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The Stony Soils Reclamation Systems in Agricultural Lands: A Review

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Abstract

The agricultural soil is a highly variable and complex active medium for the plant's life. Due to prolonged formation processes, it must be considered as a non-renewable resource, easily subject to many degradative processes, in most cases due to human activities. These activities lead to the definition of "anthropic" soils, often labelled also as "disturbed", "manipulated", "artificial", or "deviations" of the natural soil continuum. In the agronomic sense, however, when these deviations result from the optimization of structural characteristics of fine earth fractions, they may represent the main quality parameters of soil in terms of physical, chemical, and biological fertility. Nevertheless, over the fine earth fractions, many agricultural soils have a variable percentage of varying coarse fractions in their arable layer, interfering with cultivation needs, damaging the machinery, and requiring extra energy and time for soil tillage. They may even make the use of machinery impracticable. When these conditions occur, it becomes necessary to proceed with soil destoning to recover arable land and optimize the cultural management according to modern farming techniques and machines for soil cultivation. The research aimed at evaluating the different possibilities of reclamation of stony soils and the machines that can be used in different environmental conditions, according to the various cultivation needs, and for the recovery and optimization of the non-renewable resource "soil". This review briefly summarizes the soil destoning techniques currently available for agricultural lands: 1) the collection and removal of stones from the field; 2) the on-site stones crushing; 3) the stone burial.

Keywords

Agricultural Sustainability, Soil Quality, Stoniness, Soil Destoning Systems

1. Soil Origin, Definitions, and Classifications

Soil is a highly complex and variable active medium made of mineral particles, organic matter, water, air and living organisms. It represents the natural habitat for the gene pool and the growth medium for plants' life, and it results in being the food, biomass, and raw materials provider for human activities. Soil also stores, filters, and transforms many substances, including water, nutrients, and carbon [1]. Such functions (e.g., producing biomass, acting as a carbon store) are crucial for food production, climate regulation and adaptation, carbon sequestration, water filtering, and biodiversity preservation [2] [3].

Soil is prone to many degradative processes and threats (*i.e.*: erosion, mineralization of organic matter, destructuration processes, lack of biodiversity, floods, and landslides). Because of the prolonged soil-forming process resulting from specific climate conditions, geomorphology, the composition of parent materials, biotic activity, and human influence, it shall be considered a non-renewable resource. Combinations of degradative processes are the factors most responsible for variable grades of desertification phenomena [4]. Soil formation begins with the exposure of the rock layer to the altering action of environmental agents. Such action reduces it into smaller and smaller fragments that, combined with other particles and following the interaction with the vertical water flow [5], gradually give rise to the stratigraphy of various layers (horizons) that represents the soil profile. Soil horizons differ in terms of many features, e.g., colour, thickness, chemical composition, physical properties, biological activity, and pH [6].

Various classification systems were developed throughout early human history to distinguish among the soils important to human lives [7]. In 1862, Fallou coined the term pedology for the scientific study of soils, and around 1870, Dokuchaev developed the fundamentals of soil investigation, introducing a new concept of soils as independent natural bodies, each with its morphology caused by a unique combination of climate, living matter, earthy parent materials, relief, and age of landforms [8].

Being the soil system constantly evolving, Jenny [9] conceived the Equation (1) that represents the most well-known model of soil formation describing the soil (S) resulting from the interaction of biotic and abiotic factors such as climate (cl), organisms (o), relief or topography (r), parent material (p), time (t), and other not specifiable forces (...):

$$S = f\left(cl, o, r, p, t, \cdots\right) \tag{1}$$

The acronym CLORPT means that soil-forming factors are independent of a soil system and vary in space and time. In addition, the not specifiable forces of the model include human activities, which in most cases are those having the highest impact on soil structural characteristics so that the resulting soils are often labeled as "disturbed", "artifacts", "manipulated", "artificial", and considered more as "deviations" rather than a part of the soil continuum [10] [11] [12]. Based on the CLORPT model of soil formation, McBratney *et al.* [13] formulated the SCORPAN model represented by the Equation (2):

$$Sc/Sa = f\left(s, c, o, r, p, a, n\right) \tag{2}$$

Here, soil classes and soil attributes (*Sc*/*Sa*) result from the interaction of soil (*s*), climate (*c*), organisms (*o*), topography (*r*), parent material (*p*), age (*a*), and spatial position (*n*). The scorpan approach allows the quantitative prediction of soil classes or continuous soil attributes based on empirical observations: it does not explain the factors of soil formation. In addition, the soil itself can be used as a factor because it results from the characterization of its properties or soil properties from its class or other properties. Minasny *et al.* [14] reviewed and listed the past studies using the scorpan approach.

1.1. The World Reference Base

In 1998, the World Reference Base (WRB) [15] replaced the FAO/UNESCO Legend for the Soil Map of the World [16] as the international soil classification standard. It classes the soil as "any material within 2 m from the Earth's surface that is in contact with the atmosphere, with the exclusion of living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m"; and defines it as: "a continuous natural body which has three spatial and one temporal dimension", represented by the hires:

- formed by mineral and organic constituents and includes solid, liquid, and gaseous phases;
- constituents, organized in structures specific to the pedological medium, form the soil's morphological aspect and result from the history of the soil cover and its actual dynamics and properties;
- constantly evolving, so its fourth dimension is time.

However, the soils resulting from the interaction with anthropic activity (anthrosols) still present one of the most significant classification challenges: they currently represent more than 3000 soil names at the highest levels of world soil taxonomy (**Figure 1**) [17], of which more than 320 major soil types have identified in Europe alone, differing significantly each other in physical, chemical, and biological properties [18] [19] [20] [21].

1.2. Soil Horizons

A soil horizon is a layer commonly parallel to the soil surface, whose properties differ from those of the adjacent overlying and underlying horizons such as color, structure, texture, and rupture-resistance class. Soil master horizons are usually named with the capital letters, with the addition of lowercase letters suffixes to denote other characteristics [18]. In agricultural soils, the horizon identification usually is limited to defining, from top to bottom, the A, E, B, C, and R horizons (lower layers are characterized by a higher density and lower organic matter content than the upper layers).

The "A" identifies the surface mineral horizon with organic matter (humus) accumulation, also named "topsoil". "B" defines a subsurface soil structure, also called "accumulation" or "illuvial" horizon. The "C" corresponds to the parent material, with little or no pedogenic alteration, or still unaltered by soil forming

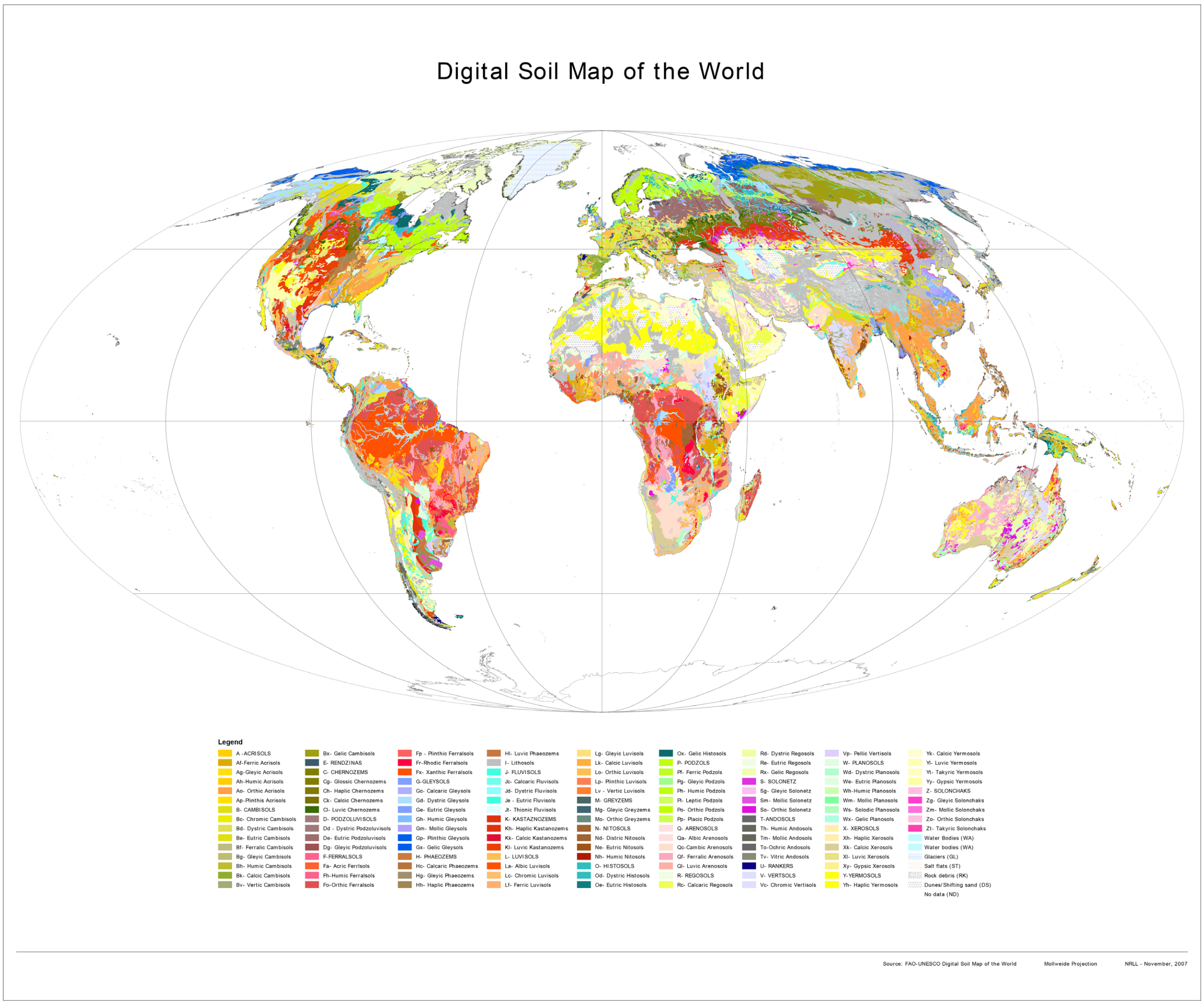

Figure 1. FAO-UNESCO digital soil map of the world (Thanks to ICDC, CEN, the University of Hamburg for data support).

processes. When present, the "E" horizon, also called "eluvial", is lighter in color than the "A" horizon above or the "B" horizon below. The "R" layer refers to the bedrock, which represents the worst-case scenario in agricultural land use and crop management if close to the soil surface [5].

1.3. Topsoil Structure and Texture

Soil structure refers to the organization and arrangement of soil particles and their resultant porosity. It is a composite soil quality that exerts significant control on most physical, chemical, and biological processes that occur in both natural and anthropic soils, including transport and storage of liquids, gases, and heat, root penetration and proliferation, microbial life, and the decomposition and storage of organic soil matter.

Soil texture refers to the percentage distribution by weight of their elementary particles, of diameter size less than 2 mm. These particles, distinguished as sand

(0.05 to 2 mm), silt (0.002 to 0.05 mm), and clay (less than 0.002 mm) constitute the fine earth of soil, that is defined based on the prevalence of one of these fractions, as indicated in the texture triangle (**Figure 2**) [22].

In agronomy, soil structure also refers to the quality of topsoil, or active layer, in terms of water holding capacity, ease of tillage, and suitability for root growth and microbial life, which relates to crop growth and productivity and their variations/evolutions according to different types of soil management [23] [24] [25] [26] [27].

In cultivated soils, the topsoil, or active layer, is defined as the A horizon only, while the E, B, and C horizons compose the subsoil, or inert layer, forming the cultivation profile of the soil. Consequently, topsoil is more sensitive to environmental conditions and changes than other parts of soil profiles. Accordingly, thin topsoil sections show microstructures, organic matter types, and features related to faunal activity or specific environmental conditions and cultivation techniques [28] [29] [30] [31], that contribute to determining the quality index of the topsoil as per **Table 1**.

1.4. Soil Quality

Many Authors have given various descriptions of the soil quality concept, most frequently referred to as soil agricultural destination and the active layer's physical, chemical, and biological fertility [32] [33] [34] [35]. Among these, those referring to soil quality either as its "capability to function within an ecosystem and positively interact with the environment" [36]; or the capability to "receive, store and recycle water, minerals, and energy to support plant production at

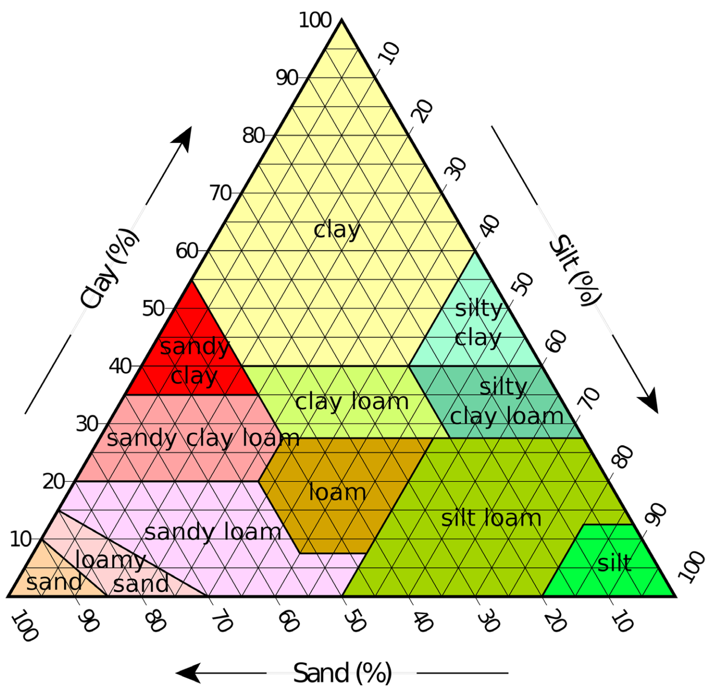

Figure 2. Soil texture triangle based on USDA particle-size classification.

Table 1. Topsoil quality index.

Category	Soluble salts (dS/m or mmho/cm)	pH	Sand (%)	Silt (%)	Clay (%)	Texture class*	Organic Matter (%)	% Coarse fragments (> 2 mm in diameter)**	Sodium Adsorption Ratio (SAR)*
Ideal	<2	5.5 to 7.5	<70	<70	<30	L, SiL	≥2.0	≤2	<3 for any texture
Acceptable	<4	5.0 to 8.2	<70	<70	<30	SCL, SL, CL, SiCL	≥1.0	2.1 to 5.0	3 to 7 (SiL, SiCL, CL) 3 to 10 (SCL, SL, L)
Unacceptable	>4	<5.0 or >8.2	>70	>70	>30	LS, SC, SiC, S, Si, C	<1.0	> 5.0	> 10 for any texture

*: L = loam; SiL = Silt loam; SCL = sandy clay loam; SL = sandy loam; CL = clay loam; SiCL = silty clay loam; LS = loamy sand; SC = sandy clay; SiC = silty clay; S = sand; Si = silt; C = clay. **: This guideline also includes no fragments larger than 1 1/2 inch (381 mm) in diameter.

optimal levels, while preserving the health of the environment" [37]; or as the "integrated measure of both the capacity of the soil to function and the degree of expression of this functionality in relation to a given use" [38]; or to "function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" [39].

From an agronomic point of view, many factors influence soil quality in terms of physical, chemical, and biological fertility. Each of these relates to specific indicators levels, which are:

- for physical characteristics: the particle size, structure, mass, and humidity, on which depend other parameters such as porosity, softness, specific gravity, toughness, crackability, cohesion, adhesion, plasticity, aeration state, specific heat, and thermal conductivity;
- the chemical and chemical-physical characteristics mainly depend on the fine earth composition, pH, and redox potential;
- the biological characteristics are a function of microbial pools that influence the processes of organic matter humification, mineralization, nitrification, atmospheric nitrogen fixation, etc.

In the qualitative assessment of soil's agronomic vocation for crops cultivation, other two significant factors are the slope and exposure: lying refers to the inclination of the surface to the horizontal plane, which conditions water regimentation, machinery accessibility for cultivation, crop choice, yield, and production costs; while the exposure refers to the orientation of the soil surface to the cardinal points, which is more significant for slope soils, affected by the climatic environment in terms of insolation and wind exposure.

2. Soil Skeleton

The rock fragments or coarse fraction of soil with a diameter over 2 mm, up to those having a horizontal dimension less than the size of a pedon [1], constitute the soil skeleton.

As intensive agriculture is predominantly interested in fine- and the medium-textured active layer of soils, in determining the texture, soil fractions over 2 mm of diameter (gravel and stones) are usually excluded because they are considered as an inert fraction in soil-crops dynamics. However, the skeleton can play a significant role in soil physical and chemical properties, such as water retention and flow, structure improvement, protection against compaction and erosion, thermal regulation, and bulk density. In some cases, the skeleton also shows chemical properties similar to or higher than those of the fine earth. It may contribute in weathering events involving the dissolution of carbonates and forming secondary minerals with the subsequent creation of voids. It also may release nutrient cations and render the most weathered clasts like fine earth. Therefore, it plays a significant role as a reservoir of nutrients, as a source of effective cation exchange capacity (ECEC), and as adsorber of organic pollutants, also with favorable effects on plant growth [40] [41] [42] [43].

On the other hand, an excessive presence of skeleton in the soil's arable layers hinders or is incompatible with the operational requirements of modern cultivation techniques and pieces of machinery (*i.e.*, minimal tillage, precision sowing), which require fields without obstructions and arable layers of fine heart, as soil coarser fragments easily impede or damage them [44] [45] [46].

3. Soil Stoniness Assessment

The coarse fraction of the soil's arable layer has been variously defined in terms of skeleton classes percentage by weight, size, surface coverage, volume [47] [48] [49] [50] [51]; or through dimensionless indexes such as: Stoniness Degree (Equation (3)), Crushing Degree (Equation (4)), Stoniness Index (Equation (5)),

$$\mathrm{SD} = \mathrm{StM}/\mathrm{SoM} \tag{3}$$

$$CD = \frac{\sum_{i=0}^{5} n_i \cdot StMi}{SoM} \tag{4}$$

$$\mathrm{SI} = \mathrm{SD}/\mathrm{CD} \tag{5}$$

where StM = Stones Mass; SoM = Soil Mass; *i* and *n* index as per **Table 2** [52].

In the most advanced farming management types, the maximization of cultivation

Table 2. Stone classes index.

i value	Stone Size (mm)	*n* value
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

results, in terms of crop yield, machinery efficiencies, and reduction of operative costs, depends directly on topsoil quality, as defined above; in soils with significant quantities of coarse fractions or stones of the greatest classes in the arable layer, the assessment of soil quality shall also include the influence of skeleton.

Depending on the nature of the parent material, the soil skeleton is highly heterogeneous in terms of lithology and degrees of alteration, which also influences the systems and techniques of soil reclamation: *i.e.*, in the presence of stones of high hardness, it is preferable to resort to the removal of the skeleton, rather than to the on-site crushing; as well as in the case of materials that can worsen, if pulverized, the chemical-physical characteristics of the soil [53].

Even though the stones reclamation of agricultural land is an expensive process, the excessive stoniness of the arable layer of agricultural soils entails an interference with cultivation needs, in particular when adopting new cultivation techniques (e.g., precision farming), and machines for soil cultivations (e.g., tilling, seeding, fertilizing); and damage or makes impracticable the use of the machinery.

In these conditions, it becomes necessary to proceed with soil destoning, to recover arable land, and optimize management to save non-renewable resources and maximize cultivation results, both in the least developed countries and those with greater availability of machinery and technologies [43] [44] [45] [46].

The Disturbance Degree (DD) calculation evaluates the stoniness impact on the efficiency and operational capabilities of soil tilling and cultivation machines. The DD directly relates to the skeleton, size of the stones, and their size classes distribution as per Equation (6)

$$DD = 0 \times X + 10 \times Y^5 + 10 \times Z^2 + 10 \times U^{0.9} + 10 \times W^{0.5} \tag{6}$$

where X, Y, Z, U, W, indicate the proportions, expressed in unit terms, of the different particle size classes, the sum of which must always be equal to 1 (100%).

Of these, the X class, corresponding to the fine earth, always has zero value; Y class (gravel, fine & medium gravel: 2 - 20 mm) does not represent an impediment to soil tillage's; the Z class (gravel, coarse gravel; medium stone: 20 - 50 mm), at about 40% - 50% affects the operational capabilities of the PTO moved machines; the U class (cobble, large stones: 50 - 150 mm), sets significant limits for machining already from 15% - 30%; the W class (stones, huge stones: >150 mm), involves severe problems of soil tillage's management already at the 10% of presence [54].

4. Soil Destoning Systems

The choice of a better reclamation method depends on environmental and managerial factors, such as soil structure, percent, typologies and size of the stones, crop needs, machinery availability. The most used destoning systems in agricultural lands are basically three: the stones collection and removal from the field, the on-site stones crushing, and the stones burial [55] [56] [57] [58] [59].

4.1. Stone Removal

The stones removal usually consists in a three-step process: collection, transportation, disposal. The objective of these operations is the removal of stones that reduce the efficiency of the cultivation machines. The simplest approach in stony soils reclamation is to gather the stones from the surface of the field using various kinds of machineries, usually pulled and PTO powered (**Figures 3(a)-(d)**) for picking and loading the stones.

Large stones intermixed with the soil or entirely below the surface of the ground require a deep plowing for breaking the soil (**Figure 4**) [60] before their removal or, in the case of boulders, the use of a rock digger (**Figure 5**) [61].

In the case of boulders too large to be dug out and drawn off, there are two options available besides leaving them in the field: dig a deep hole next to a boulder and tip into it or split the boulder into smaller pieces to make them easily transportable.

Figure 3. Samples of: (a) Stone windrower; (b) Stone picker; (c) Stone windrower & picker; (d) Stone collector with conveyor belt.

Figure 4. Three point carried Ripper.

This kind of stone removal usually must be repeated for several years to reach a good level of stones reclamation.

The main negative aspects of stone removal from the soil are the reduction of topsoil volume and the lowering of the field plan (proportionally to the removed stones) plus the costs for the preventive soil preparation (ripping, stones windrowing), and the handling and disposal of the removed stones. In addition, the reduction of topsoil volume and the lowering of the field plan may cause the resurfacing of another skeleton, which makes it necessary to repeat the stone reclamation in case the soil tillage is more profound than the reclaimed layer. Although, in some tropical agricultural environments, stones recovered from soil reclamation are used in the construction of stone bounds both for the regulation of water runoff in case of heavy rains in years with high rainfall, and in years of drought, to increase the retention and infiltration of rainwater into the soil, and the amount of water available to plants [58] [62].

Another stone reclamation system uses a particular type of stone gatherer that works in previously ridge-till arranged soils whose width corresponds to the machine's working width, that collects, sieves, and unloads the fine earth in the reclaimed ridge-till row. In contrast, the stones are retained and taken to a rear conveyor belt that unloads them in lateral windrows corresponding to the carriageways of machines used in cultivation operations (**Figure 6**) [63].

Figure 5. Rock digger.

Figure 6. Stone separator for windrowed soil.

4.2. On-Site Stones Crushing

The on-site crushing of stones is adopted on cultivated stony land to improve soil structural characteristics and workability or on uncultivated soils to recover lands for agricultural use, forming an active functional layer for cultivation operations.

Deep soil scarification or plowing usually precedes the crushing of stones to crack and crumble rocky banks, bring buried stones to the surface, and optimize the operative capabilities of machinery; in the case of large boulders, also pneumatic or hydraulic hammers can be used.

The stone crushing in sandy and siliceous soils involves rapid wear of the crushing hammers, so it is usually adopted in more friable (calcareous) soils and with a high degree of stoniness to avoid contact with the fine earth and enhance the crushing efficacy.

For these operations, various typologies of stone crushing machines are available, brought and PTO moved, or towed and self-engine powered, that can directly crush the stones on the ground or act on previously collected and windrowed stones.

The stone crushers all operate with the same principle: a rotating horizontal axle with different peripheral kinds of wear-resistant hammers (e.g., with teeth for calcareous rocks or hammers for granite stones) impacts with stones, causing their crushing (**Figure 7(a)**, **Figure 7(b)**).

Larger stone crushers can work to a depth of up to 40 - 50 cm; however, the specific energy consumption (as energy per cubic meter of crushed soil) increases considerably as the depth increases, so it is often of better convenience to keep the crushing not over 15 - 20 cm of deep and repeat the operation several times. Also, the choice of better machines for stone crushing depends on several factors such as the soil nature, the level of stoniness, the stones typologies, the surface extension, and what kind of soil one wants to get [64] [65] [66] [67].

In addition to high costs and low effectiveness in the case of granite stones (**Figure 8(a)**), the disadvantage of on site stone crushing consists of modifying the composition of the soil, with adverse effects on its physical, chemical, and biological characteristics (**Figure 8(b)**). Such soil deterioration often requires corrective actions for the subsequent years [41] [42]. Moreover, if not properly planned and executed, it can also lead to environmental disasters [67].

Figure 7. (a) Stone crusher with teeth for calcareous rocks and (b) with hammers for granite rocks.

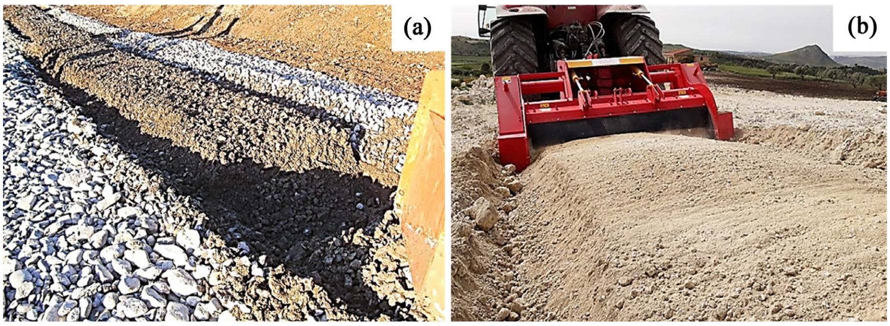

Figure 8. (a) Crushing efficiency on granite rocks; (b) Stone crusher on calcareous rocks.

4.3. Stones Burial

An alternative method to removal and on-site stone crushing consists of the skeleton's burial to obtain an arable layer of only fine earth. Starting from the late 1700 s, farmers in Great Britain and the United States started to bury soil skeleton and use it as field drainage when reclaiming lands too wet for ordinary cultivation, and improve soil structural conditions and crop yields. Among several different designs proposed for drains, one of them involved digging a ditch and filling it with stones up to 30 ÷ 45 cm from the surface, then filling the last 30 ÷ 45 cm of the ditch with fine earth to form the arable layer (plow zone) of the field [55].

Several machines that separate and bury the skeleton using continuous soil sieving are available. Such machines commonly derive from horizontal rotary soil milling machines, equipped with a counter-rotating rotor, with a variable number of squared profile blades and a rear-mounted grid, to retain the skeleton inside the carter. They afterward release it on the bottom of the dug layer and cover it with the fine earth ejected through the screening grid as the machine advances (**Figure 9**).

These stone buriers machines are designed to prepare soil seedbeds, usually in horticultural cropping. However, they also bury stones, clods, and crop residues, even in uncultivated lands, to constitute a superficial layer of fine earth whose

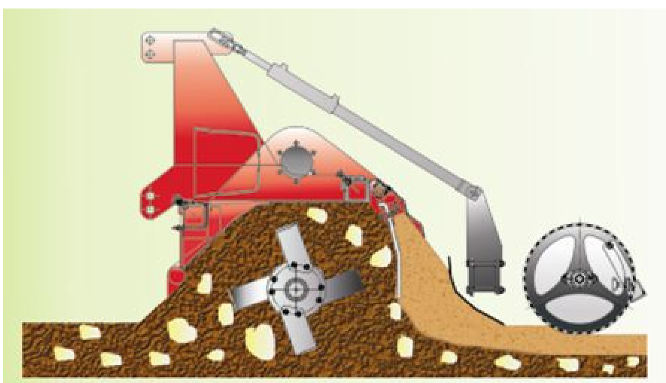

Figure 9. Stone burier draft.

thickness depends on the working deep and the stoniness of the soil. They form a drainage layer contextually, avoiding the formation of the hardpan layer and water stagnation risks, as occurs in the seedbed preparation with the rotary tiller machines [68] [69] [70].

When adequate conditions exist, this kind of soil skeleton burial allows to obtain a fine earth seedbed, without reducing the topsoil volume and field plan level, as in the case of stone removal, nor modifying the physio-chemical characteristics of the soil, as can occur in stone crushing.

The main drawback of such machines is their low working depth, generally not over 30 cm, limiting their range of action to the seedbed preparation in soils without excessive stoniness or large stones.

A more expensive but long-term stony soil reclamation system, useful in cases of high soil stoniness/stones class, consists of burying the skeleton beyond the tillage depth, thus obtaining the desired arable layer of fine earth only. The operation can be done for the whole field, or only for the field zones with a Stone Index or Disturbance Degree higher than those bearable by machines needed in soil cultivation. This technique consists of digging trenches of depth-dependent on the percentages and size classes of the skeleton and the desired depth of the fine earth layer. Then, the excavated soil is sieved to discharge the separated stones to form a draining layer at the bottom of the trenches and cover them with the sieved fine earth remaining fractions to form the new active (arable) layer. Given the lack of specific machinery, it is possible to proceed with industrial earth-moving machines to carry out this type of reclamation of stony soils, providing them with appropriate modifications of the conveyor belts and the drainage path to stratify the sieved fractions in the expected order (**Figure 10**) [71].

Figure 10. Self-moving industrial trencher.

5. Conclusions

Suitable soil management is a key factor for successful farming process in any cropping system, both traditional or extensive, and, more significantly, in modern site-specific agricultural management. In the current conditions of soil use due to the expansion of urban and industrial activities and the increase of soil degradation and desertification processes, in the absence of realistic possibilities to reverse this trend in the short term, it is of primary importance to maximize the efficiency of agricultural management. Since the usability of different agricultural techniques is strictly dependent on soil quality, managing this last for machinery and cultivation is the first parameter for cropping success.

This fact primarily depends on the farmer's ability to choose the most effective cultivation management for optimizing the active soil layer's physical, chemical, and biological fertility, reducing the production costs and enhancing the environmental sustainability of agro-industrial lands; limiting at the same time the overexploitation and degradative phenomena of the non-renewable resource "soil".

Among the factors that most influence the cultivation results, in terms of crop yield, machinery efficiency and reduction of operating costs, the presence of soil skeleton is of particular importance: depending on the quantities and dimension of stones present in the arable soil layer, coarse gravel and medium stone (20 - 50 mm), reduce the operational capabilities of the PTO driven machines from about 40% to 50%; cobble and large stones (50 - 150 mm) set significant limits for machining already from 15% - 30% of presence; stones and huge stones (>150 mm) involves severe problems of soil tillage's management already at the 10% of presence.

Although the stones reclamation of agricultural land is an expensive process, if the skeleton amount exceeds the Disturbance Degree (DD) acceptable by machinery, it becomes necessary to proceed with destoning. The most used stones reclamation systems in agricultural lands are the stones collection and removal from the field, the on-site stones crushing and the stones burial.

The choice of the best method involves organizational factors, such as soil structure, the nature of the stones material, *i.e.* hardness, the DD of the skeleton, as the size of the stones, size classes distribution, and volume percent, and crop needs and machinery availability.

The state-of-the-art about the reclamation methods of stony soils highlights the availability of various technologies and machinery designed and usable in different working conditions, according to specific environmental conditions and cultivation needs. Given the operational needs of agro-industrial crops and the diffusion of precision farming techniques, it is of particular importance to operate on arable layers composed of fine earth only, or with a skeleton content compatible with cultivation machines. This is the discriminant factor in the coarse fractions management, also taking into account the possible negative effects of the various stones reclamation methods, such as the lowering of the field plan, in the case of the stones removal, or the modification of the chemical-physical characteristics of the soil, in the case of on-site crushing; while the stone burial under the arable layer could be a more effective reclamation system in the long term, without the drawbacks of the two others mentioned systems. An economic analysis should be conducted in the choice of the better reclamation method, e.g., concerning removal, the economic value of the stones could be considered because companies operating destoning operate in road pavement or building sectors as well and may have an interest in the removed material. However, it is necessary to pay attention to the regulatory framework of each country because stone removal and reuse may fall among the non-agricultural production activities or be considered a borderline activity between soil reclamation and mining, like quarry works. Such aspects require specific regulatory studies that go beyond the scope of this review.

The specificity and costs of the machines and yards for the different methods of reclamation entail their availability for service contractors or large farms. The development of suitable machines for each reclamation method can result from the levels of interest and convenience in the implementation of advanced cultivation methods, which mainly require optimized soils for boosting machineries efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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