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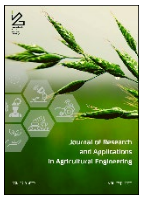

Hazards caused by stones in the arable layer of agricultural fields and methods for their removal

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The current importance of using various methods of mechanical weed control. These methods are based on the action on the growing undesirable plants (weeds) in the soil of the working elements of tools carrying out mechanical weed elimination (knives, wide blades, chisels) used, for example, in weeders. Their direct contact with stones deposited in the cultivation layer of the field results in excessive, faster frictional wear or even destruction. Other machines at risk of damage from contact with stones are, for example, the cutting units of crop harvesting machines and the working units of combine harvesters for harvesting winter squash and sugar beet. The article identifies the hazards caused by stones in agricultural fields, related to hampering field work and worsening plant vegetation and harvesting conditions. Various stone removal methods are described and illustrated with technical examples. Spot removal of large stones and two-stage and one-stage harvesting from the entire field area are discussed. It was pointed out that the diverse range of machines available on the market makes it possible to fully mechanise the removal of stones, and that the high costs of such a procedure can be fully compensated by the removal of hazards to the working units of the machines and an increase in the quality of the crop.

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1. Introduction

Stones are the mineral, granulometric fraction of soil which, according to the now obsolete BN-78/9180-11 standard [1], included fine stones of 20-100 mm, medium stones of 100-200 mm and coarse stones of more than 200 mm [2]. The classification of the Polish Soil Association, in force since 2008, is more detailed and lists among the skeletal parts a gravel fraction of 2-75 mm, a stony fraction of 75-200 mm, a boulder fraction of 200-600 mm and a block fraction of more than 600 mm [2]. Taking this classification into account, stones in addition to the stony fraction can also include blocks, boulders and coarse gravel. The stone content of the soil varies greatly, with soils with a stone content of more than 50 t·ha-1 being considered as very stony soils according to PN-90/R-55003 [3]. The maximum stone content in

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the arable layer of soils in the post-glacial areas of Poland may be as high as 500 t·ha-1 [4], which is several times higher than the possible maximum yield of, for example, sugar beet. It is estimated that 10-15% of soils in Poland are stony to such an extent that mechanical removal of stones is justified [5]. Soils with what is considered excessive stone content (more than 10 t·ha-1) are so diverse in Poland and cultivated by farms with different economic capacities that the use of different decalcification technologies is justified [6].

The stone content of the arable layer can also be determined using dimensionless values. Toscano et al. [7] citing also other works [8-11], propose to use the following relationships for this purpose:

1) Stoinees Degree (SD):

$$SD = \frac{StM}{SoM}, \quad (1)$$

2) Crushing Degree (CD):

$$D = \frac{\sum_{i=0}^{5} n_i \cdot StMi}{SoM}, \quad (2)$$

3) Stoinees Index (SI):

$$SI = \frac{SD}{CD}, \quad (3)$$

where:
StM - Stones Mass,
SoM - Soil Mass,
i and *n* - indices read from Table 1 [7 based on 12].

Stones are deposited throughout the soil profile comprising the arable layer, subsoil and bedrock. Unfortunately, the removal of stones from the field surface or the entire arable layer does not mean getting rid of them forever, as they systematically move upwards from deeper layers of the soil profile [13].

The causes of stone displacement are movements of the earth's crust, frost and soil cultivation. Freezing water in the soil increases its volume and causes the soil to loosen and the stones to be pushed out. Of the tillage operations, deep ploughing and subsoiling have the greatest impact on stone displacement. While ploughing covers the stones on the surface with turned soil, the stones deposited at the bottom of the plough layer are displaced upwards. Deep ploughing, on the other hand, does not mix the soil, but the stones are lifted with the loosened soil and can be pushed from the loosened subsoil more quickly into the arable layer [7,14,17].

2. Threats and damage caused by stones

Stones cause a few hazards related primarily to making field work more difficult and worsening the conditions for plant vegetation and harvesting [27]. Working components of machinery in contact with stones may be damaged, and large boulders may cause serious failures, e.g. of the frame or the drive train of the machine. The working elements of tillage machines, seeders, planters, weeders and harvesting units are mainly exposed to direct contact with stones, and the cutting units of mowers, shredders and harvesters are also exposed to contact with stones lying in the field [15,16,17]. Just how tough a foe stone is well illustrated by the well-known proverb "A scythe hits a stone". Losses caused by machine failures are not only the cost of new parts and labour-intensive repairs, but also the cost of downtime, which reduces the efficiency of field work [18]. Stones also increase the risk of fire when threshing grain, harvesting or chopping very dry straw at high temperatures, as they can cause sparks that start fires when in contact with rotating parts [19-21].

Table 1. Stone class index

Index *i*	**Size of the stones *mm***	**Index *n***
0	<2	1,0
1	2 ÷ 20	0,8
2	20 ÷ 50	0,6
3	50 ÷ 150	0,4
4	150 ÷ 400	0,2
5	>400	0,0

3. Risks and damage in soil cultivation

The soil tillage process in any tillage method involves contact between the working tool and the soil, which causes friction and, as a result, wear on the working tools. Depending on a few factors, such as soil class, compactness, moisture content and degree of stoniness, this causes more or less wear on the working tools [2]. Stones that are in the soil undoubtedly accelerate wear and often cause permanent damage to the working tools.

During deep tillage operations such as ploughing, subsoiling, working elements such as ploughshares, chisels, dredgers are most often damaged or in many cases are destroyed by the breakage of fixing bolts resulting in loss. Also in shallow operations, working tools are damaged by stones which, among other things, cause the discs to bend and even, in the case of large boulders, jam between the discs or tines.

By using both shear and spring protection or hydraulic tool holders, tools that come into direct contact with stone are often completely destroyed (Figure 1).

It should also be remembered that fragments of rocks, stones or coarse fraction of soil above 2 mm, up to the one with dimensions smaller than the size of a pedon [22], that is, a fragment of the pedosphere (the Earth's soil mantle, the surface layer of the Earth’s crust covered by soil-forming processes) constitutes a soil skeleton. For its evaluation, a suitable sample is prepared, a soil slicephysically being a prism cut from the soil. This soil slice must have a volume that allows the whole system of genetic levels (soil profile) to be recognized. It can be up to a few square meters in area and from a few tens of cm to about 2 m deep [7]. Depending on the nature of the components of this skeleton on stony soils, i.e. the types and geometric sizes of the stones that make it up, different technologies and equipment can be used to carry out their reclamation processes. It is extremely important to carry out this work, because by properly and cyclically clearing stoned soils from agricultural land, one has a direct impact on the amount of repair costs for machinery and equipment working on the land and the yield obtained.

In order to facilitate the selection of machinery and technology for the reclamation of stony arable land, an index called Disturbance Degree (DD) can be determined [7,8,12]. This indicator assesses the impact of stoniness on the work performance and operational capabilities of machinery suitable for cultivation operations. The DD index directly relates to the structure, composition of the soil skeleton, size of stones and distribution of their size classes according to equation (4) below [7,8,12]:

$$SDD=0\cdot X+10\cdot Y^{5}+10\cdot Z^{2}+10\cdot U^{0,9}+10\cdot W^{0,5}, \quad (4)$$

where:
X, Y, Z, U, W - expressed in units, the proportions of the different soil skeleton particle size classes, the sum of which must always equal 1 (100%).

These soil skeleton particle size classes have different effects on the soil tillage operation. Class X always has a value of zero, the content of the elements included in this class has no influence on the conduct of tillage operations, as only the fine soil fraction is included in this class.

Fig. 1. Lemken rotary plough with hydraulic protection for each body. Source: Authors

Class Y comprises fine and medium gravel with a fraction size of 2–20 mm, which does not represent a significant obstacle to proper tillage. Class Z includes the coarse gravel and medium stone fractions (20 –50 mm), which are estimated to have a significant effect on the ability to carry out cultivation work, especially by machines with PTO-driven components, at a level of around 40–50 % of their content in the respective soil skeleton layer. Large stones (50–150 mm, cobblestones, etc.) are in the U class, setting limits, restrictions and restrictions on tillage work at levels as low as 10–30 % of the soil skeleton. The last fraction, denoted by the letter W, contains large stones with a dimension of more than 150 mm. Their presence in the soil skeleton in question already poses serious problems for soil cultivation. Their presence in the skeleton is already problematic at a level of 10% of its composition [7].

4. Hazards and damage in combine harvesting

During combine harvesting, the working elements do not, or at least should not, come into direct contact with the soil. This does not mean that such contact does not occur in extreme conditions. This is the case, for example, when harvesting heavily lodged grain, when the cutting unit necessarily must work at the lowest possible cutting height of a few centimetres. In such situations, unplanned contact between the cutting unit components and the soil can occur. The stones in the soil, even of small size (skeleton class Y), can blunt or chip the blades of the cutter bar and in extreme cases, sparking can even occur during sudden contact between the blade and the stone [7].

When harvesting lodged grain from stony fields, it can also happen that stones can enter the combine harvester along with the lodged grain that is cut and picked up from the field. As a result, if the machine's safety systems (detectors, stone gripping device, etc.) do not operate correctly and in good time, mechanical damage to the threshing drum can occur, entailing high repair costs and, more importantly, machine downtime during the harvesting season. In such cases, the effect of such unwanted contact between the stone and the combine's working elements can also lead to sparking, leading to a machine fire [19,21,23].

5. Risks and damage during root crop harvesting

Machine harvesting of root crops requires contact between the working elements and the soil, which occurs at a depth of several to several tens of centimetres, depending on the crop. In stony fields, where no descaling operations have been carried out prior to planting or planting the crop, mechanical damage to the plough blades of the ploughing units can often occur through chipping, warping, blunting and, in extreme cases, even complete breakage. In the case of this group of machines, stones, as already mentioned, can cause mechanical damage to the harvested tubers or roots during their cleaning and transport by conveyors to the machine tanks or to the means of transport [24, 25]. In very rare cases, mechanical damage to the conveyors may also occur, especially if they are made of plastic or crush the plastic covers of their metal working parts (e.g. bars) [26].

6. Methods for removing stones from fields

The choice of the right method for the reclamation of farmland, arable land, depends on both environmental factors and general factors resulting from organizational and technical possibilities. The first group may include the structure of the soil and soil skeleton, the percentage of stones their typology and size ranges. The second group, on the other hand, includes the availability of machinery to carry out this type of work, factors resulting from proper crop management and the technological requirements of agricultural machinery suitable for carrying out these field crops [8, 13, 28, 30]., sparking can even occur during sudden contact between the blade and the stone [7].

The complete process of removing stones from agricultural land (mainly arable land) consists of three stages: collection, transport and disposal [8]. The procedures of collecting stones from fields and meadows can be carried out with several technologies. The most used under Polish conditions are discussed in more detail in this article.

6.1. Manual removal

Manual collection of stones is usually carried out after sowing, in fields with small areas. The stones are collected into a transport vehicle, usually an agricultural trailer or other machine with a load bed, which is driven from the side. The main disadvantage of this method is that it is very labour-intensive, which, combined with the lack of people willing to do this work, makes it practically unsuitable. Another problem that arises is due to the physical capabilities of the pickers. They can lift stones weighing up to 50 kg, so large boulders, let alone blocks, cannot be collected by hand due to their own weight. Field stones have a high specific density (1.7 t·m-3) [29], so with a shape similar to a cuboid, a boulder with a side size of 50 cm can weigh about 220 kg and a block of 70 cm even more than 600 kg.

Large and heavy boulders embedded in the soil (class W) can be removed using a backhoe loader, preferably fitted with an openwork bucket, but it is also possible to use a specialized, tractor-mounted stone extractor offered, for example, by Degelman (fig. 2) or Bergen [31]. The working elements of the stone extractor consist of two ploughing tines, resembling the shape of an arc-shaped subsoiler tine bent forwards, and one or two hydraulically adjustable hook arms holding the ploughed stone. Extractors are most commonly capable of removing stones with a diameter of up to 1 m and a weight of up to 1.000 kg, deposited at depths of up to 85 cm, but some manufacturers (e.g. Roadside Ironworks) offer extractors with much greater capabilities (stones weighing up to 1.500 kg).

Where smaller stones belonging to classes U and Z are present, other machines and methods are used to remove them from the soil.

Agrimet manufactures a Stoner device adapted for the spot collection of stones lying on the field surface, mounted on loaders or front-end loaders (Fig. 3). The main working unit of this device is a hydraulic motor-driven, openwork (bar spacing 65 or 85 mm), cylindrical basket with a diameter of 920 mm. The rotary movement of the basket allows soil and other debris to be intensively sifted from the raked batch of stones, before being dumped at the edge of the field or loaded onto a trailer.

Degelman offers a machine for the spot collection of large stones and boulders of 15 to 120 cm in size lying on the field surface (Fig.4). The stones are picked up from the field surface by a hydraulically controlled openwork bucket, from which they are transferred to a hopper from which they can be dumped onto a heap or trailer after being lifted and tilted [32].

Local clusters of stones in the field can also be removed with an openwork bucket mounted on a loader (Fig. 5) or front-end loader, whose main purpose is to load not only stones but also agricultural produce, e.g. sugar beet, from heaps. By manoeuvring the bucket appropriately, stones can be picked up, sieved, transported and loaded onto a trailer [34].

6.3. Two-stage mechanical harvesting

Two-stage stone harvesting is carried out in two separate operations, first the stones are ploughed shallowly and scraped with a scraper and then collected with a collector. Machines for such stone harvesting are offered, for example, by Schulte (Fig. 6) [35] or Degelman (Fig. 7) [36]. The main working unit of the Schulte scraper (Fig. 6) is an active rotor with helically positioned tines, which pulls stones out of the soil, generally to a depth of 10 cm [35, 36]. The scraper rotor can be mechanically or hydraulically driven and its rotation when picking up stones is counter-rotating. It is set obliquely to the direction of work at an angle of 10–30° and the tines are arranged in a spiral, so that the stones are moved laterally and deposited in a narrow row, formed in one or two working passes. The power requirement of the scraper depends on the depth of the rotor, the stoniness of the field and the compactness of the soil and is a minimum of about 15 hp per metre of working width. The working width of a scraper can exceed 4 m, and the greater the width, the greater the specific power requirement, which is a result of the longer stone travel distance [35, 36].

Fig. 2. Degelman stone extractor [31]

Fig. 3. Agrimet's stone point collection device [32]

Fig. 4. Degelman stone collector [33]

Another group of machines are stone collectors. These machines pick up stones from the field or those previously raked into rows and collect them in a hopper, from which they are then discharged onto a heap at the edge of the field or, if the hopper is lifted high, onto a trailer. The collector's pick-up assembly consists of an openwork grate topped with reinforced tines, and a stripper that collects the stones from the field surface onto the grate, along which they are moved to the hopper (Figs. 4, 8). Equipped with tiltable drawbars, these machines can be easily moved from the transport position to the working position, and vice versa, allowing the stones to be picked up laterally without the wheel running over the row of stones. The power requirement of the collector depends on the stone and the hopper capacity and is a minimum of approximately 75 HP [33, 37].

6.4. Single-stage machine harvesting

Machines for complex single-stage stone harvesting, offered by Polish (e.g. Gropel, Skład Kamienia, Usarya) and foreign manufacturers (e.g. Elho, Galenberg, Haybuster, Kongskilde, Tutkun, Thyregod), are commonly referred to as collectors, but two groups of machines can be distinguished among them, differing in their mode of operation and working depth (Table 2).

The first group of machines for single-stage stone harvesting are scraper-collector machines, which are characterised by a large working width (usually about 5 m) but a shallow depth of pulling stones out of the soil (usually up to about 7 cm). One of the Danish-made machines is Kongskilde's Stonebear collector (Figure 9). The machine, as described by the manufacturer, is not only designed to collect stones from the surface of cultivated fields, but can also be used to carry out clearing work on surfaces intended as building sites, lawns, beaches, tennis courts, etc. The machine allows the harvesting of stones from 3 to 30 cm in diameter from a working width reaching up to 5.2 meters, and its working depth is 7 cm. One of the main components of the collector are the scraper rollers with teeth welded around the perimeter.

Fig. 5. Sonarol stone spoon [34]

Fig. 6. Schulte stone scraper [35]

The scraper rollers rotate against the direction of travel and, when set at a certain angle, scrape the stones from the surface of the field, causing them to move towards the centre of the machine. The central part of the machine is fitted with a special pick-up screen, which separates the stones from the soil [39].

The sieve has a cutting blade at the front to facilitate the cutting of the soil as it is to be sieved. The sieve itself comes in different configurations of hole sizes (channels) depending on the size of the stones to be separated. Above the screen, there is a drum conveyor with spring tines which is responsible for throwing the stones from the screen into the hopper and facilitating the sifting of soil from the stones. Thanks to the pivoting hopper, the collected stones can be dumped onto a transport vehicle or onto a heap [39].

Another type of compacting and skimming machine is the Husarya SCS-100 (Fig. 10) from the Polish company Usarya. It is a machine capable of working to a depth of up to 20 cm, with a working width of 5.5 m. The Husarya collects stones ranging in size from 2.5 to 50 cm. The machine is classified for surface collection of stones, however, with its design and solutions it differs significantly from the concreta. The maximum working depth is greater than that of conventional stone-collecting machines. In addition, it features double toothed rotors on two side arms, and one centrally positioned rotor, all set at a certain angle to the machine. The excavated material, in the form of soil and stones, is fed onto a scraper conveyor, which transports the collected mass to a cylindrical cleaning drum rotating on its own axis. Inside the drum, guides are fitted in a spiral manner to transport the stones to the hopper as the drum rotates. A movable hopper with a capacity of $3m^3$ allows the reloading of the collected stones onto another means of transport or a heap [42].

The second group of machines for single-stage stone harvesting consists of digging and gathering machines characterised by a small working width (usually 1.5 m), but a large working depth, pulling stones from the soil (usually up to 30 cm). The main working unit of this group of machines is the screening unit. Before any material reaches it, the soil layer, together with the stones and other undesirable objects in it, is undercut by the blade and moved by the rotor through the screening unit. The sifted stones are then transported to the hopper. This is how machines of the Kaplan series from the Turkish company Tutkun operate (Fig. 11) [43].

Fig. 7. Dagelman stone scraper [36]

Fig. 8. Schulte stone scraper [37]

Another method of descaling involves sifting the soil and moving the stones on a long conveyor is used in machines resembling conveyor diggers (Fig. 12). One Grimme machine works in this way, which is the S.C series Stone Separator used in the cleaning of ridged crops most often in the preparation of fields for potato planting. Descaling with this machine involves separating stones, clods and other unwanted dirt from the soil in pre-formed ridges. Depending on the degree of stoniness of the field in question, the picked-up stones may be transported to other means of transport or deposited at the bottom of the furrow between the beds. The formed beds have a defined width and spacing as well as a corresponding height. The height of the beds can be up to 40 cm, depending on how deep the potatoes are planted. Depending on the type of soil and degree of stoniness, the main working tools for separating stones are rollers, bands or stars. The soil is taken up by means of a blade, on the sides of which there are disc cutters [44].

Table 2. Characteristics of machines for single-stage stone harvesting

Producer (Machine model)	Working width [m]	Working depth [cm]	Diameter of stones collected [cm]	Weight of the machine [kg]	Payload or container capacity [kg] or [m^3]	Power requirements [HP]
Scraper and collector machines						
Elho (Skorpio) [38]	5,5	to 7	4–40	6800	1,5–2 m^3	90–140
Kongskilde (Stonebear) [39]	5,2	to 7	3–30	3620	1,8 m^3	80
Haybuster (Rock-Eze) [40]	3	to 7,5	3–40	2000	0,76 m^3	80
Gropel (ZK-7 Hydro) [41]	7	to 15	3–40	–	2000 kg	100–200
Usarya (Husarya SCS-100) [42]	5,5	to 20	2,5–50	12400	3 m^3	110–140

Digging and collecting machines						
Tutkun (Kaplan) [43]	2,0	do 30–35	3–35	3850	8500 kg	80–90
Gallenberg (CDSP2-29-5) [44]	1,5	do 30	4–60	8000	8000 kg	200
Thyregod (TS-1500) [45]	1,5	do 30	min approx. 3	3720	–	90–120

Source: [own elaboration based on data from companies].

Digging and gathering machines can also be used to pick up stones previously raked into rows with a scraper. They are fitted with hoppers as standard, but solutions with a conveyor loading the stones directly onto a trailer are also offered (Fig. 13). An example of such a machine is the 350-Sa model from Scottish company Reekie Engineering Co. Ltd. At the front of the Reekie 350-SA stone separator are keyed ploughshares working with a rotating feeder that has interchangeable working elements for crushing lumps [45].

Above the bar conveyors, additional so-called mats are fitted, which are made up of transverse rods connected to three flexible rubber strips. The purpose of these mats is to assist in screening, crushing and moving stones and lumps through the bar conveyors. At the end of the machine there is a unit for separating large stones, which are directed into a hopper and then discharged at the edge of the field by means of a bar conveyor.

7. Other methods of removing stones from agricultural fields

7.1. Stone crushing on site

In the case of fields which are heavily stoned, particularly with stones belonging to soil skeleton classes Z and above, methods involving the crushing of stones lying on the ground are also used to prepare the fields for the planned crop. This is usually preceded by ploughing or deep loosening of the soil to bring as many stones as possible to the surface. This optimises their crushing capacity. The machines used to carry out this work (crushers) are either driven from the tractor's WPM or are self-propelled. All stone crushers work on a similar principle, their main working unit being a drum with hammers that crush the stones by hitting them. The splitting of the stones is a result of the combination of the weight of the machine (the crushing unit), its rotational speed and the shape and arrangement of the beaters on the perimeter of the working error [7]. These machines can even work to depths of 4050 cm (larger self-propelled machines). Tractor machines work to a depth of 15–20 cm. This depth, if no other conditions apply, is more economically justifiable even with the need to repeat the operation several times. Energy consumption per cubic metre of soil broken up is considerably lower even for several passes than for a single operation at a depth of 2–3 times greater, for which the choice of large, heavier machines is necessary. An important economic aspect that must be taken into account when choosing this reclamation method is the frictional wear of the machine's working elements, which depends on the nature of the soil, (much faster on sandy and siliceous soils and less on soils with calcareous scales, for example), the typology of stones or the level of soil stoniness [46].

Fig. 9. Schulte stone scraper [37]

Fig. 10. Schulte stone scraper [37]

Fig. 11. Tutkun's Kaplan digging and gathering machine [43]

7.2. Backfilling (burial) of stones

Another method for the reclamation of heavily stoned fields is to bury the soil skeleton at the point of separation from the soil to obtain a stone-free arable layer. This method has been used for more than 300 years. The stones buried underneath the arable layer form part of the drainage, especially on soils with high moisture content. The most common way to carry out this method is by digging a ditch into which stones that have been separated are thrown using, for example, the machine shown in Figure 14, and covering the ditch with the cleared layer of soil [47].

Another way is to use a machine called a stone burier. One such machine is shown in Fig. 15. This is a machine equipped with a horizontal roller with knives, as in a classic soil tiller, and in addition, behind the drum, under the cover, it has a separating screen that retains the stones by directing them to the subsoil underneath and the sieved soil covers them to the thickness of the cultivation layer. A string roller at the end of the machine is used to level the soil layer.

Machines of this type can work to the depth of 30 cm and are able to effectively separate stones belonging to the Y and Z skeleton classes and the lower part of the X fraction, i.e. no larger than 100 mm [48].

8. Conclusions

Currently, mechanical methods of plant protection are coming to the fore due to worldwide environmental trends. The use of this type of technology is therefore growing in importance, along with the use of many different methods of mechanical weed control. These methods are based on the action on the growing undesirable plants (weeds) in the soil of the working elements of the tools that carry out the mechanical elimination of weeds (knives, wide blades, chisels). These working elements used, for example, in weeders, through direct contact with the stones

Fig. 12. Grimme stone separator CS 150 [29]

Fig. 13. Reekie 350-SA stone separator [30]

deposited in the cultivation layer of the field, are exposed to excessive, faster frictional wear and even destruction.

Other machines prone to damage from contact with stones are, for example, the cutting units of crop harvesting machines. Uncontrolled impacts from stones can, for example, cause the knife in the cutter bar of a combine harvester to break off, blocking of mower discs leading to the breaking of safety devices and, in extreme cases, damage to the drive gear wheels or blockage of the feeding unit of a forage harvester. Other crop harvesting machines exposed to the negative and even destructive impact of stones in the crop are potato and beet harvesters. In both cases, stones moving in the machine together with the plant parts being worked (potato tubers, beet roots) also cause a significant increase in their damage.

The only viable way to reduce these adverse effects of stones is to remove them from the arable layer before the main crop is cultivated. In the case of potato crops (the crop most susceptible to damage from stones in the soil), a marked increase in yield by up to 30% and a reduction in the percentage of tuber damage by up to 70% was observed in fields where the descaling process was carried out [27]. The choice of technology for clearing fields of stones and, **co**nsequently, the purchase of a machine is justified in farms with large acreage, farming on stony soils.

Among the available machines for removing stones from fields, it can be noted that there are few machines that combine stone removal processes with other agrotechnical treatments, such as those shown in Figures 14 and 15. Combining two or more treatments undoubtedly reduces the costs associated with the operation of such machines and reduces the amount of damage to machinery and plants caused by stones. The overview of field descaling technologies and machines presented here is intended to assist agricultural producers, farmers in the process of selecting machines and associated technologies for field descaling that are suitable for their soil and environmental conditions. This cross-cutting study will be

Fig. 14. Standen UniPlus Stone and Clod Separato [47]

a) b)

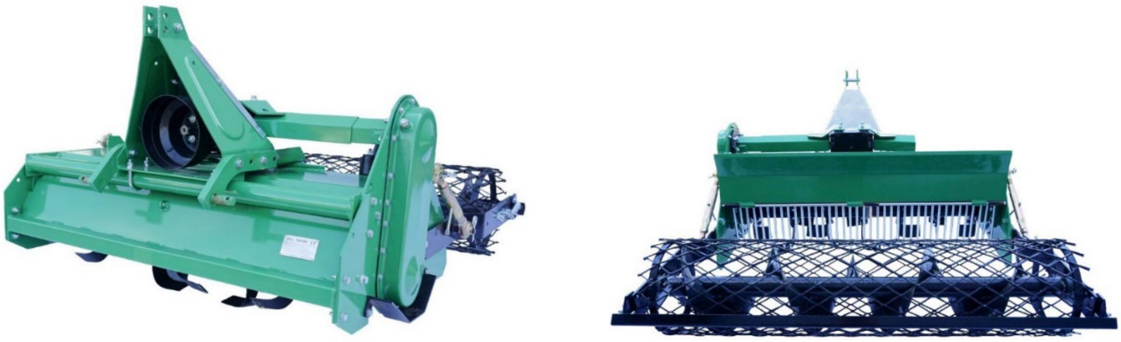

Fig. 14. SB 145 TRX separation soil tiller: a) front view, b) rear view [48]

a source of information for farmers to carry out an informed selection of suitable machinery and associated technologies for removing stones from the arable layer of fields**.** The special addressees of our oposals are owners, managers or their advisors managing farms with arable fields of medium size (up to 100 ha). This range of farms is still common in Central and Eastern Europe today**.**

Machine harvesting is therefore a legitimate, but also very costly and time-consuming operation, which is why it is usually used in specialised crops such as potatoes or in horticultural crops, especially root crops.

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