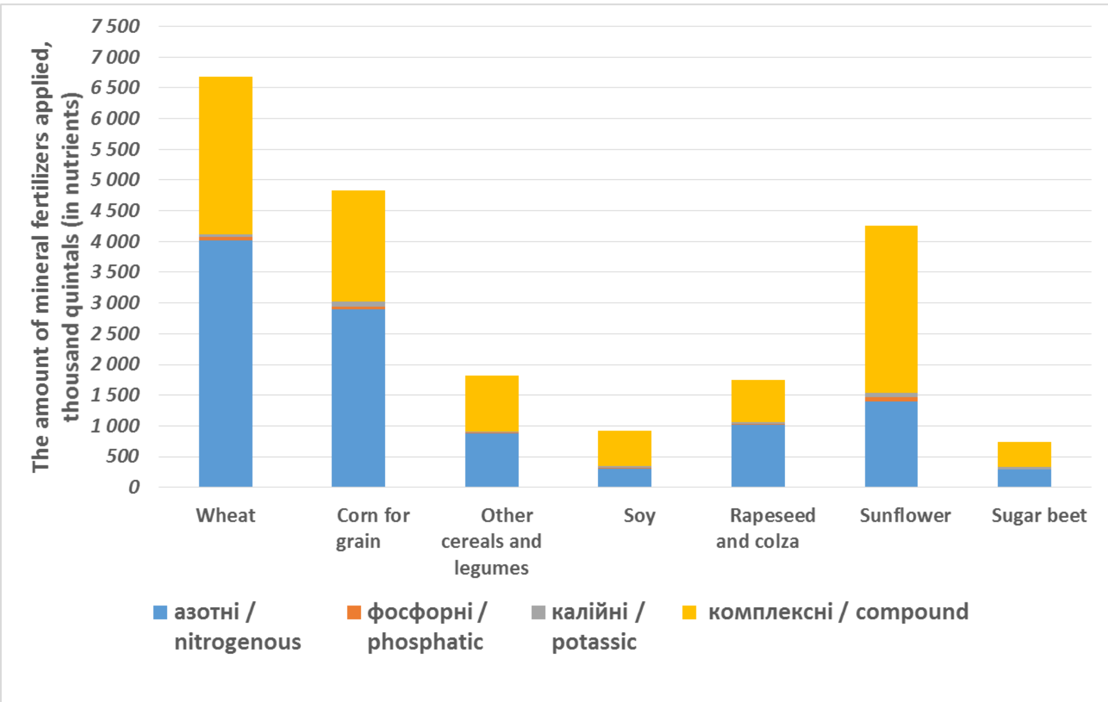


Fig. 3.3. Application of mineral fertilizers for various crops in 2018

Farmers have recently given greater preference to **fast-acting nitrogenous fertilizers**, such as ammonium nitrate (33% of ammonia fertilizers), urea-ammonia mixture (22%), urea (19%), ammonium sulfate (11%). Last but not least, this is due to the price ratio for various mineral fertilizers.

Ukraine remains an **import-dependent country** in terms of providing agriculture with mineral fertilizers. Thus, according to the State Fiscal Service, in 2017 Ukraine exported 673.7 thousand tons of nitrogenous fertilizers, while their imports amounted to 1743.5 thousand tons. Exports of potassic fertilizers remain insignificant – 1.8 thousand tons, while imports reached 92.1 thousand tons. Ukraine mainly buys phosphatic fertilizers – 35.4 thousand tons.

The main suppliers of fertilizers to Ukraine – Belarus, Poland, Russia. The key indicator for farmers is the ever-increasing price of mineral fertilizers [45]. **Potassic fertilizers remain quite expensive** and their reduction in price is not expected yet [46]. The main amounts of this product come from Belarus in the form of potassium chloride. Ukrainian producers prefer Belarusian products because prices for other products are much higher. Many NPKs (azophos) are also supplied from Belarus, with which domestic farmers try to **replace the lack of potassic fertilizers**.

4. Properties of ash as a fertilizer

Ash is one of the oldest fertilizers used by mankind. The practice of one of the primitive types of agriculture – fire-cutting, provided for burning of the forest, subsequent plowing of the soil fertilized with wood ash and cultivation of crops for three, sometimes up to five years. After that, soil fertility decreased significantly, and people moved to cultivate another area. With the further intensification of farming methods, the reproduction of soil fertility was achieved by applying manure and other organic fertilizers, using clean fallow, green manure, etc.

The modern system of agriculture is intensive, maintaining soil fertility in it is achieved by crop rotations, application of organic and mineral fertilizers. The **main part of mineral fertilizers is produced by industry**, in compliance with certain standards that provide the required content of active substances and physical characteristics of the fertilizer, adapted to certain methods of its application into the soil. The value of ash as a fertilizer gradually decreased due to move to more intensive farming systems. After the transition to the use of fossil fuels in all areas of production, the source of biomass ash could only be wood heating systems of private homes, mainly in rural areas. Also, until recently, the practice of burning straw and other crop residues in the fields existed, that is banned now. However, its main purpose was not to fertilize the field with ash, but to get rid of crop residues that hindered further tillage.

4.1. General recommendations for the use of biomass ash as fertilizer

Modern reference books on agrochemistry in Ukraine consider ash as a **valuable local potassic-phosphatic-lime fertilizer** [47]. As local are meant that fertilizers which accumulated or produced directly on farms and are used ibidem (manure, slurry, compost, bird droppings, ash, silt ponds and lakes). Various limestone rocks (lime, mortar, etc.) are also used as local fertilizers, which are extracted on site and used for chemical land reclamation.

It is noted that wood ash usually contains up to 15% K_2O in the form of K_2CO_3, 7% – P_2O_5 and about 40% CaO. Unlike industrial fertilizers, it does not contain chlorine, so it is the best form for chlorine-sensitive crops. It is also noted that potassium in the ash is in the form of potassium carbonate (K_2CO_3), which is **well soluble in water**. 1 kg of wood ash contains 200-700 mg of boron, so it can be used as a boron fertilizer. Phosphorus in the ash is in the form of compounds of different solubility. Some of them are soluble in water, others – in weak organic acids and weak solutions of mineral acids. **About ¾ all the phosphorus** contained in the **ash is in a form accessible to plants**. When interacting with soil, especially acidic, the rest of the phosphorus ash also becomes available for plant nutrition. Therefore, ash as a source of phosphorus in its effect on the yield of agricultural plants is not only not inferior to the action of water-soluble forms of phosphatic fertilizers, but in some cases surpasses them. Ash applied into the soil creates **favorable conditions** on acidic podzolic soils not only for the growth and development of plants, but also for the **activity of beneficial microorganisms** and especially ammonifying and nitrifying bacteria. Ash perfectly **loosens the soil** and changes its structure, making it light, moist and permeable. The effects of ash application **are indicated for four years**.

4.1.1. Plants that can be fertilized with ash. Recommended methods of its application

In various sources of information you can find enough recommendations for the use of ash as fertilizer. However, **most of it relate to ash use in homesteads**, rather than in commodity agricultural production.

It is believed that the ash can be used **on all types of soils for all crops**, **regardless of the method of application**: in autumn main fertilizing for fallow plowing, in spring for cultivation of fallow, for fertilizing winter and row crops and perennial legumes superficially in early spring. Ash contains lime, so it is most effective on acid soils of light particle size distribution and peatlands. The dose of ash is calculated by its content of potassium and phosphorus. Ash is applied during the main tillage or pre-sowing cultivation.

Sugar beets, potatoes, hemp are demanding to potassium nutrition. Ash applied to **potatoes** acts much more effectively than other potassic fertilizers. When one kilogram of wood ash is added for potatoes cultivation, the number of tubers increases by six to eight kilograms, and the starch content in it increases.

Legumes (peas, soybeans, beans, chickpeas, rank, horse beans) do not need nitrogen, because the tuberous bacteria that live on their roots accumulate a significant amount of it. Therefore, after legumes, nitrogen can be omitted or used in minimal quantities, and mainly use **potassic and phosphatic fertilizers**. Under **buckwheat** it is more expedient to bring chlorine-free potassic fertilizers, in particular ashes.

Ash is also suitable for fertilizing **flax and soybeans**, supplemented with organic fertilizers.

It is recommended firstly to apply ash for **vegetable crops** (cabbage, cucumbers, peppers, tomatoes, onions, radishes, garlic, eggplant), **grapes, citrus fruits, strawberries, raspberries, currants**, as these crops do not tolerate chlorine, as well as for **trees, berries shrubs**. The use of ash protects **cabbage** from diseases of hernia (a disease caused by a fungus parasitizing on the roots) and blackleg.

One hundred square meters requires up to 12 kg of ash. **Each kilogram of it, according to experts, corresponds to 220 g of superphosphate in granules, 240 g of potassium chloride**. It is best to use the ash not in its pure form, but with organic fertilizers, where nitrogen is in a bound state: **peat, fermented manure or compost** in a ratio of 1: 2; 1: 4. To **enrich the compost** with ash each compost layer is to be poured by it. This practice helps to create in a pile of manure excellent conditions for the reproduction of useful microorganisms that replenish its nutrients.

The **ash extract** can also be used. It is considered useful to feed fruit plants with a solution of ash in mid-summer, when the fruits ripen and plants may be deficient in calcium and phosphorus.

There is a practice of **soaking the seeds in water with ash before planting**.

It is also practiced to **apply ash to furrows and planting holes**, but this should be done carefully so as not to burn the roots, due to the high alkalinity of the ash. Therefore, a layer of ash must be isolated by layer of soil from the root system of seedlings.

Also, ash has long been widely used in gardens and orchards to **control pests and plant diseases**. Sifted fine ash is sprinkled on moistened leaves of plants and the soil around them, which prevents the movement of snails and slugs.

Ash is also used for growing **ornamental and houseplants** (roses, gladiolus, clematis, lilies, peonies).

Contrary to claims that phosphorus is fully available in plant biomass ash, the study [48] states that such phosphorus can only partially maintain a stable level of phosphorus in the soil because it is low in ash and poorly soluble in the soil. Therefore, it is necessary to compensate for the lack of phosphorus by applying appropriate fertilizers. **Usually the phosphorus content in straw ash is higher than in wood ash**.

Dose adjustment of ash application should be carried out taking into account soil conditions (soil and agrochemical survey) and the crop for which it is planned to be applied. Application doses should be close to the optimal ones, calculated taking into account the removal of nutrients by the planned harvest and the utilization rate of nutrients by crops.

As one of the positive effects of ash application, some researchers call **the reduction of heavy metals entering the soil**, because they are added there mainly with artificial fertilizers, so if the ash replaces some of the fertilizers, the addition of heavy metals will decrease.

4.1.2. Precautions when using ash. Transportation and storage

Ideally, the processing of wood ash and its application to the soil should be carried out in such a way as to use all the necessary useful properties and at the same time reduce the negative impact on fauna, terrestrial vegetation and surface waters.

The ash from the combustion of any plant residues **does not contain nitrogen**, which is critical for plants during the growing season. Therefore, in addition to ash, it is necessary to apply nitrogenious fertilizers. But it is not recommended to apply nitrogenous fertilizers at the same time as ash, because it leads to large losses of nitrogen: it is converted into ammonia and evaporates. Therefore, **ammonium nitrate, ammonium sulfate and ammonium chloride, manure-based organic fertilizers, bird droppings, feces and manure should be applied separately from the ash**. When using ash in a mixture with humus, in order to reduce nitrogen losses, this mixture should be prepared only shortly before application to the soil.

Phosphatic fertilizers should not be used together with ash [49], as ash has an alkaline reaction in which phosphorus compounds become virtually inaccessible to plants. **It is not recommended to mix ashes with phosphorite flour and tomaslag**, it is necessary to avoid to bring ashes on those sites which were fertilized earlier (for 1-2 years) by considerable quantities of these fertilizers. When combined with ash small doses of phosphorite flour or slag, it is necessary to apply it for plowing, and ash for cultivation or locally.

It is also necessary **to avoid the application of wood and straw ash together with lime**, apply it on recently limed soils, as this **reduces the efficiency of the ash**. Wood and straw ash and **potassic fertilizers** should be **pre-mixed** and applied to the soil in one go.

It is impossible to use ash on alkaline soils (pH> 7), because the increase in soil alkalinity prevents the absorption of nutrients by plants, as well as to apply it for crops that prefer soils with high acidity: radish, watermelon, sorrel, blackberry, hydrangea, ornamental conifers.

It is not recommended to fertilize the seedlings of garden plants with ash until the stage of formation of the first true leaves. In diseases of seedlings, ash is not used so as not to impair the feeding system. If the cause of disease is a lack of phosphorus on the background of excess calcium or sodium, the use of ash will be detrimental to plants.

It is recommended to **deepen the ash into the soil**, otherwise it can contribute to the **formation of crust harmful to plants**. When applying to planting nests, ash **should not come into contact with the root system** or with a layer of humus, compost, compound fertilizers: ash is applied in layers, sprinkled with a layer of soil 10-15 cm. In the absence of peat or humus, to prevent wind spread of ash and also for its uniform distribution on the fertilized area, straw and wood ash can be applied mixtured with slightly damp soil.

There are tips **not to add ash to the soil in autumn**, because the soluble substances of ash with melt water move to the lower layers of the soil.

It is noted that due to the unevenness of the fractional composition, a large amount of dust, the use of ash is complicated, **it is difficult to ensure the application of the required dose**. Some believe that it should not be used dry at all, but only in a mixture with water.

It is also recommended **not to use fresh ash** [50], as it dissolves very quickly in the soil and can damage sensitive plants and microorganisms. Ash laid under a **canopy for several weeks to several months** is compacted, absorbs a certain amount of moisture, which reduces the amount of dust and makes it more convenient to use. In addition, hardened ash **is less soluble**, which makes the release of nutrients into the soil longer and more even. To do this, in some European countries it is granulated. When applying well-stabilized ash in moderation (up to 3 tons per hectare), no negative environmental impact is actually observed.

With excessive application, especially on soils rich in humus, **ash can increase nitrification**, which leads to nitrogen loss and adversely affects useful microorganisms.

It should also be borne in mind that in addition to nutrients, ash may also contain environmentally hazardous **heavy metals**.

Typically, filtration ash contains a significant amount of organic pollutants, its share is approximately 10%. Such ash can be disposed of by industrial processing under certain conditions in road construction or by adding a small amount to organic fertilizers, provided that the limit value is not allowed.

The dose of ash application largely depends not only on the type of biomass, but also on agronomic factors, such as rainfall, treatment of crops with pesticides, application of additional fertilizers. Therefore, before adding ash to the soil, it is necessary not only to analyze the soil, but also **to analyze the ash itself**.

One study on the use of ash in forestry [51] states that **the content of unburned carbon in the ash more than 5% by dry weight impairs the effectiveness of ash as a fertilizer and liming agent**, increases its volume, impairs the ability to compact, press or granulate. In addition, the presence of unburned particles in the ash increases the fire hazard in forests.

When handling ash it is recommended:

- do not store it outdoors, because atmospheric precipitation washes away easily soluble potassium compounds, after which it is suitable only as a lime-phosphatic fertilizer, in addition, when dried after wetting, it can harden and become unusable;
- sieve before laying the ash for storage;
- store it separately from food in a dry place, out of reach of children and animals, do not store in living quarters [52];
- store ash away from wells, boreholes, other sources of drinking water for humans or animals (generally not closer than 15-20 m for usual soils and not closer than 30-40 m for permeable soils [53]);
- do not apply to the soil in windy or too dry weather;
- to transport in the closed container, or in the covered car, to consider a possibility of strong dust formation;
- take into account the strong corrosive ability of ash;
- wear gloves and follow hygiene rules when working with ash;
- in case of contact with skin, eyes, rinse with water;
- avoid contact with mucous membranes, seek medical advice if swallowed.

4.2. Agronomic efficiency of ash use as fertilizer. Comparison with conventional fertilizers. Research results

There are various data on the content of active substances in the ash, in particular – see ***Table 4.1***.

Table 4.1. Chemical composition of different types of ash,%

Ash types	K_2O		P_2O_5		CaO	
Information source:	[50]	[54]	[50]	[54]	[50]	[54]
Cereal straw:						
wheat	9-18	13.6	3-9	6.4	4-7	5.9
rye	10-14	16.2	4-6	4.7	8-10	8.5
buckwheat	25-35	35.3	2-4	2.5	16-19	18.5
Sunflower stalks	30-35	36.3	2-4	2.5	18-20	18.5
Firewood:						
birch	10-12	13.8	4-6	7.1	35-40	36.3

Ash types	K_2O		P_2O_5		CaO	
Information source:	[50]	[54]	[50]	[54]	[50]	[54]
pine	10-12	6.9	4-6	2.0	30-40	31.8
spruce	3-4	3.2	2-3	2.4	23-26	25.3
willow		4.6		2.1		43.5
Manure		1.0		5.0		9.0
Peat:	0.5-4.8		1.2-7.0		15-26	
lowland		1.0		1.2		20.0
riding		0.3		0.5		3.0
Coal:						
in its pure form		0.1–0.4		0.1–0.4		–
mix with firewood		1.0		2.0		–

Comparing the specified content of nutrients with its previous content in traditional fertilizers (***Table 3.1***) it can be noted that **in the wood ash**:

- **potassium content is close to the lower limit** of its content in compound fertilizers and almost twice lower than the lower limit of its content in potassic fertilizers;
- **the phosphorus content is lower than the lower limit** of its content in both compound and phosphatic fertilizers.

The content of phosphorus in the ash of agricultural biomass is approximately the same, and the content of potassium is significantly higher than in the wood ash. In buckwheat and sunflower ash, the potassium content is in the range typical for potassic fertilizers.

Despite a significant number of recommendations declaring the effectiveness of the use of biomass ash as fertilizer, the **specific results of the use of ash**, its impact on crop yields, and even more so the comparison with the effectiveness of traditional fertilizers **are very rarely described**. There is a particular lack of such information regarding the application in Ukraine.

4.2.1. Application in Ukraine

In particular, it is known [55] that the agricultural firm "Dim" in Bila Tserkva district of Kyiv region, where a straw boiler is installed, use up to 1000 large bales of straw during the heating season, thus forming about 55 tons of ash containing 6.4% phosphorus, 13.6 potassium, 5.9 potash, which is scattered in fields in loose form. Unfortunately, the **analysis of the effectiveness of its application is not provided**.

In one of the studies [56] conducted in Ukraine, it was found that the use of wood ash as a fertilizer showed **active growth** and more compact (in terms of time) **ripening of tomatoes**.

Another study [57] studied the effect of ash and ameliorant application (KCl) on the transition of 137 Cs from soil to young shoots and leaves of mountain ash and brittle buckthorn in radionuclide-contaminated forest ecosystems of Polissya, Ukraine. It was found that the combination of ash and ameliorants has a better effect on reducing the accumulation of radioactive cesium in plants than the use of each of the agrochemicals separately.

4.2.2. Application in other countries

Confirmation of the impact on yield

Studies conducted in Belarus [58] have shown that the use of wood ash in combination with the NPK 210: 160: 330 increased the yield of green corn by 241 quintal/ha compared to the option where the fertilizer was not used at all. The increase in the yield of green mass of corn in the variant with the use of wood ash and complete mineral fertilizer in comparison with the variant with only complete mineral fertilizer was 44 quintal/ha. The application of 1 t/ha of wood ash on the background of NPK significantly increased the yield of the first crop rotation (corn) in the year of ash application, and also provided almost the same productivity of the crop rotation compared to the background version with reducing doses of mineral potassic fertilizers by 60 kg/ha a.s.

A study of fertilizing potatoes with compost and wood ash from CHP (Republic of Komi, Russia) [59] showed a decrease in soil acidity from pH5.0 to pH5.5, which reduced the incidence of late blight, **increased potato yield** and increased its starch content by 1.5%.

The field study showed an **increase in barley yield** to 18% and **corn** to 11% in one of the plots when using biomass ash on the background of nitrogenous nutrition compared to the control area, where only nitrogenous fertilizers were used. In the second area, where a similar experiment was conducted, but with a different type of soil, the use of ash **reduced the yield of spring wheat and lupine** [60].

In Canada [61], three-year field studies of the effects of 6, 12.5 and 25 t/ha of wood ash and nitrogenous fertilizers showed a 50% **increase in barley and** 124% **oilseed rape yields** compared to nitrogenous fertilizers alone.

Also, **increase in the yield of oats** was found when using wood ash after the boiler of the pulp and paper mill [62] in experiments on its cultivation in a greenhouse. A 45% increase in yield was recorded compared to the non-liming area, while in the area with standard doses of dolomite lime in an amount equivalent to ash application, the yield increase was 8% (ie, the difference between the effects of ash and dolomite lime use amounted to 37%). A similar **increase for beans** when fertilized with ash was 18-33%. The soil after ash treatment had higher concentrations of phosphorus, boron and sulfur and less zinc, iron, copper and manganese.

In the Czech Republic, studies have been conducted [63] on the effect of wood ash on spring wheat yields and the accumulation of cadmium in it, in combination with the conventional nitrogenous nutrition. There was a **decrease in the absorption of cadmium by plants**, which was explained by the increase in soil alkalinity and the absorbent properties of the ash relative to cadmium. In addition, the **grain yield increased** by almost 100% and in most experiments the **yield of wheat straw increased**.

Laboratory studies conducted in Poland [64] showed a positive effect of ash fertilization on chlorophyll content and improved photosynthesis in plants of barley, wheat and oats, accelerating their growth, increasing grain weight. Field studies of the impact of wood ash from one of the Polish CHPs and agrobiomass ash showed an **increase in triticale yield** of up to 20%. This and other [65] studies conducted in Poland **showed a positive effect of increasing doses of ash on the crop** compared to the control experiments, in which there was no fertilization, equivalent to the ash introduced in the experimental plots by the amount of active substances.

Studies conducted in Pakistan [66] on calcined soils with the use of biomass ash and basic application of NPK showed **an increase in wheat yield** to 37%, due to improved soil structure and increased availability of calcium, magnesium and potassium for plants.

Confirmation of the possibility of using instead of phosphatic fertilizers

Studies in Denmark [67] have demonstrated the **ability to maintain soil phosphorus levels when using biomass ash instead of triple superphosphate**.

Approximately the same conclusion was made in Germany [60] on the basis of experimental studies of oilseed radish, buckwheat, phacelia and other crops using agricultural biomass ash, although the experiments **did not show an increase in yield** compared to conventional potassic and phosphatic fertilizers.

Other researchers from Denmark [68] have revealed the effect of ash fertilizer after gasification of agrobiomass on soil phosphorus content and yield of spring barley. The fertilizer was made in the form of granules with the addition of some other components, from which heavy metals were removed. Its **effect on yield** was **similar to triple superphosphate**, the content of soluble phosphorus in the soil was 40-90% of the value when using superphosphate.

Confirmation of the possibility of use as an ameliorant, liming material

Austrian researchers [69] experimentally confirmed that biomass ash in the amount of 0.5 t/ha **can be effectively used for liming** on acidified meadows instead of lime.

Another study [5] claims that **4.4 tons of hearth ash can replace 1 ton of conventional liming agent** due to its effect of soil liming.

Another study [70] showed that when using lime and ash biomass separately, the impact on the soil is almost the same, but **the effect of mixture of ash and lime is much better** than each component separately. Therefore, ash can be considered rather as an auxiliary component for liming soils.

The possibility of using ash for liming showed also the study on the application of wood ash, formed in the pulp and paper industry, conducted in the United States [71]. At the same time, this study showed **quite small amounts of potassium and phosphorus, which pass from the ash into the soil**.

The possibility of using ash as a liming agent in the forest soils is noted in the study [72]. It also notes that **biomass ash can be used in the cultivation of energy crops** on lands containing excess chlorine to reduce the absorption of chlorine by plants.

The report of the International Energy Agency [73] provides information on the study of impact of biomass ash mixed with compost on the composting process and its fertilizing properties in mixture with digestate after biogas plant. It is revealed that **such compost can be used as an ameliorant** on acidic tropical soils.

Other agronomic effects

There is information that ash can be **used to improve the quality of pastures**, non-floodplain meadows, overgrown with moss and acid grasses. Such meadows, after fertilizing with ash, significantly increase the amount of grass, and the composition of grasses changes: instead of cereals, especially sour and coarse, grasses from the legume family, for which potassic fertilization is favorable (clover, peas, etc.), begin to develop [74].

Studies that have identified the shortcomings of biomass ash as fertilizer

However, not all studies recognize the effectiveness of ash as fertilizer, at least in its pure form.

Studies conducted in Poland [75] using volatile ash obtained by burning a mixture of wood and agricultural biomass in the fluidized bed boiler, showed the **inexpediency of direct use** of the ash due to the imbalance of its components, large amounts of potassium in the form of insoluble compounds, and heavy metals . Such ash can be used either after addition of some corrective components, or as a raw material for the production of phosphatic and potassic fertilizers.

Studies conducted in Thailand on the fertilization of rice with combined fertilizers, including rice straw, rice ash and nitrogenous fertilizers [76], **did not reveal the effect** of such fertilizer **on the crop** compared to fertilization with nitrogenous fertilizers alone.

Another study [77] found **an increase in the incidence of wheat root disease** Gaeumannomyces gramini with increasing doses of ash entering the soil.

Some researchers [78] believe that **biomass ash should be considered more as a source of potassium**, because phosphorus is in it in a form that is not very accessible to plants in normal soil conditions, although for use on forest soils it may not be a big problem. In general, **ash can be a source of nutrients for fertilizer production**. Although, as noted, it is important in the production of fertilizers that raw materials have a **low price, large amounts and predictable characteristics**. According to these criteria, as well as the content of nutrients, ash loses to other raw materials.

In Ukraine, ash is traditionally used as a fertilizer on homesteads, some empirical experience of its use has been accumulated. Despite the generally positive reviews of those who use it, there are opposing views, in particular, the statement that ash has a bad effect on the root system, is not good for stone fruits, it is better to use a compound fertilizer, etc. [79],[80].

The statement about the low quality of ash as a fertilizer can be found even in social advertising: "Contrary to popular belief, ash is a very bad fertilizer and, therefore, burning leaves every year leads to increasing soil impoverishment" [81].

Thus, we can draw some conclusions based on the results of these studies:

1. Most studies show that biomass ash **can be used for liming soils**.
2. The use of biomass ash is **able to maintain the same level of phosphorus** in the soil as the use of traditional phosphatic fertilizers (although the amount of ash application by weight will be higher due to its lower phosphorus content).
3. A number of studies indicate an increase in crop yields with increasing doses of biomass ash in combination with the standard nitrogenous or NPK-nutrition, which was used, including in control experiments. This demonstrates only **an increase in yield as the result of increased application of fertilizer** (ash).
4. There are practically no studies that would compare the effect of ash on the yield, provided that the control experiment introduced the same amount of active substances (P, K), which is applied with the ash in the studied areas. As a result, **it is not possible to say with certainty that biomass ash has advantages over traditional fertilizers in terms of impact on the crop**.
5. **In some cases**, depending on the type of soil, its composition, reaction, humidity of the growing season and other characteristics, **the use of ash does not show a positive effect on yield**, and sometimes even reduces it.

Therefore, the use of biomass ash to achieve the desired agronomic effect requires consideration of many factors. It seems that **the issue of effective use of ash as fertilizer can not be considered fully explored**, not least due to the diversity of origin and physicochemical characteristics of this ash.

4.3. Disadvantages and barriers for using biomass ash as fertilizer

Many researchers point out that biomass ash has a number of properties that are unfavorable for its effective use and create a number of inconveniences that are or may become the barriers to its use as fertilizer. Below are the main ones.

- it is not a compound fertilizer, it does not contain nitrogen;
- phosphorus is in poorly soluble form under normal conditions [8], as well as low solubility of calcium [5];
- incompatibility with ammonia fertilizers;
- the use of ash is limited by the amount that provides optimal soil alkalinity;
- increased health risk;
- unfavorable physical characteristics (low bulk density, small particle size, significant dust formation during transportation and application to the soil), which cause high transportation costs, problems of ash distribution by mechanical means [53] and other inconveniences of use;
- lack of application technologies focused on biomass ash;
- the use of traditional machines for fertilizer application (spreaders of granular and powder fertilizers) does not give the desired effect: uniform application does not ensured, the complexity of regulating of application norm, formation of the vault, etc. [48];
- unstabilized ash can damage plants [82];
- low content of nutrients compared to the content of heavy metals (especially Cd, As, Zn) [83], prolonged use of "wrong" (eg, filtration) ash can lead to the accumulation of heavy metals and other toxic substances in the soil, reducing its fertility [84];
- often a high content of inert material;
- a large difference in quality characteristics and ash yield depending on the types of input raw materials, its origin and combustion technology;
- mineral raw materials for the production of fertilizers are cleaner and more stable in composition, phosphorous and potassium in mineral fertilizers are "cleaner" and more accessible to plants [83];
- lack of interest in the industry in the production of ash fertilizers;
- lack of interest of the agricultural sector in the use of ash-based fertilizers, even where this area is quite developed, for example, in Denmark [68];
- the need to provide for intermediate storage of ash due to the mismatch between the time of its formation and use [85].

Accordingly, some prefer **not to use it as a fertilizer**, but to apply it in other areas, mainly **in construction and other industries**: backfills, insulating layers, fillers for concrete, cement and lime mortars, concrete products that do not require high strength, unstressed concretes, synthesis of geopolymers [86]. This is especially true of **volatile ash** obtained by burning biomass in fluidized bed, as it can contain a significant proportion of inert material from the boiler.

Additional barriers:

- small commodity amounts;
- lack of relevant regulatory developments (there are no special provisions on agronomic use, ash of other types of biomass, except wood, is not included in the list of substances permitted for use in organic farming, the use of ash in concrete technology is limited to volatile coal ash);
- lack of awareness, knowledge and desire of operators of heat generating plants, potential end users and authorities to improve the use of biomass ash. For example, in Cherkasy a few years ago, the regional environmental inspectorate considered ash biomass "hazardous

waste", for which the boiler operator was fined, despite the results of chemical analyzes, proving the opposite [87];
- due to price ratios, administrative and other barriers, logistical and technical problems, the removal of biomass ash to the landfill is often the cheaper option than its useful utilization [73].

4.4. Ways to increase the efficiency of using ash as fertilizer

There are a number of ways to treat ash to use it as a fertilizer, to get rid of some of its shortcomings (*Table 4.2*).

Table 4.2. Ways to improve the consumer qualities of biomass ash

The method of ash handling	Expected useful result	Prerequisites and requirements
Control of the condition and composition of ash in the boiler house [88]	Ash is homogeneous in particle size distribution, with adjustable (within certain limits) content of various components.	Control of biomass combustion modes, appropriate equipment design, addition of special substances to reduce sintering of ash, control of chem. composition of biomass fuel. Coincidence with the conditions of efficient heat production
Grinding, sifting	Separation of large particles, ballast and debris, improving reactiivity	Labor costs (equipment is usually available on farms)
Reduction of alkalinity during long-term storage and humidification [85] **("ageing")**	Reduction of alkalinity, compatibility with nitrogenous fertilizers, possibility of application not only on acid soils, reduction of dust formation, regulation of solubility	It is necessary to provide the adequate conditions of humidification, but not to allow caking. The use of special equipment such as concrete mixers. The required storage time is 8-12 weeks.
Neutralization with acids	The same	Additional costs for equipment, technology, reagents
Mixing with lime for soil liming	Relative reduction of ballast substances in the mixture, use of alkaline properties of ash	Acidic soils
Liquid fertilizer [89] based on ash (aqueous extract)	Relative reduction of ballast substances, reduction of dust formation, possibility of application together with liquid organic fertilizers in the same way, promotes use in dry weather	The practice of using liquid fertilizers in farms. It should be borne in mind that only the most soluble compounds pass into the solution, which reduces the value of fertilizer.
Mixing and application with manure, peat, plant residues, or, in their absence, mixing with moist soil	To get a fertilizer more balanced in acidity and nutrient composition. Less dust, more convenient application to the soil (standard spreaders)	The presence of peat, manure, etc. in the farm. To reduce nitrogen loss, the manure mixture is prepared immediately before application. It is better to use fermented manure.

The method of ash handling	Expected useful result	Prerequisites and requirements
Preparation of compost of plant residues with ash. Peat composts	Decomposition of plant residues is accelerated, we get a more balanced fertilizer in composition. The transition of some nutrients into a more accessible form (especially phosphorus).	Application of composts and technologies for their production in farms. Extraction of peat in the immediate vicinity (separate production). The maturation time of the peat mixture is 6-12 months.
Vermicomposts [90]	The same	The same
Granulation of biomass ash, with fixing agents or addition of other fertilizers [91]	Unification of granulometric composition, increase of bulk density, partial change of chemical composition, slowing down of dissolution in soil, standard methods of storage and application into soil	Acquisition of appropriate equipment and development of technology (the main stages are similar to the production of pellets). The need for additional gluers for granules. Economic feasibility, taking into account the additional costs of granulation
Production of organomineral fertilizers [92]	Ability to select components to achieve a given content of active substances, the desired acidity. Enrichment with organic components for various purposes (eg, humic acids)	Industrial production. Economic feasibility of using ash as a raw material
Use as a raw material for the production of potassic or phosphatic fertilizers	Bringing to the current standards of agronomic practice: increasing the content of active and reducing ballast substances, the expected physical and chemical characteristics, standard approaches to application to the soil	Industrial production (or shop in the sunflower oil plant). Economic feasibility of using ash as a raw material

Other ash treatment methods under study:

- mixing with sewage sludge [93] or digestatefrom biogas plants to improve the conditions of their dehydration and subsequent use as fertilizer;
- treatment of volatile ash with acid for extraction of heavy metals and other hazardous substances, followed by treatment with carbon dioxide obtained from fuel combustion [94];
- electrodialysis extraction of heavy metals [95].

The Danish experience shows that ash is mainly **used in its raw form**, as the use of known technologies for its processing is quite expensive. However, one Danish company has set up an industrial line to process ash produced by burning straw [96]. But the resulting fertilizers were too expensive [73]. The situation may change if the price of mineral fertilizers increases significantly.

Thus, in Ukraine it is necessary to conduct research and develop recommendations on the best methods of ash management, which provide an optimal balance between the cost of such treatment and the consumer qualities of the obtained fertilizer.

5. Evaluation of the feasibility and possibilities of using ash as fertilizer

5.1. Comparison of the ash price with traditional mineral fertilizers

If to consider the biomass ash as a "competitor" of potassic and phosphatic fertilizers, we can compare its price offered on the Ukrainian market with the price of conventional fertilizers, per unit mass of active substance. However, this calculation is only indicative, because, firstly, it does not take into account the difference in the availability for plants of active substances of ash and traditional fertilizers. Second, traditional potassic and phosphatic fertilizers can contain up to 32% sulfur compounds, which is also a nutrient for plants. However, since sulfur is not one of the main nutrients (N, P, K) and is practically not contained in the ash, its content in traditional fertilizers is also was not considered.

The market price of biomass ash is assumed to be **1000 UAH/t for all types of ash**.

The prices of some types of fertilizers and its chemical composition are given in the appendices (**Appendix 7**).

A comparison of ash and traditional fertilizers at the unit price of active substance is given below (***Table 5.1***).

Table 5.1. Price comparison of active substances in traditional fertilizers and biomass ash

Fertilizer	Price, UAH/t incl. VAT	K_2O, kg/t	P_2O_5, kg/t	N, kg/t	Total a.s., kg/t	Price of a.s., UAH/kg	CaO, MgO kg/t	Price of a.s., incl. CaO+ MgO, UAH/kg
Potassium sulfate	12000	400	–	–	400	30.0	45	26.97
Potassium chloride	10950	600	–	–	600	18.25	–	18.25
Potassium monophosphate	44500	520	340	–	860	51.7	–	51.7
Superphosphate simple	7000	–	190	–	190	36.8	200	17.9
Superphosphate double	11700	–	320	100	420	27.9	–	27.9
Superphosphate triple	15300	–	460	–	460	33.3	220	22.5
Superphosphate enriched	12914	–	400	–	400	32.3	100	25.8
Phosphogypsum packed up	750	–	–	–	–	–	900	0.8
Dolomite flour	5000	–	–	–	–	–	530	9.4
Reclamation limestone 0-1 mm	360	–	–	–	–	–	900	0.4
ASH								
- wood	1000	120	60	–	180	5.6	380	1.8
- straw	1000	150	70	–	220	4.5	70	3.4
- sunflower	1000	320	40	–	360	2.8	20	2.6

These data show that the **sum of active substances of ash is 3-18 times cheaper** than in traditional mineral fertilizers. However, **traditional ameliorants**, such as phosphogypsum and limestone, **are cheaper than ash** in terms of active substance.

We can also compare the price of ash and traditional fertilizers based on comparisons of its action found in the literature. Recall that according to some experts, **the effect of liming soils 4.4 tons of hearth**

ash can replace 1 ton of conventional lime, and in terms of action as a fertilizer, **each kilogram corresponds to 220 g of superphosphate in granules, 240 g of potassium chloride**. Thus, we can enter the empirical ratio of the required mass of ash to superphosphate as 4.55: 1, ash to potassium chloride as 4.2: 1; ash to ameliorants as 4.4: 1. By the way, these ratios roughly correspond to the ratios of the corresponding active substances content in the ash and traditional fertilizers and ameliorants. According to these ratios, the price of potassium chloride and superphosphate, equal to the price of ash by the effect of fertilizer, should be 4200 - 4600 UAH/t, but, as we see from the table, it is higher than these values by more than 2 times. As for traditional ameliorants, even with this comparison, they are cheaper than ash.

Thus, if we consider biomass ash only as an ameliorant, its use in this role is not economically justified. But in terms of price, biomass ash may well be a cheap substitute for traditional fertilizers, given the specifics of its use described earlier.

Based on statistics on the use of different types of phosphatic and potassic fertilizers and its market prices (2020), we can conclude that the weighted average price per ton of potassic and phosphatic fertilizers used in Ukraine is 10 750 UAH/t (***Table 5.2***). Then, if **the use of 1 ton of ash** is equivalent to about 220 kg of traditional fertilizers, **it saves on average about 1300 UAH comparing traditional fertilizers, or 56% of the cost** of phosphatic-potassic fertilizer.

Table 5.2. Statistics on the use of phosphatic and potassic fertilizers in Ukraine

Phosphorus and potassium fertilizers	Applied in 2018 (State Statistics)		Price (2020), UAH/t
	In physical mass, thousand tons	In active substances, thousand tons	
Superphosphate double	45.4	14.1	11700
Superphosphate triple	7.2	3.3	15300
Phosphorite flour	1.9	0.6	5000
Other phosphatic fertilizers	15.4	3.1	3100
Kalimag-30	4.1	1.2	5800
Kalimagnesia	5.3	1.4	8750
Potassium salt	2.2	0.8	5500
Potassium sulfate	11.9	6.2	12000
Potassium chloride (potassium chloride)	38.3	23.0	10950
Other potassic fertilizers	13.2	2.6	8678
Other compound phosphatic-potassic fertilizers	53.1	21.2	10750
Total	**198.0**	**77.5**	**10245**

5.2. Possible quantities of use (ash market capacity as fertilizer)

In 2018, **198 thousand tons of phosphatic and potassic fertilizers** were used in Ukraine. For the theoretical maximum replacement of these fertilizers with biomass ash, according to the previously mentioned ratios, about 900 thousand tons of ash would be needed. This significantly exceeds not only the estimated current amounts of ash formation (about 70 thousand tons), but also promising in 2035 (about 550 thousand tons). Thus, under appropriate conditions, **the agricultural sector could utilize all biomass ash** generated in industry and energy.

Of course, due to a number of features of its use (see section 4.3), not all biomass ash can be used directly as potassic-phosphatic fertilizers. However**, if it is applied together with organic fertilizers or in the form of organo-mineral fertilizers** (see section 4.4), it is possible to significantly expand the use of biomass ash, because in this case it becomes an **element of compound fertilizers**. If we apply the recommended [49] ratio of the amount of ash to humus as 1: 4, then, taking into account the amount of organic fertilizers (in 2018 – 10,675 thousand tons, of which 8,478 thousand tons is manure of farm animals), in the form of a mixture with humus (fermented manure), all the ash of biomass that requires disposal can theoretically be used.

In addition, the cultivation of different crops requires different amounts of phosphatic and potassic fertilizers (***Fig. 5.1***). The largest amounts are used for sunflower, corn for grain, wheat, sugar beet, rapeseed (in the share of 82.

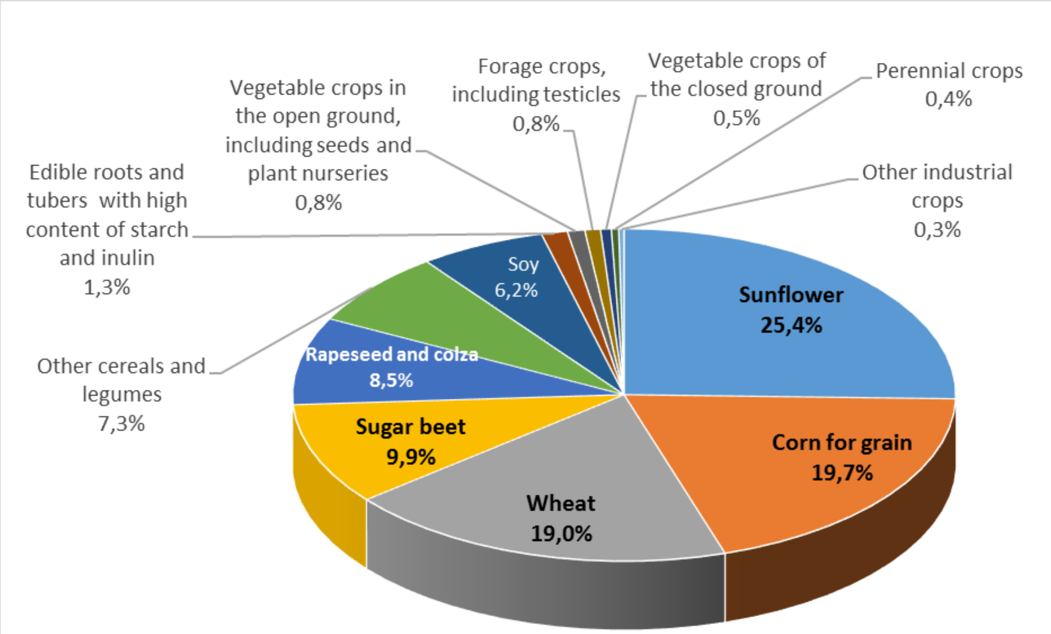


Fig. 5.1. Distribution of agricultural crops by shares in use of potassic and phosphatic mineral fertilizers (2018)

However, if we consider the "intensity" of the use of potassic and phosphatic fertilizers, such as the specific use per unit area of cultivation, it turns out that there are a number of crops that differ many times from the average values (***Table 5.3***).

Table 5.3. Specific use of phosphatic and potassic fertilizers in Ukraine per unit of fertilized area for different crops

Crops	Phosphatic-potassic fertilizers applied, in physical mass, thousand tons	Fertilized areas, thousand hectares	Use of fertilizers, kg/ha	Equivalent amount of biomass ash, thousand tons (conversion factor 4.5)
Vegetable crops of the closed ground	1.0	0.2	5155.30	4.64
Edible roots and tubers with high content of starch and inulin	2.5	12.1	207.36	11.29
Sugar beet	19.6	231.6	84.71	88.29

Vegetable crops in the open ground, including seeds and plant nurseries	1.7	27.6	60.93	7.57
Perennial crops	0.7	33.2	21.30	3.18
Rapeseed and colza	16.9	919.2	18.38	76.01
Corn for grain	39.0	3105	12.56	175.45
Sunflower	50.3	4132.1	12.17	226.30
Soy	12.2	1136.3	10.73	54.85
Other cereals and legumes	14.4	1625.5	8.85	64.72
Wheat	37.7	4492.7	8.39	169.67
Other industrial crops	0.5	67.5	7.65	2.32
Watermelon crops	0.0	1.4	0.00	0.00
Forage crops	1.5	328.1	4.60	6.79
Total and average values	**198.0**	**16112.5**	**12.3 (aver.)**	**891.1**

The above data show that the largest specific application of potassic and phosphatic fertilizers per unit area are for **indoor vegetable crops, roots and tubers, sugar beets and vegetable crops in the open ground**. In terms of physical amounts of fertilizers, the leader among these four are sugar beets. The equivalent amount of biomass ash for application as fertilizer for only the four above crops is 111 thousand tons. It can be assumed that for these crops the use of ash as fertilizer can bring greater savings in the cost of fertilizers per unit area of fertilizing. We can draw the following conclusion: one of the additional advantages of using own biomass boiler house for greenhouses may be the possibility of using the resulting ash as fertilizer. Since biomass ash contains almost no chlorine, its use may be particularly favorable for crops that react negatively to its presence in the soil.

5.3. How attractive is this type of fertilizer for consumers and producers?

Obviously, in order for biomass ash to be used as a fertilizer in large quantities and become a commodity, it must meet certain requirements of both producers and consumers. As for consumers, they will compare the consumer qualities of biomass ash with other types of fertilizers. **Ash as a fertilizer must meet the following requirements**:

- the composition meets to the needs of plants (partially satisfies);
- active substances must be in a form accessible to plants (partially satisfactory);
- the effectiveness of application as fertilizer must be confirmed (partially satisfactory);
- can be easily applied to the soil in the right doses (satisfactory if the chemical composition is known);
- the content of heavy metals is within the permitted limits (satisfactory, subject to control of origin and chemical composition);
- not smell, do not pose a threat to human safety and the environment (satisfactory);
- be suitable for storage (satisfies under appropriate conditions).

In addition, for production and sale as fertilizer, the agrochemical must be accepted in the State Register of Pesticides and Agrochemicals.

As ash does not fully meet all the necessary conditions, **its shortcomings must be compensated by price**. From a formal point of view, ash in terms of active substances is cheaper than traditional mineral fertilizers. This is undoubtedly a factor conducive to the expansion of its use. However, this does not mean that any farm will use ash as fertilizer just because it is cheaper. Much depends on the specialization of the farm in terms of growing certain crops, established agronomic techniques, available amounts and characteristics of ash, and so on. Thus, from the above data (***Table 5.1***) it is seen that the total content of potassium and phosphorus in wood ash can be 1.2-2.0 times less than in ash of straw or sunflower husk. This can reduce the price of wood ash as fertilizer. And although its calcium content is several times higher than that of straw ash or sunflower husk, which improves its quality as a liming material, this advantage may not be appreciated by the market, as there are cheaper materials for soil liming.

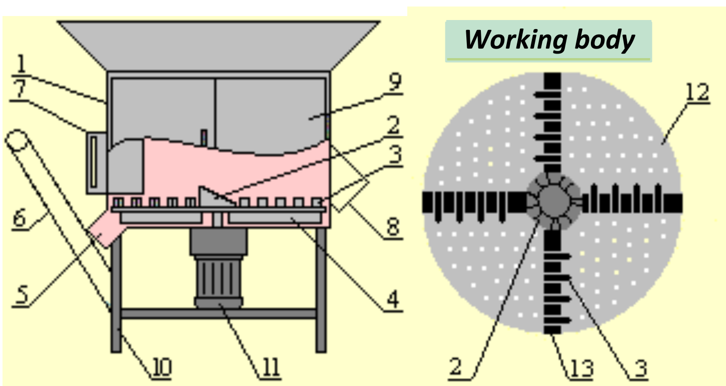
According to some experts, the application of ash into the soil does not require any special equipment in addition to what is already available in farms. The traditional systems of mineral fertilizers can be used. All types of ash with continuous application on the fertilized area can be sown with conventional fertilizer and lime drills, as well as by machines for applying mineral fertilizers [97]. Application of ash in rows can be done with grain seed drills.

For transportation and application of pulverized fertilizers, including ash, it is possible to apply machines АРУП-8 and РУП-8 (respectively on automobile and tractor drive), МТП -8 and РУП-10 on the basis of ЗІЛ-130/131 truck and the tractor Т-150К and others. For transportation and application of non-dusty limestone fertilizers are used dump trucks and body spreaders МВУ-5, МВУ-8, МВУ-16, КСА-3, МХА-7 and others.

But, as practice shows, **the application of biomass ash into the soil by traditional techniques for fertilizer application** (spreaders of granular and powder fertilizers) **may not give the desired effect** – does not ensure uniform application, the difficulty of regulating the application doze, the formation of vaults in the hopper. To perform this operation, as shown by experiments [48], the most suitable are pollinators for the application of dusty pesticides (eg, ОШУ-50). Requirements for its use and maintenance are the same as for the application of pesticides. The ash may be applied before the surface tillage with multi-track tools or before the main tillage. For efficient operation of the sprayer as a machine for surface application of ash, it is possible to use ax-like tips, which more evenly cover the soil surface with ash due to the guide partitions. It is also possible to use combined sprays, which provide simultaneous humidification when applying ash. In this case, a tip for liquid is installed inside the cylinder nozzle. Ash is blown through the cylinder nozzle, which is moistened with a sprayed liquid coming out of the liquid tip.

For grinding, sieving and mixing of ash, the shredder of cohesive fertilizers ИСУ-4 with capacity of 4 t/h can be used (**Fig. 5.2**) [97], or another machine available for such use. The machine is mounted on tractors of traction class 6-14 kN. The working bodies are driven by the tractor's PTO via cardan transmission. When working in stationary conditions an 7 kW electric motor used for the drive.

For loading of ash in the spreader it is possible to use loaders of mineral fertilizers available in farms, for example the ЗШ-3 screw conveyor with productivity of 300 kg/min., The ЗАУ-3 loader on the basis of truck ГАЗ-53А. An excavator loader can also be used for moving fertilizers from piles.



1 – bin; 2 – cutter; 3 – knives; 4 – blades; 5 – unloading window; 6 – unloading conveyor; 7 – gate; 8 – window for unloading waste; 9 – service doors; 10 – frame; 11 – drive (from the PTO or electric motor); 12 – variable sectors with holes; 13 – cross base

Fig. 5.2. Shredder of cohesive fertilizers ИСУ-4

When used **in the form of liquid fertilizer** (water ash extract), the fertilizer can be transported and mixed with liquid waste from livestock farms (***Fig. 5.3***) [89], followed by application to the soil by conventional manure spreaders.

Obviously, it will be important to acquire and promote positive experience in the use of biomass ash as fertilizer, the development of sound recommendations for its use, including advice on techniques and technologies of application to the soil.

Fig. 5.3. The use of ash as liquid fertilizer

As for potential producers and suppliers of biomass ash and fertilizers based on it, this can be especially beneficial when using **ash from large heat generating plants**, especially if it is removed from boilers mechanically and less contaminated with external debris. At large enterprises (boiler houses, CHPs), especially of the sonflower oil industry, there are conditions for the organization of separate production lines not only for packaging ash, but also for the production of other types of fertilizers based on it (eg, humates).

At present, there is almost no possibility of industrial use of ash from small boilers of municipal heating or budget facilities. Such boiler houses, as a rule, have a minimum of technological equipment for operations with ash, they do not have special conditions for its long-term storage, so often it is in the open air near the boiler room or at best in containers whith other waste. The way out of this situation may be the removal of such ash by cars of the same company that removes it to landfills, to warehouses of specialized enterprises that could be engaged in ash processing and fertilizer production (sorting, sieving, mixing with other components, packaging). The expediency of organizing such enterprises requires separate consideration. Currently, it is common practice **to distribute such ash free of charge to the local population**, which uses it as fertilizer in backyards. At least, this reduces the company's costs for the removal of ash to the landfill.

Depending on the type of fuel biomass, the specific economic effect for the heat producer in the sale of bottom ash at a price of 1000 UAH/t can be from **4 to 25 UAH per 1 Gcal** of heat produced from biomass (the higher the ash content of the fuel, the higher the effect). When selling heat to consumers at 1,200 UAH/Gcal, the revenue from ash sale and savings on its removal will range from **0.5 to 2.0%** of gross income by main activity. If under these conditions to accept the production profitability of heat produced from biomass in the range of 8-20%, the economic effect of the sale of ash will be from **2 to 28% of profits from main activities**.

5.4. Biomass ash utilization drivers

There are a number of circumstances that will contribute to solving the problem of biomass ash utilization in Ukraine in the future, including its use as fertilizer:

- Tendency to introduce waste management according to the principles of circular economy (return of nutrients to the natural cycle, reducing the need for mineral resources).
- Increased use of fuel biomass and, consequently, ash formation.
- Increasing tax rates for waste disposal in landfills.
- The growing popularity of organic production, the accept of ash from various types of biomass in the list of permitted for use in organic production.
- Deficiency of potassic and phosphatic fertilizers, its high price.
- Ukraine's dependence on imports of potassic and phosphatic fertilizers.
- Growing global shortage of raw materials for the production of phosphatic fertilizers.
- Lack of land for opening new landfills.

Conclusions and recommendations

According to estimates, the current level of energy use of biomass in Ukraine produces about **67.5 thousand tons** of biomass ash, excluding ash from sources of individual heating of population. The main method of ash treatment is its placement in ash dumps and landfills, which is a fairly cheap option for businesses.

Biomass ash contains a number of nutrients that have been absorbed by plants from the soil and remain in the ash after combustion, in particular phosphorus and potassium, which are among the main macronutrients needed by plants and have a significant impact on crop yields. In addition, biomass ash contains a number of other important macro- and micronutrients that are also needed by plants. Depending on the origin, the biomass ash may contain up to 36% potassium compounds, up to 7% phosphorus compounds and more than 40% calcium compounds.

Physico-chemical characteristics of ash depend on both the characteristics of biomass and the methods of its combustion. There are bottom, cyclone and filtration fly ash. Filtration ash from burning biomass in a fluidized bed has significant differences. Bottom ash is considered to be the most suitable for use in agriculture.

The world experience of using biomass ash testifies to various possibilities of its useful utilization, in particular in technology of building materials, road construction, and also as fertilizer and soil improver in agriculture and forestry. The main principles are environmental safety, as well as economic feasibility, which provides for the use of ash in the way most consistent with its physical and chemical characteristics.

The model of the circular economy, which is becoming increasingly popular in the world, is based on the reduction, reuse and utilization of energy, transition from fossil fuels to renewables, recovery of resources, recycling and preservation of the natural cycle of substances, environmental priorities. The goals of the circular economy are reflected in the strategy "The European Green Deal" presented by the European Commission in December 2019. The Ukrainian National Report "Sustainable Development Goals: Ukraine" envisages, in particular, ensuring the sustainable use of chemicals, as well as reducing waste generation and increasing their recycling and reuse based on innovative technologies and industries.

In this sense, biomass ash should first be considered as a source of nutrients to be returned to the soil. However, the variety of its physical and chemical characteristics, which depend on both the characteristics of biomass and the methods of its combustion, require the search for the most rational ways of its use, which would be both economically feasible and environmentally safe.

Ukrainian legislation for many decades has focused on artificial fertilizers, as the use of biomass ash in agriculture has not been significant. The use of biomass ash as fertilizer in Ukraine does not have a full promotion regime. This is reflected in the system of state registration of agrochemicals, which gives permission for the production and use of fertilizers. Unlike a number of European countries, where ash has legal conditions for use in agriculture and forestry, in Ukraine it must compete with mineral fertilizers to be able to become a commodity and be used in agriculture.

Biomass ash in Ukraine is traditionally considered a local fertilizer to be used where it was formed. However, most of it is formed in industry and thermal energy, and the chain that should bring it back to the natural cycle of substances is broken. Currently, its use as fertilizer is quite limited and unsystematic.

Despite the historical experience of using biomass ash as fertilizer, its agronomic efficiency in the conditions of modern intensive agricultural production needs additional confirmation. The lack of such information is especially felt in Ukraine. The very small number of modern domestic experimental works and field studies of the effectiveness of biomass ash as fertilizer compared to the number of such works abroad is noteworthy. In particular, there are no experimentally substantiated local recommendations on mass ratios, according to which it is possible to replace traditional mineral fertilizers with biomass ash.

Barriers to the use of biomass ash in agriculture are a number of its characteristics, including low nutrient concentration compared to artificial fertilizers, lack of nitrogen, contradictory data on the solubility of calcium compounds and the availability of phosphorus compounds for plants, too rapid dissolution potassium compounds due to the small particle size of ash, high alkalinity, reduced efficiency when used simultaneously with nitrogenous and phosphatic fertilizers, high content of inert material, the possibility of exceeding the permissible content of heavy metals, hygroscopicity and caking ability during prolonged storage, inconvenience when applied to the soil due to low bulk density, small particle size, dust formation, "hanging" in the hoppers, etc. The instability of the chemical composition and the difficulty of uniform distribution over the area interferes with the correct dosage, which is one of the foundations of modern fertilizer practice, focused on the application of specified ratios of substances for a balanced plant nutrition. For these reasons, farmers do not show much interest in its use.

There are a number of technologies and techniques to overcome these negative qualities. Some of them have long been known, such as the use of aqueous ash extraction, the application of ash with humus, addition to compost of peat or plant residues, controlled moisture and long-term storage to reduce alkalinity. Other technologies are relatively new: granulation, production of oragnomineral fertilizers, humates, use as raw materials for the production of other fertilizers. The choice of the best technologies should ensure the achievement of optimal results of agronomic application and an acceptable level of production costs to ensure competitive advantages over traditional mineral fertilizers. This, in turn, requires theoretical and practical developments, field research of new products, the development of sound recommendations for their use. The latest trends in the fertilizer market should also be taken into account: focus on highly concentrated fertilizers, both unilateral and compound, as well as their mixtures containing a given amount and ratio of active substances depending on the planned harvest, liquid compound fertilizers, which is relevant for arid regions, development of new organomineral and humic fertilizers.

It should also take into account the growing popularity in Ukraine and around the world of organic production, which tries to minimize the use of artificial fertilizers. The inclusion of ash from different types of biomass in the list of substances allowed in organic production could be an additional driver of its use.

The market for biomass ash as a fertilizer in Ukraine is at an early stage. The main number of biomass ash products available on the market is not included in the State Register of Pesticides and Agrochemicals Permitted for Use in Ukraine, and is therefore intended mainly for use in homesteads. Only two agrochemicals were entered in the State Register, both based on sunflower ash.

The market price for biomass ash is currently 800-1000 UAH/t, which in terms of the content of active substances ensures its competitiveness as fertilizer, but not an ameliorant, as there are cheaper specialized agrochemicals. At the current ratios of prices of mineral fertilizers and biomass ash, the use **of 1 ton of ash on average saves on traditional fertilizers about 1300 UAH, or 56% of the cost of phosphatic-potassic fertilizer**.

The greatest economic effect of replacement of traditional fertilizers by biomass ash can be expected when it is used for crops most demanding of potassic-phosphatic nutrition, with the highest intensity of application of these fertilizers per unit area.

For the producer of thermal energy, depending on the type of biomass and its ash content, as well as the profitability of heat production and supply, **the economic effect of the sale of ash can range from 2 to 28%** of profits from core activities.

The possibility of using biomass ash from small boilers, the total capacity of which significantly exceeds the capacity of large heat generating facilities on biomass, which have the best opportunities for the sale of ash as fertilizer, needs to be considered separately.

There are a number of factors that will help solve the problem of biomass ash utilization in Ukraine in the future, including its use as fertilizer:

- Deficiency of potassic and phosphatic fertilizers, its high price.
- Dependence on imports of potassic and phosphatic fertilizers.
- Growing global shortage of raw materials for the production of phosphatic fertilizers.
- Lack of land for opening new landfills.
- Increased use of fuel biomass and, consequently, ash formation.
- Increasing tax rates for waste disposal in landfills.
- Tendency to introduce waste management according to the principles of circular economy (return of nutrients to the natural cycle, reducing the need for mineral resources).

To expand the possibilities of useful utilization of biomass ash, it is proposed to work in the following areas:

- Standardization of biomass ash as fertilizer. Determining the criteria of quality and origin of ash to separate the ash that can not be used as fertilizer.
- Inclusion of standardized ash in the "List of agrochemicals permitted for import into the customs territory of Ukraine, production, trade, use and advertising without their state registration."
- Consider implementing a separate certification and quality assurance scheme for biomass ash, modeled on the ECN-QAS system introduced by the European Society of Compost Producers for Digestate from Biogas Plants [98].
- Substantiation of the most rational methods of utilization in other industries of ash that does not meet the requirements of its use in agriculture.
- Encourage field research on the effectiveness of biomass ash as a fertilizer.
- Proposal to include ash of different types of biomass in the list of substances permitted for use in organic production.
- Development of logistics systems to attract biomass ash from small boilers to its useful utilization.
- Research and development of technologies to improve the consumer quality of ash as fertilizer.
- Development of different types of fertilizers based on biomass ash for different soil types and different types of crops, with an emphasis on acid soils, as well as crops demanding potassic-phosphatic nutrition, with a high intensity of these fertilizers per unit area. Development of recommendations for their use, including reasonable ratios, according to which fertilizers based on biomass ash can replace traditional mineral fertilizers.
- Raising awareness among potential consumer groups about the possibilities of using biomass ash as fertilizer, development of appropriate recommendations, which would include technologies of application with proven effectiveness. Popularization of successful experience of agricultural producers both in Ukraine and other countries.
- Further harmonization of Ukraine's norms with the EU on fertilizer production and application. For example, the implementation of the National Regulation adapted to the EU Fertilizing Products Regulation (EU) 2019/1009.

Annexes

Annex 1. Elemental composition and content of chemical compounds in biomass ash

The maximum content of elements in the ashes of different types of biomass with different combustion technologies, mg/kg dry weight

Element	All types of ash			Bottom ash			Fly ash			Mixture
	min	max	average	min	max	average	min	max	average	average
P	2	409000	15311	11	409000	26073	2	45025	9952	19912
K	24	465000	96058	142	336000	58059	234	417960	207918	60844
Ca	1	683356	219370	60	590000	269906	7	311959	129953	204585
Mg	98	160000	28467	2232	160000	38871	1	46985	17045	30795
Na	297	124715	6416	672	108000	6351	337	36735	9078	8532
S	150	140889	22753	150	137000	7511	2279	128540	45314	14478
Pb	1	48950	694	1	1890	63	12	6989	1066	137
Zn	8	113849	6436	8	3769	416	163	38916	12064	1560
Cd	1	451	40	1	24	2	1	155	57	10
As	1	130	15	1	31	7	2	40	13	24
Cl	2	467218	31014	4	18330	1632	830	351915	108096	3197

Characteristics of straw ash burned on a boiler with a movable grate [99]

Substance	Total ash	Bottom ash			Cyclone ash			Filtration ash		
		Range		Average	Range		Average	Range		Average
		min	max		min	max		min	max	
S, mg/kg	5508	3515	4293	3904	11749	12552	12150.5	27991	28309	28150
Cl, mg/kg		4144	13200	8417	39300	95951	71567.4	176000	282543	243303.4
Si, mg/kg	262740	333000	356000	344000	255000	277000	269333.3	66000	77000	72000
Ca, mg/kg	46462	118	59000	28049	72	52000	27431	12	18000	8606.6
Mg, mg/kg	18094	5000	16642	11340.8	5000	12000	8960	1630	4000	2640.8
K, mg/kg	196844	178	111000	51473.2	199	112000	52683.2	234	372000	210708.4
Na, mg/kg	9651									
P, mg/kg	19206	17	26700	9787.6	13	20800	8445.4	4	11900	5641.8
B, mg/kg										
Al, mg/kg	6353	2900	13100	6566.7	2800	9700	5133.3	200	800	466.7
Fe, mg/kg	8397	2300	7400	4666.7	6200	17000	10466.7	900	2100	1466.7
Mn, mg/kg		428	598	496.3	384	589	461	98	150	128
Cu, mg/kg	85	28	41	36.2	27	36	32.6	25	48	34.8
Zn, mg/kg	125	23	104	66.4	76	726	284.4	182	1139	584
Co, mg/kg	20	1	3	2	1	2	1.3			
Mo, mg/kg		1	4	3	3	4	3.7	7	11	9.3
As, mg/kg	32									
Ni, mg/kg	45	4	10	6.4	5	16	7.4	1	8	3.6
Cr, mg/kg	58	8	18	11	4	18	8.8	2	12	6.6
Pb, mg/kg	45	3	18	10.6	15	33	23	23	122	67
Cd, mg/kg	3	1	2	1.5	3	6	4.5	10	20	15.5

V, mg/kg	28									
Hg, mg/kg	5							1	2	1.5
Ba, mg/kg	90									
Ti, mg/kg	359									

Note: All values are for dry straw

Expanded chemical compositions of ash of common types of wood biomass [100]

Components	Units	Types of wood							
		Birch	Beech	Willow	Oak	Spruce	Miscanthus	Pine	Poplar
CO2	%	-	-	18.0	-	26.3	1.47	-	-
SO3	%	2.2	-	1.5	2.2	1.29	3.7	1.62	-
Cl	%	-	-	0.11	-	0.17	1.45	-	-
P2O5	%	17.0	-	9.3	7.5	2.84	1.75	4.81	14.81
SiO2	%	2.8	20.0	15.0	2.3	8.5	63.0	23.53	9.22
Fe2O3	%	0.7	1.4	0.92	0.5	0.78	0.36	2.14	-
Al2O3	%	1.4	7.0	1.6	0.9	1.03	0.45	5.1	3.26
CaO	%	45.0	26.1	32.0	65.0	42.2	7.1	33.58	47.28
MgO	%	10.8	9.2	3.0	8.3	2.4	2.85	5.14	11.58
Na2O	%	1.3	1.8	2.6	0.8	0.23	0.18	0.19	0.1
K2O	%	11.4	23.5	17.0	9.9	7.3	14.8	12.05	24.37
TiO2	%	0.1	-	-	0.1	-	-	0.06	-
Pb	mg/kg	-	-	-	-	29.0	20.0	-	-
Cd	mg/kg	-	-	-	-	1.7	0.6	-	-
Cu	mg/kg	-	-	-	-	148.0	53.0	-	-
Hg	mg/kg	-	-	-	-	1.8	0.0	-	-
Mn	mg/kg	-	-	-	-	-	-	-	-
Cr	mg/kg	-	-	-	-	-	-	-	-

Expanded chemical compositions of ash of common types of agricultural biomass

Components	Units	Types of agricultural crops							
		Rye	Oats	Wheat	Barley	Sunflower husk	Maize	Rice husk	Rape straw
CO2	%	7.1	6.7	1.3	2.5	-	-	-	13.0
SO3	%	4.19	2.97	2.9	4.43	1.3	2.2	0.77	14.0
Cl	%	7.15	13.1	2.1	11.9	-	-	0.73	5.96
P2O5	%	4.85	1.77	1.9	2.73	4.8	0.66	0.87	7.86
SiO2	%	23.2	16.9	56.3	33.8	16.6	71.7	89.39	4.1
Fe2O3	%	0.22	0.42	0.6	0.28	2.1	7.1	0.4	0.75
Al2O3	%	0.23	0.61	0.5	0.28	2.9	0.46	0.22	0.28
CaO	%	9.7	6.9	6.3	8.3	15.8	2.7	1.3	24.9
MgO	%	1.87	1.72	1.4	2.22	6.1	0.33	0.57	3.14
Na2O	%	0.12	7.52	0.2	4.11	1.5	-	0.35	1.37
K2O	%	28.9	31.8	12.6	26.1	35.6	10.28	5.04	25.4
TiO2	%	-	-	-	-	0.1	-	0.02	-
Pb	mg/kg	3.0	2.0	-	2.0	-	-	-	3.0
Cd	mg/kg	0.1	-	-	0.2	-	-	-	0.1
Cu	mg/kg	34.0	26.0	-	36.0	-	-	-	36.0
Hg	mg/kg	-	-	-	-	-	-	-	-
Mn	mg/kg	-	-	-	-	-	-	1859.0	-
Cr	mg/kg	-	-	-	-	-	-	342.0	-

Annex 2. List of standards (DSTU) on building materials using fly ash (function of ash indicates in parentheses)

DSTU B B.2.7-205: 2009 "Building materials. Fly ash of thermal power plants for concrete. Specifications.

> This standard applies to dry fly ash (hereinafter referred to as dry-cleaning ash), which is formed in thermal power plants by burning coal in a dusty state and which is used as a component for the manufacture of heavy, light, cellular concrete and mortars, as well as finely ground additive for heat-resistant concrete and mineral binders for the preparation of mixtures in road construction. The standard does not apply to ash, which is formed from the combustion of oil shale.

DSTU B B.2.7-211: 2009 Building materials. Mixtures of ash-slag of thermal power plants for concrete. Specifications.

> This standard applies to ash-slag mixtures, which are formed at thermal power plants with combined hydro-removal of ash and slag in the process of burning coal in the dusty state and which are used as a component for the manufacture of mortars and heavy, light and cellular concretes for precast and monolithic concrete structures and products. The standard does not apply to ash-slag mixtures for concrete of hydraulic structures, pipes, sleepers, transmission line pylons and special types of concrete.

DSTU B B.2.7-281: 2011. Cement. Classification (Portland cement component)

DSTU B B.2.7-43-96. Heavy Concretes. Specifications (as a fine aggregate for concrete).

DSTU B B.2.7-18-95. Light Concretes. General technical conditions (as a filler for concrete)

DSTU B B.2.7-45: 2010. Aerated concrete. General technical conditions (binder)

DSTU B B.2.7-46-96. General construction cements. Specifications (binder, filler).

DSTU B B.2.7-176: 2008. Concrete and concrete mixes. General technical conditions.

> The general suitability of type II (active mineral) additives must meet the requirements of the standards: fly ash – EN 12390-3, EN 450.
>
> EN 450: 1944 Fly ash for concrete – Definitions, requirements and quality control. Fly ash from dust combustion of coal and joint combustion of other materials is considered.

DSTU B B.2.7-25_2011 Heavy alkaline concretes. Specifications (as a fine aggregate for concrete)

DSTU EN 14227-3: 202_ (EN 14227-3: 2013, IDT). Mixtures reinforced with hydraulic binders. Specifications. Part 3. Dispersed mixtures, reinforced with fly ash.

Annex 3. “Smilaenergopromtrans” – conclusion on the quality of wood ash

УКРАЇНА

МІНІСТЕРСТВО АГРАРНОЇ ПОЛІТИКИ ТА ПРОДОВОЛЬСТВА

ДЕРЖАВНА УСТАНОВА ЧЕРКАСЬКИЙ ОБЛАСНИЙ ДЕРЖАВНИЙ ПРОЕКТНО-ТЕХНОЛОГІЧНИЙ ЦЕНТР ОХОРОНИ РОДЮЧОСТІ ҐРУНТІВ І ЯКОСТІ ПРОДУКЦІЇ

20731, Черкаська область, Смілянський район, с. Холоднянське, вул. Докучаєва, 15
тел. факс (047-33) 4-24-82, 2-10-46, 91-3-47:E-mail: Himcentr@ck.ukrtel.net; Skype: himcentr-agro

ЗАКЛЮЧЕННЯ
ПРО ЯКІСТЬ ЗОЛИ З ДЕРЕВИНИ

№ 48/04-2 **25. 01. 2012 р.**

Реєстраційний номер **2/1**
Дата одержання на аналіз **12.01.2012р.**
Замовник **ТОВ «Смілаенергопромтранс», м. Сміла**
Дата відбору **12.01.2012р.**

У представленому замовником зразку виявлено:

Показники	Вміст		Метод визначення
	На натуральну вологу	На абсолютно сухий стан	
Вологa,%	1,3	0	ГОСТ 26713-85
Кислотність, од. pH	14,0		ГОСТ 27979-88
Азот загальний, %	0	0	ГОСТ 26715-85
Фосфор загальний, %	1,3	1,3	ГОСТ 26717-85
Калій загальний, %	4,0	4,1	ГОСТ 26718-85
Зола, %		86	ГОСТ 26714-85
Органічна речовина,%		7*	ГОСТ 27980-88
Сірка, %	0,32	0,32	**
Мідь, мк/кг	45,2	45,8	СТ СЭВ 3365-81
Цинк, мг/кг	113,7	115,2	СТ СЭВ 3368-81
Свинец, мг/кг	51,1	51,8	ГОСТ 26929-94
Кадмій, мг/кг	6,2	6,2	ГОСТ 26929-94
Марганець,мг/кг	7877,0	7980,0	СТ СЭВ 3366-81
Кобальт, мг/кг	12,8	13,0	СТ СЭВ 3364-91
Бор, мг/кг	30,0	30,4	СТ СЭВ 3363-81
Залізо, мг/кг	7315,0	7411,0	ГОСТ 26929-94

Annex 4. Review of existing limit values (mandatory minimum and maximum values) for heavy metals and nutrients of biomass ash for use as fertilizer on agricultural and forest lands in different countries [4]

	Germany[1]	Austria[2]	Denmark[3]	Sweden[4]	Finland[5]
Nutrients (% min.)		Class A/B			AGR/FOR
Ca	15[1] (CaO)			12.5	10[5]/6
K	3[1] (K_2O)			3.0	-/2 (K+P)
Mg				1.5	
P	2[1] (P_2O_5)			0.7	-/2 (K+P)
N	3[1]				
Zn				0.05	
Heavy metals (mg/kg max.)					
As	40	20/20		30	25/40
B				800	
Cd	1,5	5/8	5[a]/20	30	2.5/25
Cr(tot)		150/250	100	100	300/300
Cr (VI)	2				
Cu		200/250		400	600/700
Hg	1		0.8	3	1.0/1.0
Ni	80	150/200	60	70	100/150
Pb	150	100/200	120/250[b]	300	100/150
Ti	1				
V				70	
Zn		1200/1500		7000	1500/4500

[1] Germany: only bottom ash can be used as fertilizer; the limit values do not apply to wood ash, which is exclusively disposed of on forest lands. The K-fertilizer must contain a minimum of 10% K2O. “Ca-fertilizer” should contain 15% CaO, “P-K fertilizer” should contain a minimum proportion of 2% P2O5 and 3% K2O and “N-P-K fertilizer” must contain a minimum proportion of 3% N, 2% P2O5 and 3% K2O. “Nutrient-fertilizer” should include a minimum content (B, Co, Cu, Fe, Mn, Mo, Zn).

[2] Austria: (Class A/Class B): Class A ash can be used without chemical analysis of soil, heavy metal ash between Class A and Class B limits can be used after chemical analysis of soil , which indicates that the use of ash is safe according to the content of heavy metals.

[3] Denmark: a – the permissible value of Cd for straw ash is indicated on the left/the permissible value of Cd for wood ash is indicated on the right; b – for wood ash used in forestry.

[4] Sweden: The limit values are valid for use on forest lands.

[5] Finland: left values for use on agricultural land (AGR)/right values for use on forest land (FOR). The minimum content of nutrients for use in forestry is 2% (K + P) and 6% Ca. For other uses, including agriculture, horticulture and landscaping, a neutralization number of at least 10% (Ca) must be provided.

Annex 5. Average norms of mineral fertilizers for agricultural crops, kg/ha of the active substance (Forest-steppe of Ukraine) [101]

№ п/п	Crops	Yield level, quintal/ha	Soils	Norms of mineral fertilizers		
				N	P_2O_5	K_2O
1.	Winter wheat	55	Chernozems are typical	90	90	60
		50	Chernozems are podzolic			
		50	Dark gray podzolic	120	90	90
		45	Light gray, gray forest	120	120	90
2.	Winter wheat	45	Chernozems are typical	60	60	40
		40	Chernozems podzolic Dark gray podzolic	60	90	60
		40	Light gray, gray forest	90	90	90
3.	Spring wheat	45	Chernozems typical	60	60	45
		45	Chernozems podzolic	90	60	45
		40	gray forest	90	60	90
4.	Spring barley	40-45	Chernozems typical	60	60	40
		40-45	Chernozems podzolic	60	90	60
		40	Dark gray podzolic	60	90	60
		40	gray forest	90	90	90
5.	Oats, millet	35	Chernozems podzolic	60	60	60
6.	Buckwheat	25	Chernozems podzolic	45	60	45
		25	gray forest	90	90	90
7.	Corn for grain	40	Chernozems typical	90	90	90
		40	Chernozems podzolic	90	90	60
		40	Light gray, gray forest	120	120	90
8.	Legumes	25	Chernozems typical	30	60	60
		20	gray forest	30	60	60
9.	Winter rape	25-30	Chernozems typical	120	70	140
		15	gray forest	45	45	60
10.	Sugar beets	450	Chernozems typical	160	170	150
		400	Chernozems podzolic	160	170	150
		400	Dark gray podzolic	170	160	180
11.	Potato	250	Chernozems typical	90	120	120
		300	gray forest	120	180	180
12.	Sunflower	25	Chernozems typical	60	60	60
		20	gray forest	60	60	60
13.	Silage corn	350	Chernozems typical	90	60	60
		350	gray forest	120	90	90
14.	Fodder roots	350	Chernozems typical	140	120	120
15.	Perennial herbs for green mass:	250	Chernozems typical	-	60	60
		200	gray forest	-	60	60
	Beans	200	Chernozems typical	60	60	60
	Cereals	180	gray forest	60	60	60
16.	Annual herbs		Chernozems typical	90	60	60
			gray forest	90	60	60

Annex 6. The most important types of mineral fertilizers [102]

1. The most important compound fertilizers

Name	Main components	Content of main active substances
Ammoniated superphosphate	$CaHPO_4$+$NH_4H_2PO_4$+ $CaSO_4$	1,5–3 % N, >14% P_2O_5
Amophos	$NH_4H_2PO_4$+$(NH_4)_2HPO_4$	10-12%N, 46-50 % P_2O_5
Amophoska	$(NH_4)_2HPO_4$+$(NH_4)_2SO_4$ + KNO_3+ NH_4Cl	21–25 % N. 20–25 % P_2O_5
Diamophos	$(NH_4)_2HPO_4$+ $NH_4H_2PO_4$	20-21 % N, 50-53% P_2O_5
Nitroammophos	NH_4NO_3+ $NH_4H_2PO_4$	по 24% N та P_2O_5
Nitroammophoska, azophoska	NH_4NO_3 + $NH_4H_2PO_4$+ KNO_3+ NH_4Cl	15-22% N, 11-21%K_2O та 9-21% P_2O_5
Potassium nitrate	KNO_3	13-18 %N, 46% K_2O
Carboammophoska	$CO(NH_2)_2$+ $(NH_4)_2HPO_4$+ KNO_3+ NH_4Cl	по 19,8 % N, K_2O та P_2O_5
Nitrophosphate	NH_4NO_3+ $CaHPO_4$+ KNO_3+	15–24%K_2O
	NH_4Cl+ (або $(NH_4)_2HPO_4$ або	17–18,5 % N. P_2O_5 і K_2O
	$NH_4H_2PO_4$ + $CaSO_4 \cdot 2H_2O$ або $CaCO_3$	По 18–20 % N. P_2O_5 і K_2O
Magnesium ammonium phosphate	$MgNH_4PO_4H_2O$ $(NH_4PO_3)n$	11–20 % N. 8–16 % P_2O_5
Ammonium polyphosphate	$(NH_4)_5O_{10}$+$(NH_4)_4P_2O_7$+$(NH_4)_3HP_2O_7$+ $NH_4H_2PO_4$	35 % P_2O_5, 18 % MgO, 17 % N. 80 % $P_2O_5$12–25% N. 53–61 % P_2O_5

2. The most important nitrogenous fertilizers

Name	Main components	Content of main active substances
Ammonia liquid	NH_3	82,3 % N
Water ammonia	NH_3+H_2O	16,5–20,5 %N
Urea-ammonia mixture	розчин NH_4NO_3 в $CO(NH_2)_2$	28–32 %N
Urea-formaldehyde	$NH_3CONHCH_3$	33–42 % N
Ammonium nitrate (ammonium nitrate)	NH_4NO_3	32–35 % N
Ammonium sulfate	$(NH_4)_2SO_4$	19,9–21 %N
Calcium nitrate	$Ca(NO_3)_2$:3H_20	13–15 % N
Sodium nitrate	$NaNO_3$	15–16 % N

3. The most important phosphatic fertilizers

Name	Main components	Content of main active substances
Superphosphate double	$Ca(H_2P0_4)_2$ • $H2O+H_3PO_4$	40–52 % P_2O_5
Superphosphate simple	$Ca(H_2P0_4)2$•$H_20+H_3PO_4+CaSO_4$	14–21 %P_2O_5
Defluorinated phosphate	3CaO• P_20_5+4CaO P_20_5	20–38 % P_2O_5
Precipitate	$CaHPO_4$ • $2H_20$	27–40 % P_2O_5
Phosphorite flour	$Ca_3F(PO_4)_3$	16–35 % P_2O_5
Phosphate slags	4CaO•P_20_5+5CaO•P_2O_5 SiO_2	14–20 % P_2O_5

4. The most important potassic fertilizers

Name	Main components	Content of main active substances
Potassium chloride	KCl	50–62 % K_2O
Mixed	KCl+NaCl; KCl+$MgSO_4$	30–42 % K_2O
Potassium sulfate	K_2SO_4	48–52 % K_2O

Annex 7. Prices of phosphatic, potassic fertilizers and ameliorants

Fertilizer	Chem. content	Price, UAH/t incl. VAT	Packing, kg	Producer
Potassium sulfate	potassium (50%), sulfur (18%), magnesium (3%), calcium (0.4%)	20 000-24 000	500	Khimprodukt TD TOV, Kyiv www.tdchem.com.ua TM Ahrokhimprom, Ltd, m. Dnipro
Potassium sulfate (Lubopolon)	K_2O – 40% MgO – 4% CaO – 4,5% SO3 – 13%	11 837	500	Production of Lubopolon, Poland https://ukragrozakaz.com.ua/p1026074660-sulfat-kaliya-granula.html
Potassium chloride	K_2O % 60	12 807	500	Production of Lubopolon, Poland https://ukragrozakaz.com.ua/p632196010-kalijnaya-sol-hlorid.html
Potassium chloride	K_2O % 60	10 950	1000	Production of Belarus https://selitra.biz/p616274123-kalij-hloristyj-rozovyj.html
	K_2O % 60	10 800	500	Dobryva, Ltd, Kherson https://herson.flagma.ua/kaliy-hloristy-o2467086.html
Potassium chloride	P2O5 – 52% K2O – 34%	44 500	25	Production of China, Distrib.: Dobriva, city Kamianske https://dobriva.dp.ua/product/monofosfat-kaliya/
Potassium monophosphate	P2O5 – 19%, CaO – 20%, SO3 – 32%	6 000-7 200	500	Production "Siarkopol", Poland Supplier: Ukrhimprom -2005, PE https://cherkassy.flagma.ua/superfosfat-prostoy-superfosfat-p-cas-19-20-o5864237.html
Superphosphate simple	32% P_2O5	12 500 – 12 700	500	Agrocompaniia, Ltd, Dnipro https://dnepropetrovsk.flagma.ua/uk/dvoynoy-superfosfat-np-12-24-12-s-o3500623.html
Superphosphate double	32% P_2O5 10% N 18% SO3	11 700	500	PJSC Dnipro Mineral Fertilizer Plant Supplier: Dobriva, city Kamianske https://dobriva.dp.ua/produktsiya/dvojnoj-superfosfat-2/
Superphosphate double	46% P2O5	15 300		https://hectare.ua/ru/internet-magazin/product/view/22/4782
Superphosphate triple	40% P2O5	12 914 (445 EUR/t)	500	TM Super Fos Dar Supplier: VVM Trading, Ltd., Sumy https://sumy.flagma.ua/uk/super-fos-dar-superfosfat-zbagacheniy-40-super-o7619058.html
Superphosphate enriched	calcium sulfate – 90% phosphorus – 1%	750	820	Постач:Dobriva, м.Каменськ Supplier: Dobriva, city Kamianske

	sulfur – 20%			https://dobriva.dp.ua/product/fosfogips-fasovanyj/
Phosphogypsum packed up	Ca 32% Mg 21% humates 2%	5 000	500	Prod.: UkrJiugimpeks https://prom.ua/p1000242809-organicheskoe-udobrenie-dolomit.html
Dolomite flour	calcium and magnesium carbonates – not less than 90%, incl. calcium, not less than 34% insoluble residue ≤ 2%	330-360		PE Khovan Svitlana Anatoliivna https://prom.ua/p1044728388-vapnyak-meliorativnij-dlya.html PJSC "GYPSOVYK", Kamyanets-Podilsky

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www.uabio.org/en