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Fertilisation with ash from biomass combustion and gypsum on physical properties of sandy soil

Dariusz Błażejczak[1)], Marek Śnieg[1)], Magdalena Sobolewska[1)], Anna Jaroszewska*[1)], Jarosław Pytka[2)], Krzysztof Kuglarz[3)]

[1)] West Pomeranian University of Technology in Szczecin, Faculty of Environmental Management and Agriculture, Juliusza Słowackiego St 17, 71-434 Szczecin, Poland

[2)] Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka St 36, 20-618 Lublin, Poland

[3)] Agro Trade Sp. z o.o., Bohaterów Warszawy St 35A, 75-211 Koszalin, Poland

* Corresponding author

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Abstract: The aim of the present paper was to verify the hypothesis that a single application of specific dose of ash from biomass combustion and/or gypsum has a positive effect on physical properties of sandy soil and that the said effect disappears over the following years. The following were determined in the layer of 5–10 cm: penetration resistance (*PR*), vane shear resistance (S_s), gravimetric moisture content (w_w), dry bulk density (*BD*), moisture content (W_{pF2}) and air-filed porosity (PA_{pF2}) at water potential p*F*2. At p*F*2, susceptibility to soil compaction was analysed i.e., unit stress required to cause soil deformation of an assumed value of 1.0 mm (*P*1) or 2.0 mm (*P*2). Fertilisation with ash and/or gypsum at doses of 15 and 3 Mg·ha^{-1} respectively, affects the physical properties of soil particularly in the first year following the application and that the said fertilisation is to be conducted every two years. It was found that fertilisation with ash has a particularly positive effect on w_w. The loosening effect of fertilisation with ash, measured with *BD*, was poorly pronounced. A decrease in *PR* and S_s values was observed particularly in the first year. The analyses at water potential p*F*2 showed that fertilisation with ash or ash with the addition of gypsum has a positive effect on the properties under analysis. The effect of fertilisation with gypsum at a dose of 3 Mg·ha^{-1} on the analysed properties was inconclusive.

Keywords: biomass ash, fertilisation, gypsum, soil physical properties

INTRODUCTION

The acquisition of energy from solid biomass combustion generates significant amount of ash (Uliasz-Bocheńczyk, Pawluk and Pyzalski, 2016) which may constitute a valuable raw material for fertilising purposes (Bhattacharya and Chattopadhyay, 2002; Romdhane *et al.*, 2021). The resulting ash contains adequate proportions of various macro- and micronutrients as well as a mixture of oxides, hydroxides, carbonates and silicates (Eriksson, 1998; Demeyer, Voundi Nkana and Verloo, 2001). It is believed that the said ash is one of the most sustainable available options to meet the increasing demand for artificial fertilisers and improving soil fertility (Huotari *et al.*, 2015; Tosti *et al.*, 2019). Moreover, it is emphasised that ash may counteract soil acidification (Knapp and Insam (eds.), 2011; Arshad *et al.*, 2012; Cruz-Paredes *et al.*, 2017). The studies on the use of ash, specifically wood ash, were conducted in agriculture and forestry. It was found that application of wood ash at doses equivalent to agricultural lime improved some chemical and physical properties of soil and increased plant production in comparison with agricultural lime (Arshad *et al.*, 2012). The positive effect of fertilisation with wood ash was observed, for example, with respect to corn (Romdhane *et al.*, 2021) or phacelia, buckwheat and corn (Knapp and Insam (eds.), 2011). The studies conducted in forests showed the effect of wood ash on forest soil pH and the number of bacteria (Bang-Andreasen *et al.*, 2017; Bang-Andreasen *et al*., 2021). According to Brunner *et al.* (2004), wood ash recycling may become an integral part of sustainable forest management as it closes the nutrient cycle.

The studies conducted so far on the use of biomass ash mainly focused on the effect of biological and chemical properties of soil and plant yield. There is a relatively small number of scientific studies on the effect of ash on physical properties of soil (Stanek-Tarkowska *et al.*, 2022). Physical properties of soil are important for plant growth as well as in terms of some aspects of environmental protection (Dexter and Czyż, 2000; Dexter and Czyż, 2007). Frequently analysed physical properties of soil are, among others: moisture content (w_w), dry bulk density (*BD*), porosity (*P*), penetration resistance (*PR*) and resistance to compaction, expressed with soil pre-compaction stress, and many others. Soil moisture content affects plant yield therefore maintaining adequate water retention is particularly important (Dexter *et al.*, 2001). Water retention is related to, among others, dry bulk density (Assouline, 2006) which in turn affects numerous soil processes. Dry bulk density affects, among others, infiltration, root development, water availability, general porosity and air porosity of soil, availability of nutrients and activity of soil micro-organisms (Gajda, Czyż and Dexter, 2016; Stanek-Tarkowska *et al.*, 2022). Increased values of *BD* may indicate excessive soil compaction which is one of the major problems in agriculture (Soane and Ouwerkerk van, 1994; Håkansson, Ouwerkerk van and Soane, 1995; Akker van den, Arvidsson and Horn, 2003; Schjønning *et al.*, 2015; Correa *et al.*, 2019; Keller *et al.*, 2019; Bonfim-Silva *et al.*, 2022). Increasing and excessive soil compaction leads to, among others, decreased soil porosity, change in the shape and size distribution of pores (Pagliai *et al.*, 2003), reduced soil aeration (Czyż *et al.*, 2013), diminished water infiltration (Kulli, Gysi and Flühler, 2003), increased water erosion (Fleige and Horn, 2000) and it also facilitates the entry of pesticides and fertilisers into water courses and reservoirs (Alakukku, 1996). Excessive soil compaction deteriorates the conditions for root development (Gysi, 2001; Gliński and Lipiec, 2018; Correa *et al.*, 2019). Changes due to excessive soil compaction ultimately result in reduced plant yield (Hadas *et al.*, 1990; Bicki and Siemens, 1991; Arvidsson, 2001), increased production costs (Oskoui and Voorhees, 1991) and have a negative effect on the environment. It is estimated that excessive soil compaction by the wheels of agricultural vehicles affects an area of about 66 mln ha in Central and Eastern Europe (Bowyer *et al.*, 2009). One method of preventing or limiting excessive soil compaction is appropriate fertilisation (Hamza and Anderson, 2005). Soil dry bulk density and moisture content affect soil penetration resistance (Dexter, Czyż and Gate, 2007). The value of *PR* allows indirect determination of, among others, pre-compaction stress (Mosaddeghi *et al.*, 2003), draught force of tillage implements, vehicle trafficability and growth (elongation rate) of plant roots in soil (Motavalli *et al.*, 2003; Arvidsson and Keller, 2011).

During combustion of solid fuels, including biomass, flue gas desulphurisation takes place which, in turn, results in acquisition of gypsum which shows properties comparable with that of the mineral naturally present in the environment. Owing to the content of sulphur and calcium, gypsum is used as fertiliser in agriculture. The effect of fertilisation with gypsum on chemical properties of soil is particularly emphasised (Łabętowicz *et al.*, 2004). What is more, application of gypsum may also affect physical properties of soil such as: density, porosity and penetration resistance (Rocha de Moraes Rego, 2017). The studies on the effect on gypsum on physical properties of land are also conducted in geotechnics (Kuttah and Sato, 2015). However, it must be noted that both the study material as well as the aim of geotechnical studies are distinct from those applied in studies conducted for agricultural purposes.

The aim of the present paper was to verify the hypothesis that a single application of specific dose of ash from biomass combustion and/or gypsum has a positive effect on physical properties of sandy soil and that the said effect disappears over the following years. It was assumed that the investigations are to be conducted directly under field conditions as well as on soil samples following the formation of a specified water potential – p*F*2.

MATERIALS AND METHODS

The field experiment was conducted in the period 2019–2021 in the village Wrześnica (GPS coordinates: 54°24'38" N; 16°47'37" E) on soil with granulometric composition of loamy sand according to PTG (2008), (USDA – loamy sand). Granulometric composition of soil was the following: soil skeleton – 1.63% (>2.0 mm), sand (0.05–2.0 mm) – 78.0%, silt (0.002–0.05) – 17.7%, clay (<0.002 mm) – 4.3%. Topsoil depth was, on average, 27 cm. The soil reaction was acidic in KCl – 4.66, salinity – 24.7 $\mu S \cdot cm^{-1}$. Soil reaction was determined potentiometrically in accordance with PN-ISO-10390:1997 (Polski Komitet Normalizacyjny, 1997). Measurements of soil reaction (pH in KCl) were also carried out in the years following the harvest for individual variants of the experiment as replication means.

Fertilisation with ash from biomass combustion and gypsum was conducted once in spring 2019 prior to sowing spring barley. The plot area was 480 m^2. Winter wheat was used as forecrop. Ash and gypsum were sown using a manure spreader by Bergmann TSW 5210s. For the purpose of mixing the fertilisers with soil at the depth of approx. 18 cm, Horsch Terrano 8FG cultivator was used. The following doses of ash and gypsum were used in the experiment, respectively: 0 and 15 $Mg \cdot ha^{-1}$ and 0 and 3 $Mg \cdot ha^{-1}$. Biomass ash pH and chemical composition (mixed – ash from the combustion of wood and straw) was, respectively: pH in KCl – 13.1 and P – 1.46%, K – 10.56%, Mg – 2.0%, Ca – 12.7%. Fertilisation with gypsum was carried out with SulfoPROFIT fertiliser. It is a sulphur-calcium fertiliser in a loose form which contains two mineral components available for plants: sulphate sulphur (SO_4^{2-}) and calcium (Ca^{2+}). Calcium content is 24% and sulphur content is 19%. Fertiliser reaction in water ranges from 6.0 to 7.0. This fertiliser belongs to a group of slow-release fertilisers and does not acidify the soil. The following experimental design was used:
- C – control (without fertilising with ash and/or gypsum),
- G3 – 3 $Mg \cdot ha^{-1}$ gypsum,
- A15 – 15 $Mg \cdot ha^{-1}$ ash,
- G3A15 – 3 $Mg \cdot ha^{-1}$ gypsum + 15 $Mg \cdot ha^{-1}$ ash.

Measurements of physical properties of soil were conducted following the harvest of plants. In the first year (2019), the measurements were conducted after harvesting spring barley (*Hordeum* L.) and in the following years (2020 and 2021) after harvesting grass for seeds – red fescue (*Festuca rubra* L.).

The analyses of soil properties were conducted in the layer 5–10 cm. Directly under field conditions, the following were measured: penetration resistance (*PR*) and vane shear resistance (S_s). *PR* was measured with a penetrologger by Eijkelkamp at the feed speed of 2 cm·s^{-1} using a cone with an apex angle of 30° and base surface of 1 cm^2. To measure vane shear resistance, a shear vane tester H-60 by Geonor was used, equipped with a tip of 16×32 mm in dimensions and measuring range from 0 to 260 kPa. Measurements of *PR* and S_s were conducted in 10 replications at randomly selected points. Other measurements were made in 6 replicates also at randomly selected points. Soil samples with so-called intact structure, were taken using Kopecky cylinders with a capacity of 100 cm^3 and an inner diameter of D = 50 mm. The measurements served to determine the gravimetric moisture content (w_w) and dry bulk density (*BD*) in field conditions. These samples were moistened to maximum moisture content and the moisture content at p*F*0 ($w_{\mathrm{p}F0}$) was measured, and then after the water potential p*F*2 was created on the gypsum board, the following were also determined: moisture content ($w_{\mathrm{p}F2}$), aeration porosity ($PA_{\mathrm{p}F2}$) and soil compaction susceptibility. The determined $w_{\mathrm{p}F0}$ and $w_{\mathrm{p}F2}$ values were used to determine $PA_{\mathrm{p}F2}$. Moistures (w_w, $w_{\mathrm{p}F0}$, $w_{\mathrm{p}F2}$) and density (*BD*) of the soil were determined using the dryer-weight method (drying at 105°C for 24 h). Owing to the lack of widely adopted standard method of determining pre-compaction stress (Keller *et al.*, 2004), the assessment of soil susceptibility to compaction was conducted with a simplified method. Data were obtained by means of uniaxial sample compression with Instron 5582 testing machine under the conditions of possible lateral expansion of soil, using a compaction plate of d = 35 mm (Fig. 1). The compaction plate diameter was selected to maintain d/D ratio during sample deformation i.e., $0.3 \leq d/D < 0.8$ (Błażejczak and Dawidowski, 2016). Determination of soil susceptibility to compaction (Fig. 2) consisted in identifying on compressibility curve the unit stress unit (pressure) required for soil deformation of an assumed value of 1.0 mm (*P*1) or 2.0 mm (*P*2), i.e. approximately after exceeding pre-compaction stress value of which is determined within the area of the so-called knee (Śnieg, 2012). With respect to the obtained curves (Fig. 2), the value of the said stress is to be identified within the range of sample deformation from approx. 0.5 to 0.8 mm. Determining unit stress at two values of sample deformation was due to the fact that the slope of the compressibility curve of individual samples may differ in terms of primary stress i.e. after exceeding pre-compaction stress values. Therefore, it was verified whether the obtained relationships at deformations of 1 and 2 mm were comparable.

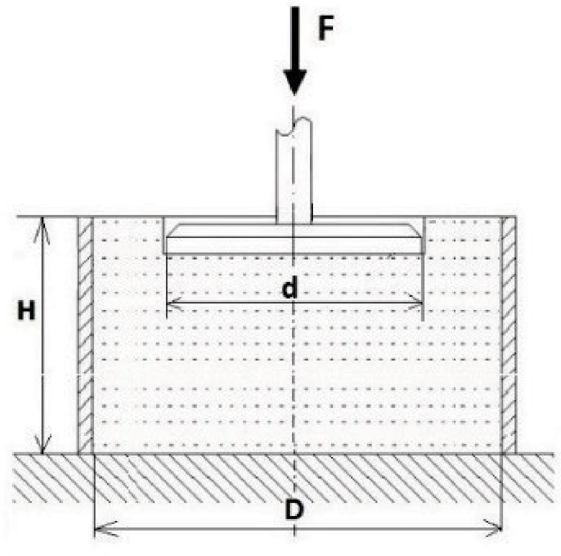

Fig. 1. Uniaxial compaction of soil samples in cylinders; F = force, H = height of cylinder, d = diameter of the compaction plate, D = inner diameter of cylinder; source: own elaboration

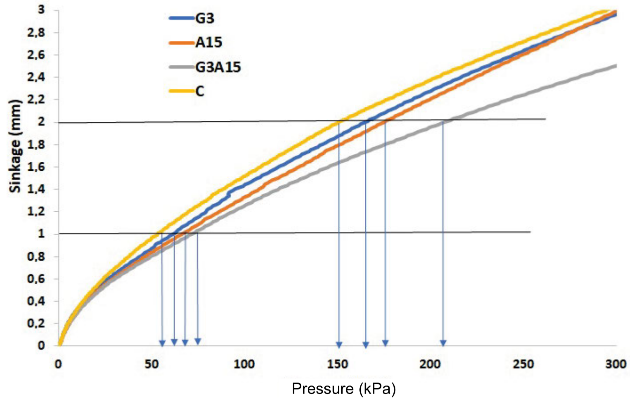

Fig. 2. Simplified method of determining the susceptibility of soil to compaction (compaction resistance) at a sample strain of 1.0 mm (*P*1) and 2.0 mm (*P*2) – a selected example; G3 = fertilisation with gypsum 3 Mg·ha^{-1}, A15 = fertilisation with ash 15 Mg·ha^{-1}, G3A15 = fertilisation with gypsum 3 Mg·ha^{-1} and with ash 15 Mg·ha^{-1}, C = control; source: own elaboration

Statistical analysis was carried out having adopted a completely randomised 2-factor block design. Multiple comparisons of means were conducted with Tukey's test at the level of significance α = 0.05. The said calculations were conducted using Statistica 13.3 (TIBCO Software Inc., 2017).

RESULTS AND DISCUSSION

METEOROLOGICAL CONDITIONS

Figure 3 presents meteorological conditions in the years of the study obtained from the meteorological station in Ustka located near the study area. Precipitation totals recorded in the years under analysis i.e., 2019–2021 were varied. In 2019, precipitation total amounted to 621.5 mm and in 2020 it was lower – 538.8 mm, with the highest value recorded in 2021 – 628.1 mm. In the months preceding the study, precipitation totals over the years of the study were, respectively: 47.3 mm (June 2019), 43.5 mm (May 2020) and 152.4 mm (August 2021). Mean temperature in the years under analysis i.e. 2019–2021 showed little differentiation. In the years 2019 and 2020 it amounted to 10.2°C and in 2021 it was 9.3°C. Mean air temperature in the months preceding the measurements as recorded in the years under analysis was, respectively: 17.5, 15.1 and 16.9°C.

SOIL REACTION

The results of the measurements of soil reaction in the years 2019–2021 conducted following fertilisation with ash and/or gypsum are presented in Table 1. The study confirms that application of ash from biomass combustion increases soil pH.

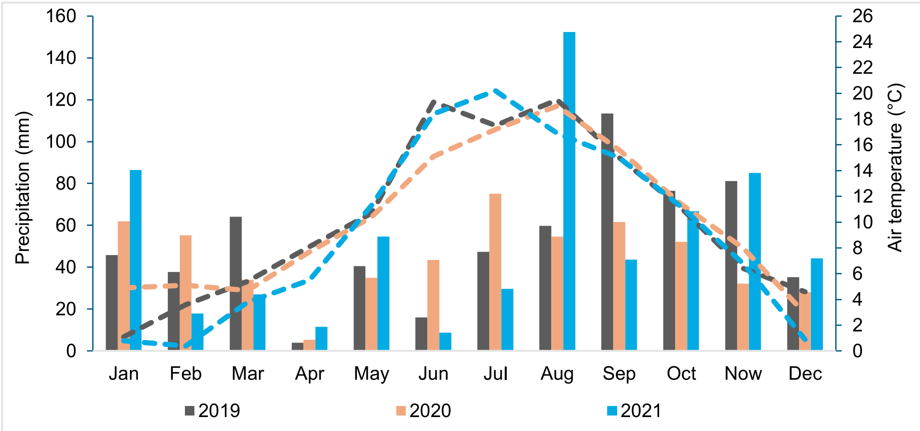

Fig. 3. Weather conditions in 2019–2021 recorded at the Meteorological Station in Ustka, bars = precipitation, lines = temperature; source: own elaboration based on data from IMGW-PIB

A dose of ash of 15 Mg·ha^{-1} resulted in an increase in soil reaction from approx. 5.0 to 6.0. The effect was found to decrease over the next years of the study. In the third year of the study, pH = 5.3 was still higher than the initial value identified in the control i.e. pH = 5.0. Application of gypsum fertiliser at a dose of 3 Mg·ha^{-1} showed no significant effect on soil reaction. Combined application of ash and gypsum had a positive effect on the increase in soil reaction, similarly to fertilisation with ash alone. It can be observed that lack of fertilisation with ash resulted in a decrease of the initial pH value in the control from approx. 5.0 (2019) to 4.4 and 4.1 in 2020–2021, respectively.

Table 1. Soil pH (in KCl) in relation to the dose of gypsum and biomass ash in 2019–2021

Gypsum dose (Mg·ha^{-1})	Reaction in years for ash dose (Mg·ha^{-1})					
	2019		2020		2021	
	0	15	0	15	0	15
0	5.0	6.0	4.4	5.8	4.1	5.3
3	5.1	6.2	4.2	5.8	4.1	5.5

Source: own study.

SOIL MOISTURE

As is presented in Figure 4, a positive and statistically significant effect on soil moisture (w_a) in individual years, as compared with the control (C), was found for the variant of fertilisation with ash alone at a dose of 15 Mg·ha^{-1} (A15). Soil moisture in the A15 variant was, on average, higher than that of the control (C) from approx. 7 to 27%. The highest increase was recorded in 2019. A slightly lower and statistically significant increase in soil moisture, from approx. 5 to 10%, was recorded in 2019 and 2020 for the variant of fertilisation with ash and gypsum (G3A15). In 2021, the differences in soil moisture between the variants C and G3A15 were statistically insignificant.

As for the variant of fertilisation with gypsum alone at a dose of 3 Mg·ha^{-1} (G3), a statistically significant increase in soil moisture by 19 and 23% was recorded in 2019 and 2021, respectively. In 2020, however, there was a decrease by approx. 5%. The opposite direction of changes in w_a in 2020 and 2021 may have been due to different meteorological conditions (Fig. 3) in the period preceding the measurements. In 2019–2021, the measurements were taken in July, June and September, respectively. Soil moisture recorded in 2020 was by far the lowest. In general, it can be stated that the obtained results confirm that fertilisation with ash contributes to water retention to a greater extent than fertilisation with gypsum.

BULK DENSITY

Fertilisation with ash (Fig. 5) at a dose of 15 Mg·ha^{-1} (A15) did not result in clear changes in dry bulk density (*BD*) in 2019–2021. In the years 2019 and 2021 there was no statistically significant change in *BD* as compared with the control (C). In 2020, fertilisation with ash resulted in a statistically significant decrease in *BD* value of approx. 5%. Fertilisation with ash and gypsum (G3A15) in individual years of the study resulted in slight yet statistically

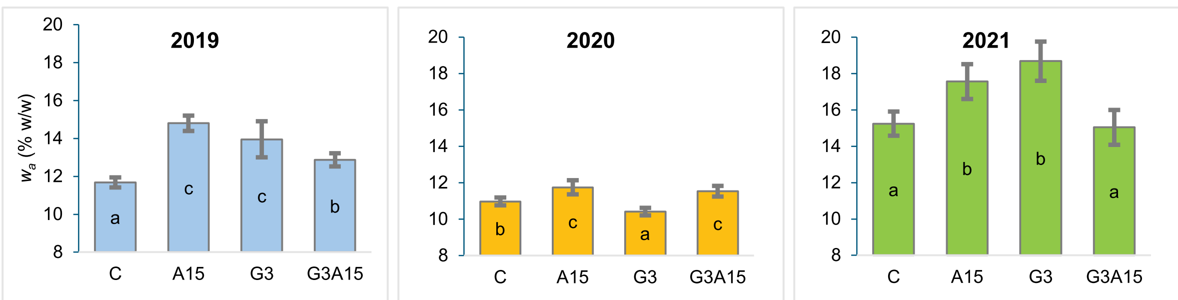

Fig. 4. Soil moisture (w_a) tests under field conditions in 2019–2021; lowercase letters indicate homogeneous groups – results of Tukey HSD test at α = 0.05 level of significance, C, A15, G3, G3A15 as in Fig. 2; source: own study

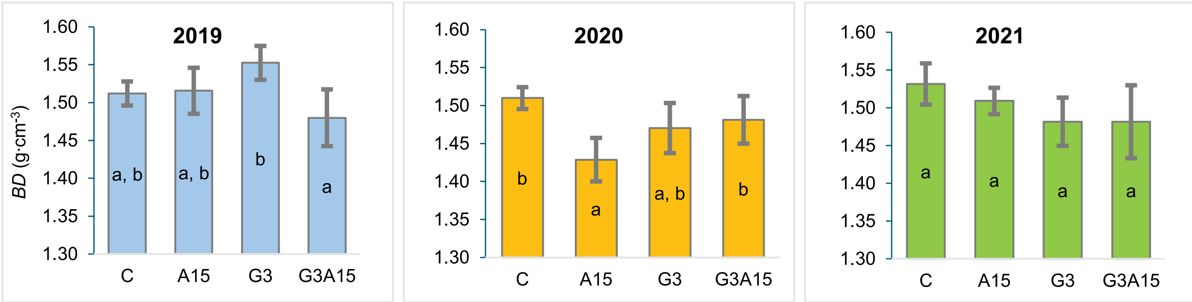

Fig. 5. Soil dry bulk density (*BD*) test results for 2019–2021; lowercase letters indicate homogeneous groups – Tukey HSD test results at α = 0.05 significance level, C, A15, G3, G3A15 as in Fig. 2; source: own study

insignificant decrease in *BD* from approx. 1 to 3%. Fertilisation with gypsum at a dose of 3 Mg·ha^{-1} (G3) in 2019 was found to cause a statistically insignificant increase in *BD* of approx. 3%. Over the next years of the study, there was a statistically insignificant decrease in *BD* values of approx. 2.5–3.0%.

Generally, it can be stated that fertilisation with ash or gypsum and ash, with the exception of G3 variant in 2019, resulted in a statistically insignificant decrease in *BD* values, which is in line with the results by Iderawumi (2020) or Stanek-Tarkowska *et al.* (2022). It should also be noted that the changes in *BD* values due to fertilisation with ash or/and gypsum did not exceed 0.1 g·cm^{-3}, i.e. the value which, according to Komornicki and Zasoński (1965), is the limit value for practical interpretation of the difference in dry bulk density.

PENETRATION RESISTANCE AND SHEAR RESISTANCE

The results of the measurements of soil strength parameters taken as penetration resistance (*PR*) and shear resistance (S_s) show similar change characteristics in individual years under analysis (Fig. 6). In 2019 and 2021, the variants of fertilisation with ash (A15) and ash with gypsum (G3A15) were markedly lower in comparison with the control (C), from approx. 12 to 28% for *PR* and from approx. 14 to 28% for S_s. In 2020, a statistically insignificant increase in *PR* and S_s was found for A15 variant, of approx. 23 and 12%, respectively. A statistically significant increase in *PR* was identified in 2019 and 2020 with respect to fertilisation with gypsum (G3), approx. 23 and 38%, respectively. The value of S_s was statistically insignificantly higher for G3 variant in the years 2019 and 2020, and statistically significantly lower in 2021.

Additionally, it can be observed that the obtained higher values of *PR* and S_s were determined not only by fertilisation with ash and/or gypsum, but also by soil moisture and density. On average, the highest values of the said parameters were recorded in 2020 when soil moisture was found to be the lowest, whereas the lowest values were recorded in 2021 when soil moisture values were the highest. This may be connected with the observed increase in soil friction angle with a decrease in soil moisture.

In general, the obtained results of *PR* measurements following the application of ash are in line with the results obtained by other authors (Iderawumi, 2020; Stanek-Tarkowska *et al.*, 2022). Also, it can be noted that the trend of decreasing values of *PR* and S_s following fertilisation with ash may, in favourable moisture conditions, result in a decrease in cultivation resistance and, consequently, reduced fuel consumption.

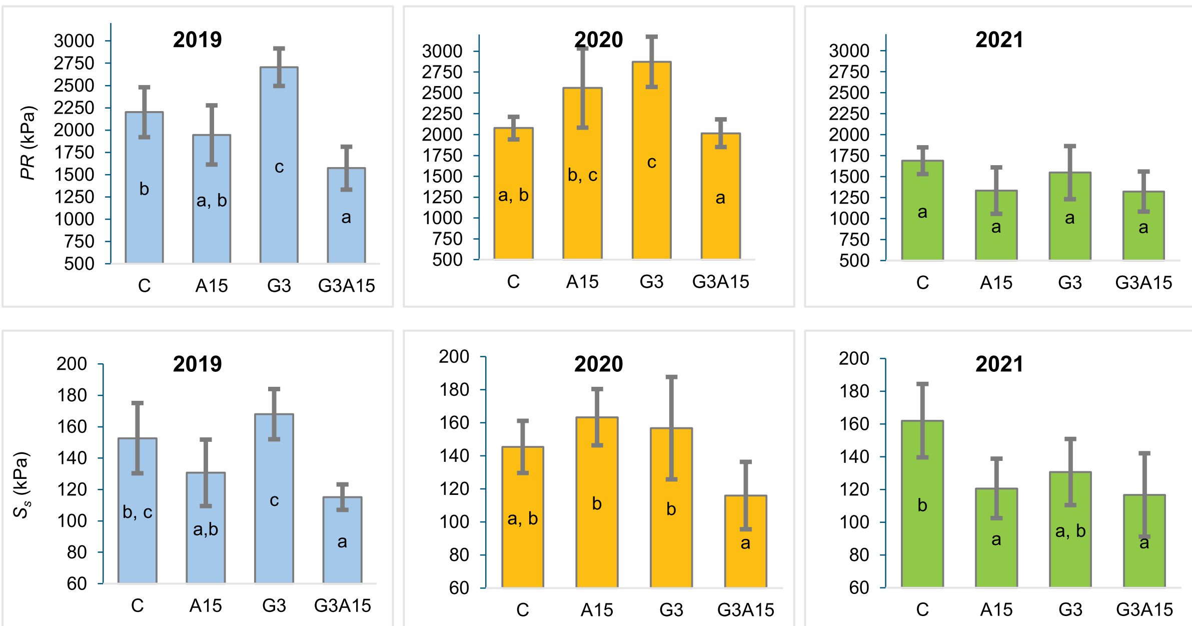

Fig. 6. Results of penetration resistance (*PR*) and shear resistance (S_s) tests in 2019–2021; lowercase letters indicate homogeneous groups – results of Tukey HSD test at α = 0.05 level of significance, C, A15, G3, G3A15 as in Fig. 2; source: own study

SOIL MOISTURE AT p*F*2

In the years 2019–2021 (Fig. 7), there was a clear increase in soil moisture at p*F*2 (w_{pF2}) from approx. 3 to 8% for variants with ash (A15) or ash with gypsum (G3A15). This is confirmed by the results obtained by other authors (Stanek-Tarkowska *et al.*, 2022) in field conditions stating that fertilisation with ash or ash with the addition of gypsum contributes to water retention. However, it must be noted that such an increase is, in some instances, partially statistically insignificant – the same homogeneous group as the control. Also, soil moisture at p*F*2 in 2019 was markedly higher than that in 2020 and 2021. This can be attributed to higher bulk density values identified in field conditions (Fig. 5) and, consequently, a greater number of smaller pores. The results may have also been determined by the use of a different plant (spring barley) in comparison with red fescue cultivated in the following years, as mean values of soil moisture at p*F*2 recorded over the following years are comparable.

Fertilisation with gypsum in the first year of the study (2019) at a dose of 3 Mg·ha^{-1} (G3) resulted in a statistically significant decrease in water retention in soil samples at p*F*2 of approx. 7%. In the following years of the experiment, there was a statistically insignificant increase of approx. 1 and 5%.

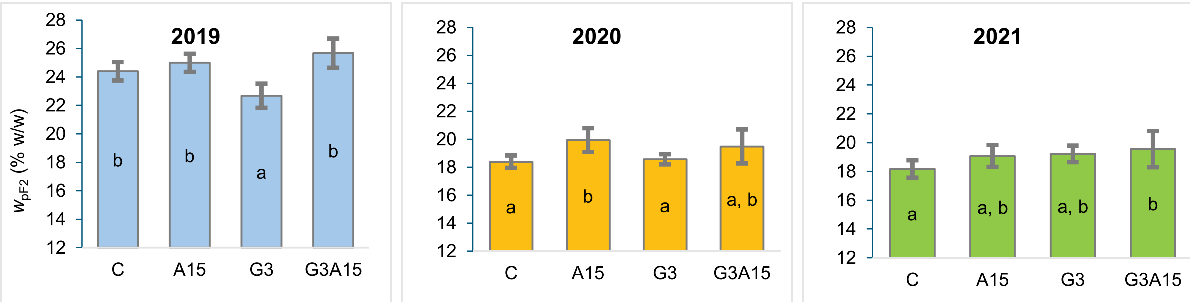

Fig. 7. Soil moisture at p*F*2 (w_{pF2}) in 2019–2021; lowercase letters indicate homogeneous groups – Tukey HSD test results at α = 0.05 significance level, C, A15, G3, G3A15 as in Fig. 2; source: own study

AIR POROSITY AT p*F*2

The identified air-filled porosity (PA_{pF2}) is the result of moisture content at p*F*2 and bulk density (*BD*). This can be observed through the analysis and comparison of values recorded in 2019–2021 (Fig. 8). Air-filled porosity negatively correlates with w_{pF2} values.

Fertilisation with ash at a dose of 15 Mg·ha^{-1} showed no clear effect on the trend of changes in PA_{pF2} in the years under analysis. In the first year, there was an insignificant decrease in PA_{pF2} of approx. 2%. In the following year, there was a statistically significant increase of approx. 15%, and in 2021 – a statistically insignificant decrease of approx. 2%. In the following years, fertilisation with gypsum resulted in an increase in PA_{pF2} of approx. 7, 5 and 5%, respectively. Fertilisation with ash with gypsum (G3A15) showed no significant changes in PA_{pF2} in the study period.

SOIL STRESS AT p*F*2 WITH SAMPLE DEFORMATION OF 1 mm (*P*1) AND OF 2 mm (*P*2)

Fertilisation with ash or/and gypsum showed the effect on the value of sample compaction resistance at a deformation of 1 mm (*P*1) which was most pronounced in 2019 (Fig. 9). An increase in resistance that year, as compared with the control, amounted to approx. 24 to 52%. Statistically significant differences, as compared with the control (C), were recorded for fertilisation with gypsum (G3) and gypsum with ash (G3A15). In 2020, there were no statistically significant differences between the C variant and the remaining variants. There was a noticeable lower value of unit stress for G3 variant. In 2021, statistically significant differences were recorded for variants A15 and G3 with an increase of approx. 40%.

The aforementioned trend was also identified at sample deformation of 2 mm (*P*2). However, in the first year, there was a statistically insignificant increase in compaction resistance from 27 to 46% for variants of fertilisation with ash and/or gypsum as compared with the variant C. In the second and third year (2020, 2021), the classification of observations into homogeneous groups was the same as with sample deformation of 1 mm. By adding the values form three years, it may be concluded that the effect of fertilisation with ash affects soil stress to a greater extent than

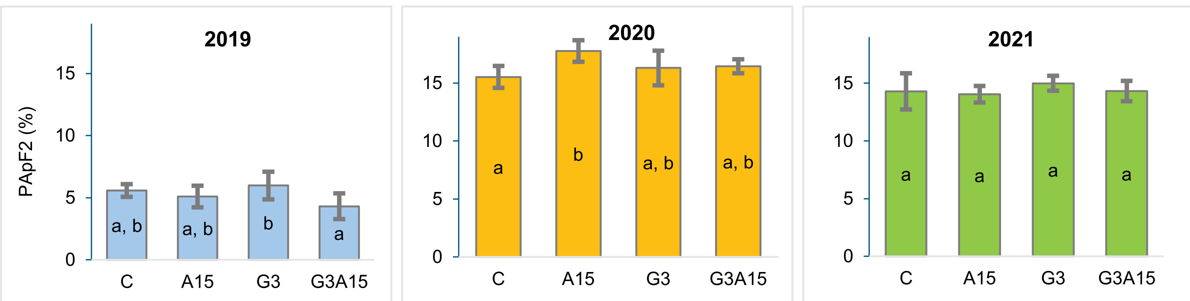

Fig. 8. Air porosity at p*F*2 (PA_{pF2}) in 2019–2021; lowercase letters indicate homogeneous groups – results of Tukey HSD test at α = 0.05 level of significance, C, A15, G3, G3A15 as in Fig. 2; source: own study

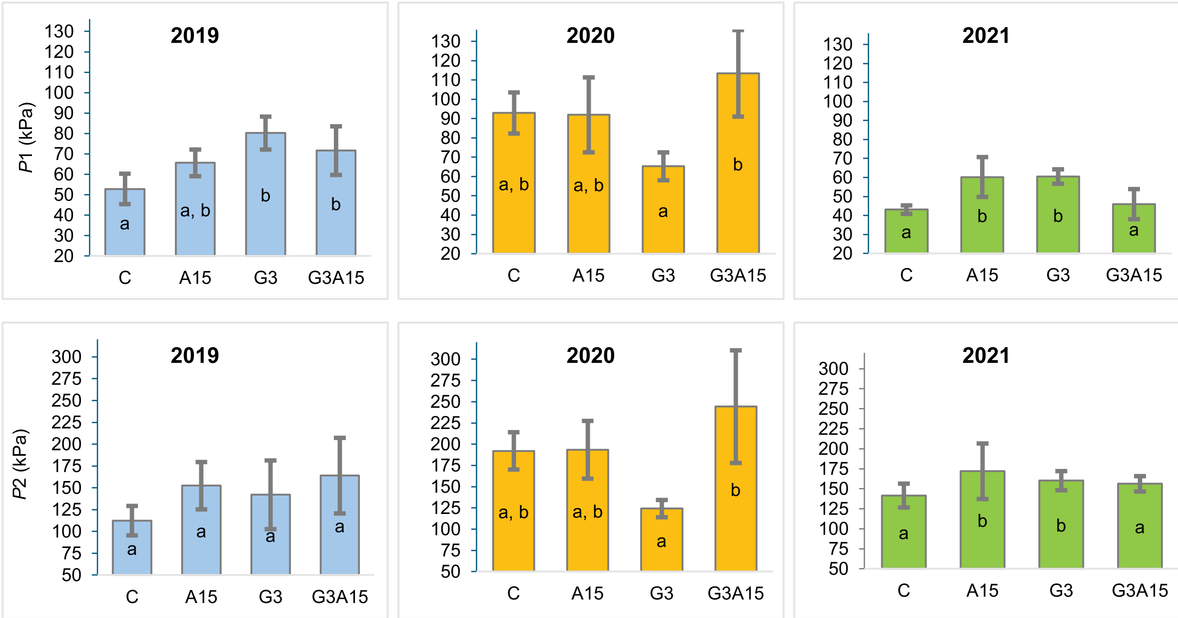

Fig. 9. Soil stress (compaction resistance) at p*F*2 with sample deformation of 1 mm (*P*1) and of 2 mm (*P*2) in 2019–2021; lowercase letters indicate homogeneous groups – results of the Tukey HSD test at the significance level of $\alpha = 0.05$, C, A15, G3, G3A15 as in Fig. 2; source: own study

fertilisation with gypsum. This may be due to the effect of fertilisation with ash on soil aggregation (Arshad *et al.*, 2012) which may have affected the soil resistance to compression.

CONCLUSIONS

The study has shown that fertilisation with ash and/or gypsum at doses of 15 and 3 Mg·ha^{-1} has an effect on physical properties of soil, predominantly in the first year following the application. The statistical analysis of the results of classification of observations into homogeneous groups demonstrated that in the third year after application of ash and/or gypsum fertilisers, the effect on physical properties of soil disappears. This may suggest that fertilisation with ash and/or gypsum should be carried out every two years. Furthermore, it was demonstrated that fertilisation with ash has a particularly positive effect on soil moisture. The loosening effect of fertilisation with ash, measured with dry bulk density of the soil, was weakly marked. Reduced soil strength, expressed with penetration resistance and shear resistance, was observed predominantly in the first year of the experiment. Additionally, it was found that for the purpose of comparative studies of the effect of fertilisation with ash and/or gypsum on soil strength properties, it is possible to use measurements of penetration resistance and vane shear resistance interchangeably.

The analysis of the general trends of the measurements obtained at water potential p*F*2 shows that the number of isolated homogeneous groups was reduced in comparison with the results obtained under field conditions. However, there is a noticeable positive effect of fertilisation with ash with the addition of gypsum on the properties under analysis.

Generally, a positive effect on physical properties of soil of granulometric composition loamy sand was identified with respect to fertilisation with biomass ash. The effect of fertilisation with gypsum on the properties under analysis was inconclusive.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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