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Comparison of methods for determining cloddiness in seedbed preparation

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Abstract

To determine the optimum degree of roughness of a seedbed, it is necessary to identify parameters that can quantify the cloddiness. This is necessary not only within experimental boundaries, but also to be able to check the quality of the work, and to objectively adjust implements. In this study, the degree of cloddiness of seedbeds was evaluated using three different methods: (1) the sieve method; (2) the image analysis and the standard deviation of the heights defining the soil profile; and (3) the counting, in the field, clods with diameter >40 mm. The degree of correlation between the results obtained by the different methods was also evaluated. The method based on image analysis was well correlated to the sieve method ($r^2 = 0.81$) and can be used as an alternative for determining the seedbed cloddiness. The standard deviation of the heights defining the profile can be correlated, with a fair approximation (correlation to sieve method $r^2 = 0.63$), to the degree of cloddiness of the seedbed, although this is also influenced by factors not linked to clod size (oriented roughness). The method based on counting clods with a diameter >40 mm is a simplification of the method based on image analysis; although its correlation to the sieve method is lower ($r^2 = 0.53$), it lends itself to field application at the stage of adjusting implements. Furthermore, given its simplicity, it appears to be suitable for use by extension services to objectively determine seedbed cloddiness and avoid excessive pulverising of soil. The type of implement affects, sometimes clearly, the relations between the various indexes, and these variations can be explained by the way the implements operate. In particular, a comparison between the sieve and the image analysis demonstrates the different distribution of clods in the vertical profile of the tilled layer; the comparison between image analysis and soil height standard deviation singles out the roughness component not caused by the dimensions of

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the clods. Finally, an analysis of indexes technical aspects under field conditions is reported.

Keywords: Seedbed preparation; Cloddiness; Sieve; Profile meter; Image analysis; Roughness

1. Introduction

Secondary tillage is an important and delicate phase in seedbed preparation that farmers often take for granted despite fuel consumption and unit costs that are sometimes comparable to those of primary tillage. Its incorrect application, with excessive fining down of the seedbed, a habit unfortunately widespread among farmers both in Italy and in Switzerland, causes considerable damage to the soil structure. It is, therefore, important to identify optimal seedbed roughness according to crop requirements and soil conservation. To do this, it is necessary to identify one or more concise parameters describing the degree of roughness, that can be utilised not only within experimental boundaries, but also to check the work quality and correctly regulate implements in the field.

The development of speedy and simple methods for determining this parameter could also lead to the devising of electronic instruments, rear-mounted on the implement, which could directly evaluate the cloddiness and instantly modify the operation of the working parts (e.g., forward speed, rotating speed of the rotors, tillage depth, angle of tines or deflectors etc.).

The method commonly used in experiments in Italy and in Switzerland for determining the degree of cloddiness resulting from tillage is sieve analysis (Kemper and Rosenau, 1986). The median-weighted diameter of the clods in a sample is determined after splitting the sample into a given number of fractions on the basis of clod diameter. As an alternative to the laborious sieve method, some authors have tried to quantify seedbed roughness with other methods based on image analysis or the determination of surface roughness.

1.1. Image analysis

In recent years, there have been many applications of this technique in agricultural research, but there has been scant use in the analysis of cloddiness, mainly because of the difficulty of discriminating a substrate almost always of the same colour with precision. Campbell (1979) proposed a method based on image analysis for determining the number of clods belonging to the different diameter classes, and compared the results obtained with those of the sieve. The proposed technique consists essentially of taking a soil sample, eliminating the portion of fine soil with a sieve, and setting out the remaining clods on a white surface to obtain a photographic image. The number of clods falling within each pre-set diameter class is then determined automatically by computer. The technique, conceived for studies on potato (*Solanum tuberosum* L.) harvest mechanisation, does not lend itself to seedbed analysis, as it is destructive, laborious and difficult to apply in the determination of the fractions of small-sized aggregates.

Stafford and Ambler (1988) used image analysis techniques with the principal precise aim of evaluating seedbed quality. The authors set up image analysis procedures to determine the number of clods per unit surface area, and evaluated the possibility of determining seedbed roughness by quantifying the shades of grey in the photographic images of the tilled surfaces; starting from these data, they calculated the autocorrelation function and did a spectral analysis. Comparing the results obtained with the judgements expressed by a panel of 25 experts, they found that the evaluation techniques they had proposed provided responses, in terms of seedbed roughness, comparable to those of the group of experts. The authors also hypothesised the possibility of using the image analysis technique for adjusting the implements for seedbed preparation in real time.

More recently, Aumüller-Gruber (1993) used image analysis to quantify seedbed cloddiness in both laboratory and field trials. An optimum correlation between the two-dimensional image and the relative volume was ascertained. To analyse only the aggregates with a diameter >2 mm, the author filtered the images through a milk glass and analysed the cumulative distributions supplied by this method and by the sieve.

1.2. Roughness

To determine roughness, it is necessary to study the morphology of the tilled surface with a profile meter. Many types of profile meters proposed in the literature can be classified on the basis of the characteristics and number of probes used: (i) profile meter with a probe that comes into physical contact with the soil and (ii) profile meter with a probe that does not come into contact with the soil. The first fairly large group includes instruments that utilise one or more probes, essentially a metal or plastic rod that comes into contact with the soil profile. The second group of instruments have non-destructive probes that do not come into contact with the soil: laser probes (Bertuzzi et al., 1990a; Destain and Verbrugge, 1987; Koob, 1986), or acoustic probes (Xu et al., 1992). Profile meters with laser or acoustic probes, although more expensive than those with needles, allow large amounts of data to be acquired in a very short time, and they can be connected to a computer; therefore, they can be used for roughness evaluation of systems in real time.

Considering that the structure of tilled soil affects the roughness, Kuipers (1957) proposed using roughness as an index of the degree of fineness obtained with tillages; the same technique was independently developed in Italy during this time by Candura et al. (1956). To quantify it, Kuipers proposed the use of a parameter R given by the following formula:

$$R = 100 \times \log \sigma$$

where σ is the standard deviation of the heights, expressed in centimeter, defining the profile of the tilled soil surface measured by a needle profile meter.

Following this, other roughness indexes were proposed in the literature based on calculating the standard error of the heights of the profiles (Burwell et al., 1963; Currence and Lovely, 1970; Zobeck and Onstad, 1987; Grant et al., 1990). These differ from Kuipers' proposal in the method of fitting the data or by eliminating the logarithm from the formula. Other authors (Bertuzzi et al., 1990b; Currence and Lovely, 1970;

Destain and Verbrugge, 1987; Dexter, 1977; Koob, 1986; Laib, 1977; Zobeck and Onstad, 1987) always starting from surveying the surface profile, proposed indexes that are not based on the standard deviation of the heights, but examine geometrical aspects of the profiles. A review and detailed description of these indexes is given in Sandri et al., 1996.

The choice of suitable index must take into account the reason for measuring the roughness. Many of these indexes have been formulated for different purposes than the direct quantification of the degree of seedbed cloddiness; therefore, as well as requiring complex algorithms, they do not provide results that can be easily related to the degree of cloddiness.

The objective of the present study was to compare, with respect to the traditional sieve method, two alternative methods: the median-weighted diameter determined by image analysis, and the standard deviation of the heights of the soil profile measured with a profile meter. With the aim of also providing a method accessible to the farmer, an index is proposed (number of clods on the surface of the seedbed with a diameter > 40 mm) that can be used in the field as a standard method for evaluating the quality of secondary tillage and implement adjustment.

2. Methodology

2.1. Experimental plan

To create seedbeds with different degrees of fineness, the seedbed, previously ploughed, was prepared using three different implements: a rotary harrow, a rotary cultivator, both power-driven, and an S-tine cultivator, all working to the same depth (80 mm) and with the same working width (3 m). The rotary harrow, with 12 vertical rotors, operated with the rear shield lowered and rear packer roller; the rotary cultivator was equipped with 53 rhomboid tines and packer roller; the S-tine cultivator had 56-mm

Table 1
Working methods of the implements used in the trials

	Implement used					
	Rotary harrow		Rotary cultivator			S-tine cultivator
Tillage intensity	Low	High	Low	High	Average	–
Location	Riet, Waldegg, Halde	Riet, Waldegg, Halde	Riet, Waldegg, Halde	Riet Waldegg, Halde	Langwies, Hausweid	Riet, Waldegg, Halde
Working width (mm)	300	300	300	300	300	300
Tillage depth (mm)	80	80	80	80	80	80
Rotor speed (rad/s)	5.9	5.9	8.3	8.3	10.9	–
Forward speed (m/s)	1.33	0.53	1.33	0.53	0.83	2.72

Table 2
Main physical characteristics of the soil (0–80 mm layer) in the trial sites

	Location				
	Riet	Waldegg	Halde	Langwies	Hausweid
Sand (0.02–2.0 mm, g kg^{-1})	440	440	390	250	490
Silt (0.002–0.02 mm, g kg^{-1})	320	350	310	350	310
Clay (< 0.002 mm, g kg^{-1})	210	180	260	350	160
Organic matter (g kg^{-1})	30	29	40	50	40
Moisture content (g kg^{-1})	230	150	170	160	140
Soil type (FAO classification)	Eutric Cambisol	Eutric Cambisol	Eutric Cambisol	Haplic Luvisol	Eutric Cambisol

spaced tines and narrow double-point shovel. The first two implements were used at different levels of tillage intensity, varying the forward speed of the machine (Table 1). Five different treatments were thus obtained, replicated in 3 blocks organised as a split-plot. The trial was repeated over three successive years on three different locations in Switzerland (Riet in 1993, Waldegg in 1994, and Halde in 1995). During these trials, other two locations (Langwies and Hausweid, both in 1994) were added, in which only rotary cultivator was used at average tillage intensity. The extension of the trials to these sites (prepared within the boundaries of a pluri-annual experiment) allowed a better evaluation of the responses and adaptability of the various methods to different pedological conditions. The main physical soil characteristics in the trial sites are reported in Table 2. Immediately after tillage, 4 sample areas were singled out on each plot (500 mm long and 300 mm wide, with the long axis orthogonal to the forward direction of the tools), on each of which the different methods were applied.

2.2. Indexes utilised

On each sample area, as outlined in Table 3, the following were determined: (1) median-weighted diameter by means of sieve analysis (MWD_{SV}); (2) median-weighted

Table 3
Analysis methods used at various sites with different implements

Location	Rotary harrow	Rotary cultivator	S-tine cultivator
Riet	MWD_{SV}, MWD_{IA}, SD_P	MWD_{SV}, SD_P	MWD_{SV}, MWD_{IA}, SD_P
Waldegg	MWD_{SV}, MWD_{IA}, SD_P	MWD_{SV}, MWD_{IA}, SD_P	MWD_{SV}, MWD_{IA}, SD_P
Halde	MWD_{SV}, MWD_{IA}, SD_P, WT	MWD_{SV}, MWD_{IA}, SD_P, WT	MWD_{SV}, MWD_{IA}, SD_P, WT
Langwies	–	MWD_{SV}, MWD_{IA}, SD_P	–
Hausweid	–	MWD_{SV}, MWD_{IA}, SD_P	–

MWD_{SV}: median-weighted diameter obtained using the sieve.
MWD_{IA}: median-weighted diameter obtained by image analysis.
SD_P: standard deviation of the heights of the profile.
WT: number of clods with a diameter > 40 mm (watch test).

Table 4
Extreme and median diameters of the clod diameter classes used for splitting the samples into fractions

Class number	Minimum diameter (mm)	Maximum diameter (mm)	Median diameter (mm)
1	0	2.5	1.25
2	2.5	5	3.75
3	5	10	7.5
4	10	20	15
5	20	40	30
6	40	80	60
7	80	–	100[a]

[a] The median diameter was chosen arbitrarily.

diameter of the clods on the soil surface by means of image analysis (MWD_{IA}); (3) standard deviation of the heights defining the profile of the soil surface analysed (SD_P); and (4) number of clods with a diameter of more than 40 mm (WT). The last parameter was only introduced during the final year of activity and at only one location, as it was a new method devised in the light of the observations and measurements in the preceding years.

2.2.1. Median-weighted diameter obtained using the sieve (MWD_{SV})

The surface layer of soil, to a depth of 50 mm, was removed from the sample area by means of a sampling spade. The sample, air-dried, was sieved to divide the clods into 7 fractions, corresponding to the diameter classes given in Table 4. The mass of each fraction and its percentage incidence on the total sample was determined. This allowed the MWD to be calculated on the basis of the following equation:

$$MWD_{SV} = \sum_{i=1}^{n} \bar{x}_i \cdot w_i$$

where SV indicates the sieve, w_i represents the percentage incidence, expressed as a function of the total sample weight, of the fraction of soil with median diameter $\bar{x}_i$. This formula results strongly influenced by the clods falling into the larger diameter classes; an alternative formula has been proposed (Kemper and Rosenau, 1986) based on logarithmic conversion, but it has not been considered in the present study, as it does not give results comparable with the other methods.

2.2.2. Median-weighted diameter obtained by image analysis (MWD_{IA})

A reflex camera (35 mm with 70-mm lens) was used for the image analysis procedure, held at a distance of 1.3 m from the soil, with the lens axis perpendicular to the soil surface. During photography, the sample area was kept in darkness by means of a transportable camera obscura with a support for fixing the camera at the centre of the upper cover, and an opening for positioning the flash on each of four sides. Four photos were taken of each sample area, maintaining the camera in the same position, and varying on the upper cover (with reference to the camera) the position of the flash by 90°. In this way, four images were obtained of the same surface that differed only in the direction of the shadows, created by the flashlight.

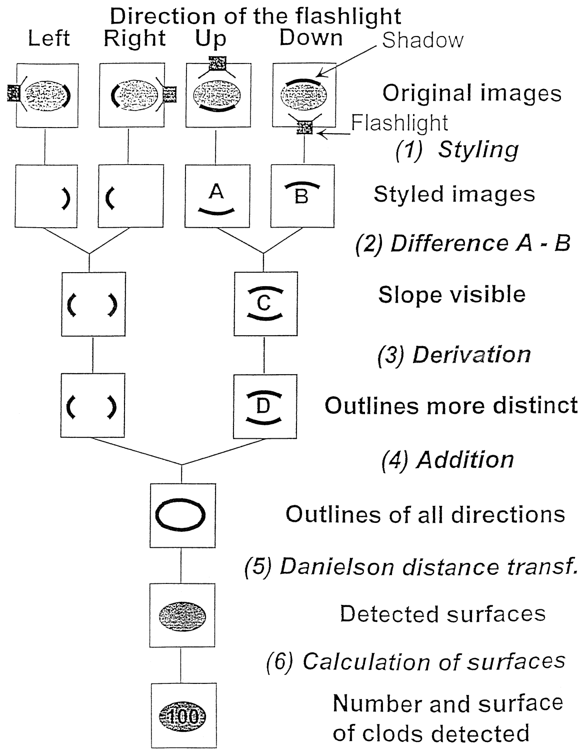

Fig. 1. Steps of the image analysis.

The elaboration phase, using a program set up at FAT (Swiss Federal Research Institute for Agricultural Engineering) consisted of the differentiation of the outlines of the clods by overlaying the 4 strongly contrasted images, having been previously digitised by scanner, and the subsequent determination of the area covered by each clod and the respective diameter. The steps of the program to work the image analysis out are (Fig. 1) as follows.

(1) Conversion of the gray scaled image into a black and white image to bring out the outlines: the limit above and below which any pixels are assigned either the colour white or black, respectively, is defined for each series of images individually;

(2) Combination of two images (A and B) to one resulting image by subtraction according to the formula:

$$C(i;j) = A(i;j) - B(i;j)$$

where C represents the resulting grey level of a pixel at the position i,j of images A and B, i indicates the horizontal position of a pixel in an image and j the position.

(3) Calculation of the first derivation according to the formula:

$$D(i;j) = C(i;j) - C(i+1;j)$$

(this is mathematically defined now) which brings out the outlines of the clods more distinctly.

(4) Combination of all outlines in one single image by adding the two remaining images.

(5) The different clod surfaces are detected by means of the Danielson distance transformation according to Kübler (1993).

(6) Each clod is given a number. The same number is then applied to all pixels of a clod. All that remains to be done is measuring the different clod surfaces, which can easily be done by counting the pixels with the same number.

The values obtained, downloaded onto a spreadsheet, were divided according to the 7 diameter classes used for the sieve (Table 4). For each class, the total surface area covered and the MWD were calculated on the basis of the equation:

$$\mathrm{MWD}_{\mathrm{IA}} = \sum_{i=1}^{n} \bar{x}_i \cdot s_i$$

where: IA indicates the image analysis, s_i represents the percentage incidence of the soil fraction with average diameter $\bar{x}_i$, given by the ratio between the area covered by clods belonging to the diameter class and the surface of the sample area.

The $\mathrm{MWD}_{\mathrm{IA}}$ was calculated similarly to the $\mathrm{MWD}_{\mathrm{SV}}$ in the sieving analysis, except that the diameters of the clods (assumed to be circular) were used instead of the weighed diameters.

Clods <5 mm were only partly detected by the image analysis. Compared to the determination by sieve, this determines an underestimate of the smallest diameter classes and an overestimate of the median-weighted diameter. To overcome this problem, the entire surface of the sample area not covered by clods was considered as belonging to the lowest median diameter class.

The median-weighted diameter determined by image analysis was chosen because it is a non-destructive method, it allows the time necessary for sampling in the field to be reduced, and it does not require the transport of large quantities of soil.

2.2.3. The standard deviation of the heights of the profiles (SD_P)

Immediately after seedbed preparation, in each sample area, the surface profile was measured by a laser profile meter, capable of measuring the height of the profile every 2 mm, with an approximation of ± 1 mm and to measure a series of parallel profiles at the required distance (Fig. 2).

The laser profile meter, made at the FAT, is a frame constructed with Phönix systems components, in which a laser beam is mounted for distance measuring, type Sick model DME 2000, controlled by a 5-phase (Berger-Lahr, type VRDM 60) stepping motor and a low-cost positioning system (Bachofen-AG, type FOE 102) with synchronous-belt-driven slide (Phönix system) for mechanical positioning; the power is provided by two maintenance-free lead accumulators (type YUASA, model NP 12-12). Data were collected by a notebook with two serial ports RS232 and one Centronics interface and the software used was programmed in Pascal.

For each sample area, 31 profiles, 500 mm long and 10 mm apart, were measured. The soil surface of each sample area was thus defined by 7781 heights deriving from 3.1 profiles of 251 heights all measured against the same reference plane.

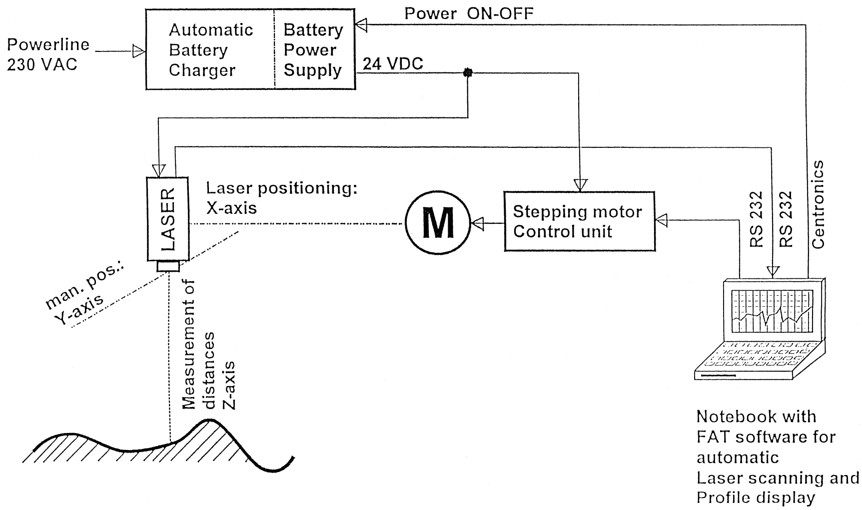

Fig. 2. Scheme of the laser profile meter.

Surface roughness was evaluated by calculating the standard deviation of the heights of the profiles (SD_P) defining the soil surface without data transformation; any slope of the profiles due to the natural slope was removed by placing the profile meter parallel to the tilled surface. The following formula was used:

$$SD_P = \sigma_H$$

where: σ_H is the standard deviation of the heights (in mm).

The standard deviation of the heights was chosen because it is a simple index of calculation and has the same unit of measure and a similar trend to the MWD_{SV} (Sandri et al., 1996). It must be specified that, in the index proposed by Kuipers (1957), the logarithmic form was utilised to bring the standard error back to within acceptable limits, given the narrow degrees of freedom of the needle profile meter measurements ($df = 380$); this system makes the interpretation of the results less direct, at least for seedbeds. In the present study, the index of the simple standard deviation derives, instead, from the reading of 7781 heights for each replication, bringing the value of the standard error within very narrow limits without recourse to the logarithmic form.

2.2.4. Number of clods with a diameter > 40 mm (watch test: WT)

Using the number of clods with a diameter > 40 mm (slightly bigger than the diameter of a standard wristwatch dial) on an area of 0.15 m^2 (the sample area size) was hypothesised as a concise index of direct evaluation of seedbed cloddiness. The diameter limit of 40 mm was chosen arbitrarily both after direct field observations and at the stage of data elaboration of the clod diameter classes. To evaluate if this index would correlate with the real degree of cloddiness of the seedbed, the number of clods were counted in the field with the aid of a 40-mm diameter paper disc before taking the sample for the sieve.

The values of the calculated indexes were arranged on a spreadsheet and a distribution test done. The regression lines indicating the degree of correlation between the different methods were then calculated by the least squares method, using a suitable program.

3. Results and discussion

3.1. Relations between the various methods

The values of the indexes examined are all normally distributed. The general relations between the various indexes are reported in Table 5. Taking the sieve method and its corresponding parameter (MWD_{SV}) as reference, it is seen that there is a good correlation with the MWD_{IA}, explaining 81% of the variations of the dependent variable. Moreover, the angular coefficient close to one indicates that in practice, the two methods can be used indifferently without the need for any conversion; the value of the intercept, equal to 3.9 mm, is to be considered to avoid a slight underestimate of the MWD_{SV} (Fig. 3).

The relation between MWD_{SV} and SD_P is influenced by the intrinsic characteristics of the respective measurement methods. In fact (Table 5 and Fig. 4), it has a lower r^2 because the analysis of the profiles is influenced not only by the sizes of the clods, but also by the oriented roughness that affects the surface shape. Furthermore, given that the clods are partially buried in the seedbed, the variations of height surveyed with the analysis of profiles are always lower than the real diameter of the aggregates. This explains the angular coefficient of the regression line that is almost double ($m = 1.88$) that of the preceding equation. In particular, during the experiment, the obvious effect of the rear roller of the implement used was, without modifying in an appreciable way the structure, and therefore, the value of the MWD_{SV}, to level the surface of the seedbed influencing the roughness.

Table 5
Regression (in the form $y = m \cdot x + q$) and correlation coefficients between the various methods used in the determination of cloddiness

Independent variable (x)	Dependent variable (y)	m	q	r^2
MWD_{SV}	MWD_{IA}	1.02	3.90	0.81
MWD_{SV}	SD_P	1.88	−4.02	0.64
MWD_{SV}	WT	0.74	10.66	0.58
MWD_{IA}	SD_P	1.66	−5.84	0.77
MWD_{IA}	WT	0.76	6.84	0.66
SD_P	WT	0.30	9.51	0.57

MWD_{SV}: median-weighted diameter obtained using the sieve.
MWD_{IA}: median-weighted diameter obtained by image analysis.
SD_P: standard deviation of the heights of the profile.
WT: number of clods with a diameter > 40 mm (watch test).
All the relations considered are significant at $p < 0.01$.

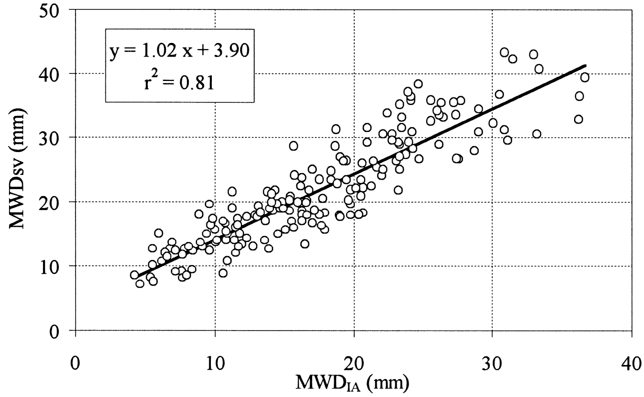

Fig. 3. Correlation between the corrected median diameter obtained with image analysis (MWD_{IA}) and that obtained with the sieve (MWD_{SV}).

The relation between the sieve analysis (MWD_{SV}) and the number of clods >40 mm (WT) (Table 5 and Fig. 5) shows how, in the case of absence of clods of this size, the seedbed results as being very fine with roughness values just under 12 mm. In the seedbeds analysed during the trial and characterised by an intermediate degree of roughness, there were around 20 clods with a diameter >40 mm (equal to 133 clods/m^2).

As regards the relation between MWD_{IA} and SD_P, there is a high correlation between the two parameters, whose regression line explains 77% of the variation of MWD_{IA} through variations of the standard deviation of the profiles (Table 5 and Fig. 6). This is probably due to the fact that both parameters refer to the surface of the seedbed and are not influenced by clods lying beneath the surface. It is worth repeating that the SD_P

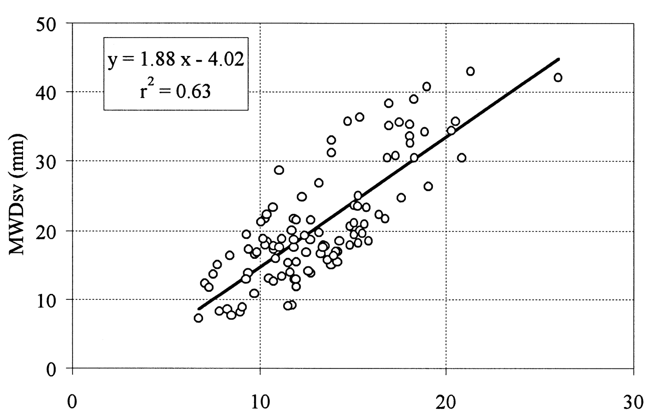

Fig. 4. Correlation between the standard deviation of the heights defining the soil profile (SD_P) and the corrected median diameter obtained with the sieve (MWD_{SV}).

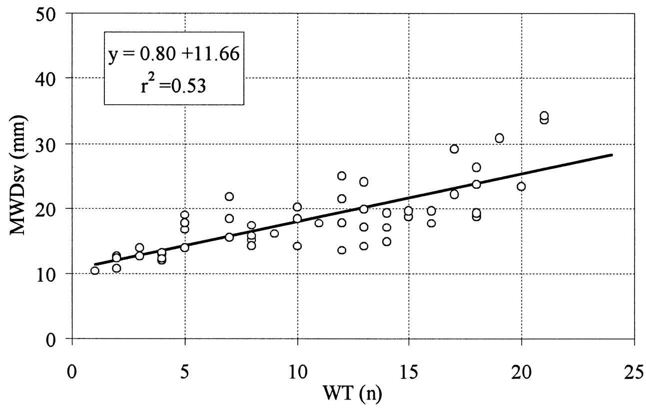

Fig. 5. Correlation between the number of clods with a diameter > 40 mm (WT) and the corrected median diameter obtained with the sieve (MWD_{SV}).

shows variations of the profile due either to cloddiness, or to any surface deformities not strictly linked to clod size, while, being a two-dimensional image, the MWD_{IA} considers only surface cloddiness as the image analysis flattens the tilled surface. This explains the low value of the angular coefficient ($m = 1.66$) that should, in theory, be higher.

The relations existing between MWD_{IA} and WT and SD_P and WT have better correlation coefficients ($r^2 = 0.66$ and 0.537, respectively) than those relating to the sieve, confirming the fact that these methods are based on the analysis of the soil surface alone. Generally, the large diameter clods have greater influence on the value of the MWD compared to those in the smaller diameter classes: in this way, the casual presence of one big clod is enough to determine a more than proportional increase of the calculated diameter. This explains why the WT method gives satisfactory results.

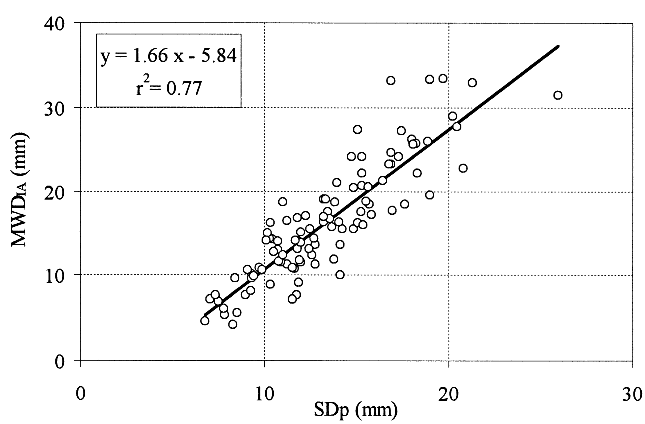

Fig. 6. Correlation between the standard deviation of the heights defining the soil profile (SD_P) and the corrected median diameter obtained with image analysis (MWD_{IA}).

3.2. Effect of the implements

The implements used interact differently with the tilled soil layer, both in regards to clods on or beneath the surface and to their effect in terms of the tillage intensity. This diversity is measured in a different way by the measurement methods considered, so their comparison could be useful for demonstrating the seedbed preparation methods of each implement. The results of these relations are reported in Table 6.

As regards the comparison between MWD_{SV} and MWD_{IA}, the presence of angular coefficients close to one indicates that the cloddiness is homogeneously distributed both in the surface layers and at depth; a lower value indicates more accentuated surface cloddiness, while the opposite is verified for values of angular coefficient higher than one. The results show that the cloddiness produced by the rotary cultivator and by the S-tine cultivator is uniform both on the surface and at depth, while the rotary harrow seems to produce a greater cloddiness in the surface layers compared to those deeper down by virtue of the lower angular coefficient.

The same considerations are valid in the comparison between MWD_{SV} and SD_P in which both the vertical positioning of the clods and, in part, also the presence of oriented roughness are evidenced. In this case, the rotary harrow, with a low angular coefficient ($m = 0.71$), is the implement that creates greater surface cloddiness.

Table 6
Linear regression (in the form $y = mx + q$) between the different methods for the determination of cloddiness as a function of the implements used

Implement	Dependent variable (y)	Independent variable (x)	m	q	r^2	p
Rotary cultivator	MWD_{SV}	MWD_{IA}	1.09	1.36	0.66	0.0000 *
Rotary harrow	MWD_{SV}	MWD_{IA}	0.87	6.48	0.72	0.0000 *
S-tine cultivator	MWD_{SV}	MWD_{IA}	1.24	0.82	0.74	0.0000 *
Rotary cultivator	MWD_{SV}	SDP	2.04	−10.37	0.70	0.0000 *
Rotary harrow	MWD_{SV}	SDP	0.71	10.03	0.15	0.0287
S-tine cultivator	MWD_{SV}	SDP	1.76	−5.41	0.57	0.0017
Rotary cultivator	MWD_{SV}	WT	0.68	9.82	0.44	0.0008
Rotary harrow	MWD_{SV}	WT	0.43	13.28	0.31	0.0046
S-tine cultivator	MWD_{SV}	WT	0.70	12.24	0.37	0.0474
Rotary cultivator	MWD_{IA}	SD_P	1.38	−3.60	0.50	0.0000 *
Rotary harrow	MWD_{IA}	SD_P	1.51	−3.69	0.61	0.0000 *
S-tine cultivator	MWD_{IA}	SD_P	1.23	0.31	0.64	0.0005
Rotary cultivator	MWD_{IA}	WT	0.65	7.44	0.53	0.0002
Rotary harrow	MWD_{IA}	WT	0.51	8.05	0.44	0.0006
S-tine cultivator	MWD_{IA}	WT	0.54	9.76	0.48	0.0174
Rotary cultivator	SD_P	WT	0.22	11.04	0.55	0.0015
Rotary harrow	SD_P	WT	0.13	10.28	0.20	0.0843
S-tine cultivator	SD_P	WT	0.49	7.94	0.70	0.0754

MWD_{SV}: median-weighted diameter obtained using the sieve.
MWD_{IA}: median-weighted diameter obtained by image analysis.
SD_P: standard deviation of the heights of the profile.
WT: number of clods with a diameter > 40 mm (watch test).
$^*p < 0.00005$.

The effect of oriented roughness is clearer in the comparison between the MWD_{IA} and SD_P methods that analyse only the soil surface. The low angular coefficient indicates that the roughness due to the effect of the rear roller, or to the formation of ridges along the direction of forward movement preponderates over that caused by the presence of clods on the surface alone. Conversely, a high angular coefficient indicates that the standard deviation derives essentially from the degree of clod shattering. In the seedbeds prepared with the rotary harrow, the fairly high angular coefficient ($m = 1.51$) confirms a greater levelling effect of this implement compared to the others. The rotary cultivator and S-tine cultivator leave a greater oriented roughness due to the effect of the roller and tines.

The regression curves between the WT method and MWD_{SV} have similar slopes for the rotary cultivator and S-tine cultivator, while the rotary harrow has a lower value. This pattern appears to be similar to that obtained from the comparison between the MWD_{SV} and MWD_{IA}. The watch test (WT) is, after all, a simplified method of estimation derived from the MWD_{IA} and considers the same aspects (diameter and number of clods on the surface). This is confirmed by the direct comparison between the two methods (WT and MWD_{IA}), whose relation varies slightly depending on the type of implement.

3.3. Technical aspects under field conditions

It is not always easy to utilize the sieve analysis. Because of the big volume of soil required to transport, it is better that the sieve is kept not far from the experimental field. Also, it is not easy to dry the soil with heat, and it takes a long time to dry it in the air.

Image analysis applied to the determination of cloddiness provides a two-dimensional view of the seedbed on the horizontal plane, so information on the layer of tilled soil directly beneath the surface is lost. However, it is not influenced by surface deformity not due to cloddiness, such as for example, ridges or furrows created by rollers (oriented roughness as defined by Romkens and Wang, 1986). The good correlation with the sieve method found during the trials means that image analysis can be used to advantage for research activities. Once the procedure for obtaining a good discrimination of the clods has been identified, the image analysis method permits data to be collected in the field very rapidly by means of easily transported equipment. It does not require a complex logistical support; the materials used in the different phases are generally already possessed by a research institute (camera, scanner and personal computer), and it is not a destructive method. It does, however, but requires a long time for the elaboration of the images (about 10 min per sample). The equipment costs, times of elaboration required and the difficulties in making the light conditions uniform mean that application of the technique in its present form is impractical as part of standard field practice and for the adjustment of implements in real time.

The measurement of roughness, if done by a laser profile meter, is a non-destructive technique that allows the use of simple indexes and provides the result in a very short time, even directly in the field. Against this is the fairly high cost of a laser profile meter and that its use in the open field requires considerable logistic support. As only the surface is measured, the standard deviation gives no information on the sub-surface layer of the tilled soil; furthermore, the reading is along a single line, so only variations of profile due either to the vertical dimensions of the clods or to the so-called oriented roughness are measured. The survey line of the profile obviously does not hit all the clods on their longest axis; therefore, many variations of profile will be smaller than the maximum diameter of the clod that determines such profile. These facts must be taken into account when planning trials, trying to increase the number of measurements on the same sample area and positioning the profile meter in the most appropriate way. The method based on the analysis of roughness could also be used for regulating implements in the field, in fact, fixing a laser probe with a display to the implement could supply the operator with instant information on the roughness level of the soil obtained with the tillage; or automatically adjust the implement accordingly. Currently, the high cost of the laser probe makes the hypothesis actually impracticable in a commercial context.

3.4. Seedbed test for farmers

The degree of correlation between WT and MWD_{SV} is fairly low with respect to the other parameters, but, in our opinion, it gives an initial impression of the roughness level of the seedbed. Given its approximation, it is not suitable for scientific purposes, but its simplicity makes it ideal for use in the field. For the farmer, it is enough to count, with the help of a paper disc or coin, the number of clods >40 mm in diameter on a surface area delineated by a suitably folding rule. By repeating the operation 2 or 3 times, the operator is able to have a sufficiently precise indication of the roughness level and to adjust, if necessary, the implement used. It is obvious that the ratio between the number of clods with a diameter >40 mm and the degree of roughness of the seedbed varies according to the type of soil and moisture content, but at present we consider that this is within acceptable limits for the purpose for which this method is proposed. Further studies are necessary to evaluate the real applicability of this technique, and to produce information on the values that this parameter must assume depending on the type of soil and the crop, for which the seedbed is being prepared.

4. Conclusions

Image analysis (MWD_{IA}) can be used as an alternative to the method based on the sieve for the determination of seedbed cloddiness; however, the way the implement pulverises the soil must be taken into consideration. The SD_P method can be correlated with good approximation to the degree of seedbed cloddiness, although it is also influenced by factors not linked to the dimensions of the clods (oriented roughness).

The present study has shown that the type of implement used affects the relations between the various indexes; these variations can be explained by how these tools work. This fact allows the interactions between the soil and the various tools to be evaluated, analysing the three methods in a comparative way. In particular, the comparison between the sieve and the image analysis demonstrates the different distribution of the clods in the vertical profile of the tilled layer; the comparison between image analysis and standard deviation singles out the roughness component not caused by the dimensions of the clods.

The WT is a simple method derived from image analysis; even if it is less precise and therefore cannot be adopted for measurements for scientific purposes, it is suitable for field application at the stage of implement regulation; furthermore, given its simplicity, it appears to be ideal for use by farmers and extension officers to objectively determine seedbed cloddiness and avoid excessive pulverising of soil.

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