Integrated Photogrammetric-Celerimetric Analysis to Detect Soil Translocation due to Land Levelling

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Abstract: Land levelling is applied worldwide in agriculture and represents a potential cause of severe land degradation. This paper presents a new lapse-time analysis to detect the spatial distribution of territory morphology changes due to land levelling. The methodology was set up by comparing the different Digital Terrain Models (DTM) respectively derived from aerial photos taken in the year 1981(picture scale 1:6,000) and from high-precision celerimetric survey performed in 2001, of a vineyard at San Gimignano (Tuscany) that was levelled just before the celerimetric survey. The precision of the new celerimetric-photogrammetric methodology was evaluated by comparing statistically the subtractions' elevations obtained in the grid nodes' position with the ones obtained by using the photogrammetric DTMs of the years 2001 and 1981. The results show that: (1) when is only used one photogrammetric replicate per year, the confidence limits for the of DTMs' difference is ± 15.6 cm ($p \leqslant 0.05$); (2) the use of DTM derived by the celerimetric survey may increase the measurement accuracy of the soil translocation of about 20 cm respect to DTM derived from aerial photos (3) Using celerimetric DTM, the confidence limits of difference resulted ameliorated to ± 6.7 cm ($p \leqslant 0.05$).
Keywords: photogrammetry, topography, soil, tillage translocation, tillage erosion, land levelling

1 Introduction

Soil is not a renewable resource. In fact, the pedogenetic processes overall are very slow, requiring from 200 to 1,000 years to form 2.5 centimetres of topsoil under normal agricultural condition (Kendall and Pimentel, 1994). Barrow (1991) estimated that, depending on the region, the topsoil is currently being lost 16 to 300 times faster than it can be formed.

Recently, tillage has also been included among the effects causing soil erosion. Mechanical tillage on steep slopes, made with instruments that completely or partially turn the soil upside down, determine the soil translocation over a landscape. These variations typically result in soil loss from the convexities and soil accumulation in the concavities and the cumulative effect during years can modify the landscape with environmental and societal impacts.

The soil flux per unit surface (tillage erosion) can produce soil losses that exceed the ones due to water erosion (Govers *et al*., 1996; Lobb *et al*., 1995; Quine *et al*., 1997) and represents an important factor of soil degradation specially in industrialised countries where the energetic input in agriculture is high.

Although the earliest studies on tillage erosion date back to the early 1940's it is only since the 1990s that the research work on this form of land degradation has been on the increase (Govers, 1999; Mech e Free.1942). This is due to the fact that the tillage erosion's effects of became visually evident only after some decades following the introduction of mechanical tillage.

High rates of soil removal on hillslope convexities, due to tillage erosion can rapidly lead to significant and possibly adverse changes in soil properties. Such changes may affect the soil quality and productivity and they can also influence water and wind erosion rates by exposing the erodible subsoil to erosive forces.

Land levelling can be considered among the causes of tillage erosion. This cultural practice is generally applied on undulating land for efficient water application and conservation while terracing.

Besides, bulldozers are often used to remove the natural vegetation or the residues of old plantations, with the consequent scalping of the soil.

In the Mediterranean basin bulldozing is usually used to clear and level the land to obtain uniform easy to cultivate slopes. Moreover, this operation is usually performed in summer, which is the period of the most erosive rainfall. After levelling, slopes are characterised by the presence of large amounts of incoherent earth materials accumulated with bulldozer. In this vulnerable condition, a few summer storms can easily cause soil losses exceeding 500 Mg・ha^{-1}・y^{-1} (Bazzoffi and Chisci, 1999).

The environmental risk of the land levelling practices can be better appreciated considering the sharp increase of Tuscany hilly areas for vineyard and olive-grove plantations occurred in the last three decades. From 1962 through 1993 total vineyard and olive-grove plantation area has increased from 69,000 ha to 138,000 ha, reaching a maximum in the eighties (170,000 ha). Almost the total amount of these sloping surfaces have been levelled and reshaped by heavy mechanical operations, that often triggered or accelerated massive erosion phenomena(landslides, gullying).

The average soil translocation caused by land levelling estimated at 3,900,000 Mg・y^{-1} or 300 Mg・ha^{-1}・y^{-1}. The data given in Fig.1 only concern the vineyard and olive-grove hilly areas (ISTAT, 1962 trough 1993).

This paper presents a mixed photogrammetric and celerimetric methodology to increase the accuracy of detection of the spatial distribution of lanscape morphology changes due to soil translocation induced by tillage and land levelling.

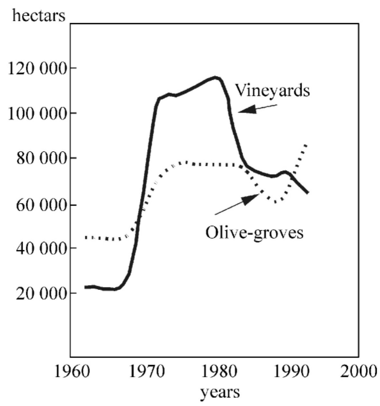

Fig. 1 Vineyard and olive-grove land prone to risk of levelling in Tuscany(period 1962—1993)

2 Material and methods

The assessment of soil erosion and redistribution due to land levelling can be done by comparing time series of elevation data with the use of photogrammetry, applied to stereoscopic aerial photographs (differential photogrammetry). This methodology has been already applied to detect soil erosion (Frazier arid McCool, 1981; Whiting *et al*., 1987) and ephemeral gully erosion from fields and small catchments on a storm, seasonal or annual basis (Welch and Jordan, 1983; Welch *et al*., 1984; Spomer and Mahurin, 1984; Thomas *et al*., 1986).

Aerial photographs have also been used to measure the volume of deposited material within catchments (Dymond and Hicks,1986) and to detect tillage transolaction (Bazzoffi *et al*., 2000).

The precision of the elevation measures determines the degree of accuracy of the differential photogrammetry, applied to the studies of landscape changes. This precision depends on different factors: inherent limits of photogrammetry due to the inaccuracy of placement of the stereoscopic model (which produces systematic errors), the quality of aerial pictures, the steepness and vegetation cover, the quality of equipment and ability of photogrammetrist.

Fryer *et al*. (1994) found that the achievable accuracy of Z values, by using aerial photographs, ranges between 2—3 10^{-4} of the flying height.

Respect to the simple photogrammetry, other factors can further reduce the accuracy of differential photogrammetry. Different soil moisture content at different aerial survey times can determine, especially in clay soils, a significant variation of the elevation caused by soil shrink or swell. Furthermore, the elevation of the reference points, assumed to be constant, may be not the same. This can be provoked by uncontrolled factors, like the slope dynamics and the reshape of the reference buildings used as control points.

As consequence, it is very important to determine the site-specific level of accuracy that can be reached and, if possible, to improve it with the use of appropriate techniques.

For this reason, a new methodology has been set up (Bazzoffi 2001). The novelties of the methodology are: (1) the over determination of topographic points for the placement of stereoscopic models (2) the use of parameters for point acquisition (min/max vector) normally used for the scale 1:1000 or larger (3) the use of three aerial photogrammetric replicates for each of the two years.

The methodology, that has been tested through statistical analyses by using the comparison of different DTMs derived from two sets of aerial photos, respectively taken in the years 1981 and 1998 of hilly area of 9.5 ha, with soils derived from Pliocene marine deposits, cultivated with cereal and fodder, at Vicarello (Volterra, Tuscany).

To further determine the precision of the methodology, was performed a differential photorestitution and a celerimetric survey of a piece of land at San Gimignano (in the province of Pisa).

Using the aerial photos, taken in 1981(picture scale 1:6,000), were produced three DTM replicates. Three other DTM replicates were made with the aerial photos (at the same scale) taken in the year 2001.

The land was levelled for vineyard plantation a few months before the second aerial survey. Contemporarily to the latter flight was performed a high-precision topographic survey.

Instead of tracking level curves, photogrammetry elevations were determined on the same grid points used for the topographic survey.

The precision of the new celerimetric-photogrammetric methodology was evaluated by comparing statistically the subtractions' elevations obtained in the grid nodes' position with the ones obtained by using the photogrammetric DTMs of the years 2001 and 1981.

3 Results

3.1 Differential photogrammetric analysis

The results of the comparison of the photogrammetric DTMs, for the Vicarello area, are reported in Bazzoffi *et al*. (2001). In this paper we only report the principal results obtained to help the comprehension of the further improvement of the methodology achieved through the combination of celerimetric to photogrammetric survey.

All the possible differential DTMs' analyses made possible by the three replicates of photogrammetric restitution concerning the years 1981 an 1998, showed a precision of 6.7 cm (absolute value) with confidence limits ($p \leqslant 0.05$) of ± 7.8 cm. These confidence limits represent the uncertainty associated to the mean elevation of a single replicate of DTM due to the photo interpreter's limit of precision. Thus, when is only used one replicate per year, the precision of the difference of DTMs becomes ± 15.6 cm ($p \leqslant 0.05$). In fact, using two DTMs the confidence limits must be doubled, due to error propagation.

Statistical analysis applied to the replicated values of differences made also possible to define, with high level of confidence ($p \leqslant 0.05$), that about 65% of the DTM's nodes were subjected to an increase or a decrease of the elevation, during the period 1981 to 1998. Thus, the use of photogrammetric replicates enabled the cartographic representation of the zones where it is highly probable ($p \leqslant 0.05$) that has occurred a morphologic change in the study period.

All the precision limits determined by statistical analysis applied to DTMs' replicates concern the uncertainty associated to the photo interpreter's limit of precision.

To improve the analysis of tillage translocation, at least the DTM of the last year should by determined through celerimetric survey.

To determine the increase of accuracy that can be obtained in this way, we elaborated the data obtained from differential photogrammetric and celerimetric analysis.

3.2 Differential photogrammetric and celerimetric analysis

The results of the analysis of differential photogrammetric and celerimetric analysis of Pietrafitta area are shown in Table 1 and Fig. 2.

Table 1 Differences between time-series DTMs (46218 grid nodes)

Contrast Id.	DTM Differences	Means m	Confid. ±95% m	Min. m	Max. m	Asimm.	Curtosis
C01-PH01	Celerim. 2001-Photogram. 2001	0.17	0.01	0.00	0.62	0.48	– 0.68
C01-PH81	Celerim. 2001-Photogram. 1981	0.20	0.01	–5.71	3.60	–0.96	1.22
PH01-PH81	Photogram.2001-Photogram. 1981	0.05	0.01	–5.71	3.51	–0.86	0.98

Volume balances

Celerim. DTM. 2001 minus Photogram. DTM 1981 = + 9 291.62 m^3
Photogram. DTM 2001 minus Photogram. DTM 1981 = + 2 331.43 m^3

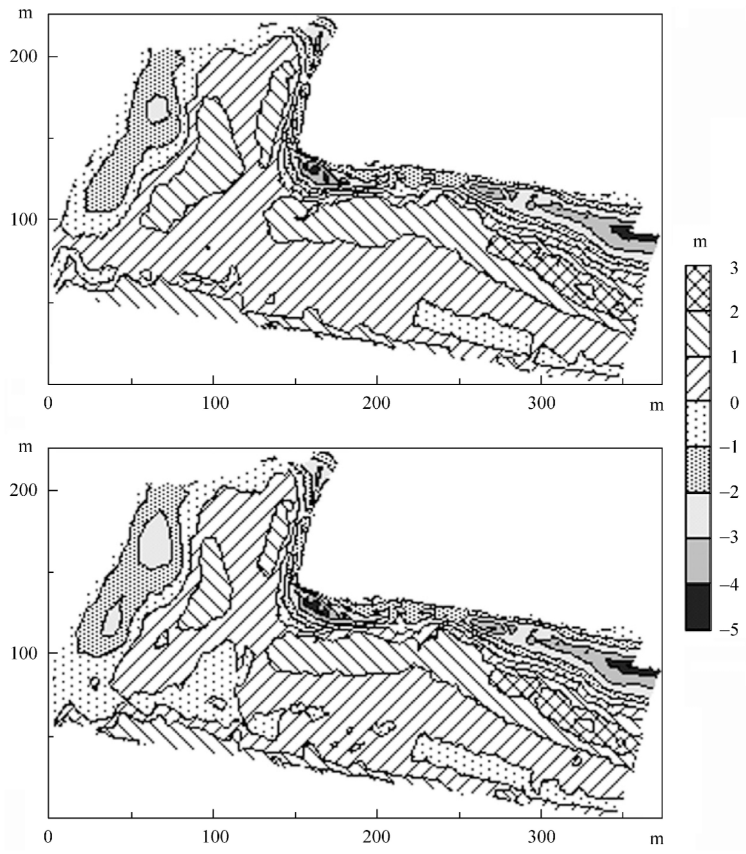

Fig.2 Pietrafitta area A: differences between Photogrammetric DTMs (2001 minus 1981)
B: differences between Celerimetric and Photogrammetric DTMs (2001 minus 1981)

It is possible to notice that the average difference of elevation between celerimetric and photogrammetric DTMs of the same year 2001 is 17 cm. According to Fryer *et al*. (1994) this value is below the photogrammetric precision limits of 24 cm — 36 cm, for this scale of aerial pictures.

The frequency distribution of differences shows a very low coefficient of symmetry, with kurtosis values within the ± 2 limits. Thus, systematic errors in measures did not occur.

Table 1 also shows a difference of 15 cm between the two average values of elevation deriving from subtractions of DTMs C01-PH81 and PH01-PH81.

In the experimental condition of this study it was possible to define the degree of reliability that DTM nodes were subjected to an increase or a decrease of the elevation, in the investigated period. This result has been achieved through the comparison, for each DTM's node, of the signs (plus or minus) of the differences C01-PH81 and PH01-PH81. The number of concordant differences' signs was 91.3% over 46,218 DTM's nodes.

This findings show that tillage translocation can be visually evidentiated also with the only use of photogrammetry (Fig.2). On the contrary, to measure the earth volumes removed or accumulated and the local variation of elevation the mixed photogrammetric-celerimetric analysis is more effective.

4 Conclusions

From the findings of this study we can conclude that the celerimetric survey can visibly increase the accuracy of tillage translocation measurements at field scale.

In this type of territorial analyses, it is hardly possible to find an existing celerimetric survey of the previous landscape situation. For this reason, to keep to the lowest possible level the uncertainty of DTMs' differences, it is important to use a celerimetric survey in place of the photogrammetric one to describe the most recent landscape situation.

From Fig.2 and table 1 it is possible to conclude that aerial photogrammetry alone, although less precise than celerimetric survey, is sufficient to describe the earth movement occurred in the studied area. For this reason, when the movements of the earth are supposed to be large, the photogrammetric comparison may be sufficient.

The earth volume balance of 9,291.62 m^3 (measured through the difference of C01-PH81 DTMs) has demonstrated that, in the studied area, the landscape has been greatly modified very much by land levelling.

The volume balance is positive because the earth incoherent material, accumulated with bulldozer, has a bulk density lower than the one of soil before excavation.

The proposed methodology can be considered suitable to measure the indicator of soil tillage translocation at field and regional scale.

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