1989

Determining crop residue cover with electronic image analysis

Elbert C. Dickey
University of Nebraska at Lincoln, edickey1@unl.edu

David P. Shelton
University of Nebraska-Lincoln, dshelton2@unl.edu

G.E. Meyer
University of Nebraska-Lincoln, gmeyer1@unl.edu

K.T. Fairbanks
University of Nebraska-Lincoln

PROCEEDINGS OF THE ELEVENTH INTERNATIONAL CONGRESS ON AGRICULTURAL ENGINEERING / DUBLIN / 4-8 SEPTEMBER 1989

Agricultural Engineering

Edited by
VINCENT A.DODD & PATRICK M.GRACE
Agricultural and Food Engineering Department, University College Dublin

OFFPRINT

A.A.BALKEMA / ROTTERDAM / BROOKFIELD / 1989

Land and Water Use, Dodd & Grace (eds), © 1989 Balkema, Rotterdam. ISBN 90 6191 980 0

Determining crop residue cover with electronic image analysis

E.C.Dickey, D.P.Shelton, G.E.Meyer & K.T.Fairbanks
University of Nebraska, Nebr., USA

ABSTRACT: Crop residue management is one of the best and most efficient soil conservation methods available to farmers. Determinations of the percentage of the soil surface covered with crop residue are often needed for: soil conservation research; erosion control demonstrations; and maintaining compliance with federal, state, or local soil conservation regulations. A number of methods can be used to estimate residue cover, however, many have limitations. To help overcome some of these limitations, a technique, which uses readily-available microcomputer-related hardware and standard video camera equipment has been developed to estimate crop residue cover from photographic slides. This procedure is relatively rapid, provides consistent results, eliminates the tedious nature of the standard photographic grid determination method, and has given excellent correlation with this standard technique.

RÉSUMÉ: La gestion des résidus de récolte est une des méthodes de conservation des sols les meilleures et les plus efficaces dont disposent les agriculteurs. Il est souvent nécessaire de déterminer le pourcentage de la surface du sol couverte par des résidus de récolte pour les recherches sur la conservation des sols, pour les indices du contrôle de l'érosion, et pour conserver la conformité avec les règlements fédéraus, régionaux, et locaus, concernant la conservation des sols. Il existe un certain nombre de méthodes pouvant être utilisé pour estimer l'étendue couverte de résidu. Pourtant, beaucoup ont des limites. Pour aider à remedier à certaines de ces limites, on a mis au point une nouvelle technique faisant appel à des materiels micro-informatiques facilement disponibles et à un équipement de caméra-vidéo standard pour estimer les pourcentages du sol couvert par des résidus de récolte à partir de diapositives photographiques. Cette procédure est relativement rapide et fournit des résultats fiables; elle élimine en outre le côté fastidieux de la méthode de détermination par quadrillage photographique standard, et donne d'excellentes corrélations avec cette dernière.

ABSTRAKT: Die Verwertung von Ernteresten ist eine der besten und leistungsfähigsten Methoden, die der Landwirtschaft zur Erdreichkonservierung zur Verfügung stehen. Festsetzung des Prozentsatzes des mit Ernteresten zu bedeckenden Bodens werden oft benötigt für: Forschung in der Erdreichkonservierung; Demonstrationen zur Kontrolle der Bodenerosion; Einhaltung gesetzlicher Vorschriften zur Erdreichkonservierung. Es existieren verschiedene Methoden zur Abschätzung der Bedeckung des Bodens mit Ernteresten, jedoch haben viele von ihnen Nachteile. Um diese Nachteile zu beseitigen ist eine Methode entwickelt worden, die jederzeit erhältliche Microcomputer-hardware und eine alltägliche Videokamera Ausstattung verwendet, um die nötigen Erntereste durch Betrachtung von photographischen Dias abschätzen zu können. Dieses Verfahren läßt sich relativ schnell anwenden, ergibt konsequente Resultate, eliminiert die Langwierigkeit der üblichen photographischen Gittermethode und steht in guter Verbindung mit dieser Methode.

1 INTRODUCTION

Tillage and planting systems which leave a protective cover of crop residue on the soil surface have been shown to reduce soil losses, and are among the least costly erosion control practices available to farmers (Nicol et al., 1974; Seay, 1970). Residues protect the soil from raindrop impact, thus limiting the amount of soil particle detachment. The series of intricate dams and basins formed by the residue also slows the rate at which water runoff occurs which, in turn, reduces the sediment transport capability of the flowing water, and further limits soil erosion. Leaving as little as 20% of the soil surface covered with corn or soybean residue reduced erosion by 50% of that which occurred from a cleanly tilled, residue free surface (Dickey et al., 1984; 1985). Further, these researchers and others (Shelton et al., 1986) have determined that soil erosion from a rainfall event is inversely related to the percent residue cover on the soil surface.

"Conservation tillage" includes all tillage and planting systems which leave at least 30% of the soil surface covered with crop residue after planting (CTIC, 1986). This definition has also been adopted by the United States Department of Agriculture Soil Conservation Service. Conservation tillage will be an important component of many Conservation Plans which are developed to comply with the conservation provisions of the United States 1985 Food Security Act (Farm Bill). Thus, residue cover measurements can be useful in planning tillage and planting operations to maintain soil erosion control. Residue cover estimates are also often required for research purposes and during extension demonstrations of conservation tillage equipment and/or soil erosion control demonstrations. Further, measurements of residue cover may be required to determine whether adequate residue remains to be in compliance with other federal, state, or local conservation programs.

1.1 Residue cover estimation methods

A number of different methods are presently used to estimate residue cover. Each method, however, has distinct advantages and limitations. The most common methods include:

1. Direct Observation Method: This estimation method is perhaps the simplest, but one of the least accurate. Residue cover is determined merely by observing field conditions. While quick and easy, this method is highly subjective, based on the observer's experience, etc. Dickey et al. (1989) found that farmers tend to estimate the percent cover by more than twice the actual amount when using this method.

2. Calculation Method: This method relies entirely on out-of-field averages or estimates to determine percent cover. Residue cover remaining for a given tillage and planting system is estimated by multiplying the amount of cover originally present by estimates of the percent residue remaining after each subsequent field operation in the selected tillage and planting system (USDA/SCS, 1985; Dickey et al., 1986).

3. Photo Comparison Method: Residue cover is estimated by comparing actual field conditions to photographs of known percent covers for the crop being evaluated (USDA/SCS, 1985; Dickey et al., 1986). This method provides a quick in-field estimate, but is also subject to interpretations of the observer.

4. Line-Transect Method: The line-transect method provides a relatively easy and reliable estimation, although Pierson et al. (1988) reported significant differences in measurements, particularly among inexperienced observers. This method uses a standard measuring tape stretched diagonally across the crop rows (USDA/SCS, 1985; Dickey et al., 1986), and is the primary method used by the Soil Conservation Service to determine percent residue cover. Variations of the line-transect method include the meterstick method (Hartwig and Laflen, 1978) and point frequency frames (Mueller-Dombois and Ellenberg, 1974; Biere et al., 1984; Yonts et al., 1987).

5. Photographic Grid Method: The photographic grid method described by Laflen et al. (1981), or a variation thereof, is perhaps the most widely utilized technique employed by researchers to determine percent residue cover. This procedure involves photographing a small area of the field using 35-mm slides, projecting the image on a screen having approximately 100 grid points, and counting the number of grid points "covered" by a piece of residue. Percent cover is determined by

dividing the number of covered grid points by the total number of grid points. Often considered to be the standard, this method is quite accurate, but is tedious, time-consuming, and relatively expensive, particularly if many determinations are to be made. Further, even with experienced observers, variation among observers has been documented (Meyer et al., 1988; Stone et al., 1988).

All of these methods to estimate residue cover involve some degree of subjectivity on the part of the human observer. It is likely that a color difference is the predominate factor in the decision process to distinguish between soil and residue, with patterns and/or textural differences reinforcing the decision.

1.2 Computer imagery

One needs only to take a brief look at a professional journal or a technical meeting program to realize that applications of computer imagery or vision have increased dramatically in recent years. This is primarily due to the development of relatively low-cost imaging systems compatible with personal computers, and the availability of inexpensive video cameras.

The primary consideration of computer imagery is to simulate human vision such that a computer can replace, interpret, and speed up visual data gathering activities. This can be done in black and white or in color, depending on the camera and computer hardware. Pattern recognition, alone or in concert with color or color intensity, can also be used in a computer vision system.

An easily used computer imagery system could have many potential applications in agricultural research and extension programs. One such application is the determination of the percent of the soil surface covered with crop residue.

The work described in this paper grew out of a three-year research project to determine corn and soybean residue cover at multiple times from harvest through the completion of various tillage and planting operations. In excess of 25,000 photographic slides have been taken to document residue cover. Each photographic slide covered an area of the field approximately 0.76 m by 1.20 m. Slides were taken using a tripod-mounted 35-mm camera equipped with a 28-mm focal length lens, approximately 1 m above the soil surface. The photographed area was shaded from direct sunlight. For approximately one-half of the slides, an electronic flash was used to help provide consistent lighting for either cloudy or sunny days. Kodachrome 64 film was used (Burr, 1986). One objective of this project was to investigate the feasibility of using computer imagery to interpret the photographic slides

2 IMAGERY SYSTEMS USED

Two different computer and camera systems have been evaluated, while a third system serves as the main data processing system. Table 1 lists the various components of the three systems.

Table 1. Listing of system hardware.[1]

<u>System 1</u>

Computer: IBM-XT; 640 Kb RAM; 8088 CPU; dual 360 Kb floppy disk drives; 10 Mb hard disk; monochrome monitor
Video capture board: Chorus PC-EYE Image Capture Board and Tecmar Graphics Master board
Video camera: Pulnix TM-540

<u>System 2</u>

Computer: IBM-PC; 640 Kb RAM; 8088 CPU; dual 360 Kb floppy disk drives; 20 Mb Hardcard; monochrome monitor
Auxiliary monitor: Sony KV1311CR
Video capture board: AT&T Truevision Image Capture Board
Video camera: Sony DXC-1800 SMF Trinicon

<u>System 3</u>

Computer: Compaq Deskpro 286; 640 Kb RAM; 2 Mb expanded RAM; 80286 CPU with 80287 co-processor; dual 1.2 Mb floppy disk drives; 40 Mb hard disk; color monitor
Auxiliary monitor: NEC Multisync JC-1401P3A
Video capture board: AT&T Truevision TARGA 16
Video camera: Panasonic AG-160

[1] Mention of product names is for descriptive purposes only. Endorsement is not implied.

From the large photographic slide database previously described, four subsets of 15 to 25 slides each were selected. These represented soybean and corn residue each with wet and dry appearing soil surface conditions. Percent residue cover represented by each of these slides was first determined using the photographic grid technique with a total of 130 grid points.

To evaluate the imagery systems, these photographic slides were then projected, using a standard slide projector, onto a projection screen, and the video camera was focused on this screen. This slide to computer transfer process was conducted in a darkened room.

2.1 Image classification logic

The image classification problem of determining residue cover involved sorting and summing the pixels in each image frame according to a set of decision rules developed using an individual pixel-by-pixel analysis and an on-screen visual inspection. To aid in the visual inspection, the selected pixels were assigned a false color on the auxiliary monitor as the classification proceeded.

Soil and residue were the two pixel categories for the black and white system (System 1). Contrast thresholds for the decision rules were set based on the grey or brightness levels determined in the pixel-by-pixel analysis.

Pixel categories for the two color systems included soil, residue, and green plants if present. Both the Image Capture Board used in System 2 and the Targa 16 board used in System 3 (Table 1) utilize 15 bits divided into three, 5-bit segments to describe the red, green, and blue color components of each pixel. Each of these three components can range in value, or intensity, from 0 to 31, as determined with the binary system using five places. For System 2, decision rules were based on these integer intensity values.

A single integer color value, using the binary system to 15 places, can also be determined from the intensity values of the three color components. Color values can range from 0 (black) to 32,767 (white). The blue component is comprised of the five least significant bits, thus it has the least impact, contributing from 1 to 31 to the color value. The green component, being comprised of the 6th to 10th bits, can contribute from 32 to 992 to the color value. The red component has the most impact on the color value, contributing from 1024 to 31,744. Integer color values, as well as the individual color component intensity values, were used to formulate the decision rules for System 3. No pattern recognition algorithms were used in either the black and white or color analyses.

2.2 Black and white imagery

Black and white imagery is based on the digital measurement of brightness levels of reflected light over the visible and near-infrared spectral regions, depending on camera sensitivity. It assumes that subjects being compared or contrasted have sufficiently different reflectance coefficients, and that the digitizing hardware and software can make this distinction. The main problem with black and white computer vision is that a highly sensitive image digitizer (6-bit analog-to-digital or better) will show all of the variations (bright and dim spots) inherent in the illumination or projection system, but not apparent to the naked eye. The digitized illumination data are thus interlaced with the subject data, making a computer classification system difficult to implement. To remove this noise, digital convolution methods, such as a low pass digital filter or optical filters attached to the lens of the camera are generally required.

System 1 (Table 1) was used to acquire crop residue cover information from the projected color slides. The video camera was equipped with a Kodak Infrared Filter 89B to provide a better soil/residue contrast by blocking out the visible spectra. Image data from the Chorus board was stored immediately in the video display RAM of the Graphics Master. The digitizer provided 256 grey or brightness levels (8-bit). However, only 16 grey levels could be displayed as false colors at the console. The 640 x 400 pixel display format corresponded to the equivalent of 166,400 intersection or grid points, since only 65 percent of the display was included in each frame analysis. Contrast thresholds for the 16 grey levels were set using the Chorus CALIBR routine (Release 2.2). The BLACK parameter set the analog-to-digital level below which video signals were digitized as "black". The WHITE parameter set the level above which video signals were digitized as "white". When, through trial and error, the appropriate BLACK and WHITE values were found, it was possible to reduce the image to only two false colors or brightness levels. The pixel counts for residue and soil were then easily obtained. However, higher spatial levels and sensitivity with the Tecmar configuration showed too much of the projection lighting system gradients, making it difficult to obtain a correlation better than $R^2 = 0.75$ for machine-read versus visually-determined (standard grid method) residue covers (Meyer et al., 1988).

Somewhat better results were obtained using the IBM 320 x 200 pixel format which automatically gave only two grey levels or false colors. A comparison of machine-read versus visually-determined residue covers for this format gave a correlation of $R^2 = 0.85$ (Meyer et al., 1988).

2.3 Color imagery

A color imaging system has an analog-to-digital converter for each of the three internationally accepted primary colors of red, green, and blue. It assumes that the items being compared have sufficiently different spectra of reflected light for the digitizing hardware and software to make the distinction.

System 2 (Table 1) was used to acquire crop residue cover information from the projected color slides. The older-model video camera used in this system had a number of contrast, color, and brightness control settings, as well as three built-in filters. A spectral analysis of the projection system was used to help adjust the camera. The built-in filter for "cloudy and rainy conditions" and manual actuation of the white balance switch, with the camera focused on a blank white screen under the projection lighting conditions, gave the best color rendition.

The monochrome monitor was used to display numerical data and image processing commands, while the auxiliary monitor displayed the projected image. The Image Capture Board converted the analog video image into a 200-row by 256-column array, equivalent to approximately 33,280 grid points for each frame analyzed.

From a spectral analysis of the projected slides, it was found that the greatest "separation" of soil and residue occurred at a wavelength of approximately 650 nanometers, which is in the red band of the visible light spectrum. The spectral separation of the residue and soil components was also more pronounced when the soil surface appeared to be moist as contrasted to dry-appearing surface conditions (Meyer et al., 1988). Due to color differences, corn residue was also easier than soybean residue to distinquish from soil.

Comparisons of visually and machine determined covers resulted in a very high correlation of $R^2 = 0.95$, for wet-appearing soil surface conditions and soybean residue. There was no significant difference in variation between greater or lesser amounts of residue cover. Dry-appearing soil surface conditions created a slightly more difficult situation to analyze. In most cases, the frame was divided into smaller windows and the classification rules were modified to obtain better machine readings. While this required a little more work, the results also showed a good correlation ($R^2 = 0.92$). The system worked equally well or better for corn residue as for soybean residue (Meyer et al., 1988).

System 2 was also used for direct video tape to computer transfer, with a standard VHS-format video cassette recorder replacing the video camera. Color intensities of corn and soybean residues were approximately 20 percent greater than with the photographic slide to video camera to computer transfer process (Meyer et al., 1988). For certain applications, such as those requiring rapid analysis, video tape may be preferable to 35-mm slides. However, comparison to a standard such as the photographic grid technique is much more difficult with video tape. Further, current video cassette recorders generally have a much lower spatial resolution than photographic slides.

System 3 (Table 1) is being used as the main data processing system. An interactive program has been written to help formulate the decision rules or to "train" the system. Five or more slides are selected at random from each group of photographic slides that were taken under similar conditions. Using an individual pixel-by-pixel selection process, a minimum of 20 pixels each representing soil, residue, or green plants (if present) are chosen. The range of integer color values for each pixel type are determined. These values are then used to establish decision rules for that particular group of slides. For example, corn residue shown in a typical set of slides might have integer color values ranging from 11,625 to 32,763 while the soil component may range from 4294 to 14,800. In this case, pixels with color values falling between 13,213 and 32,766 would be classified as residue, while those between 0 and 13,212 would be classified as soil. The number of pixels classified as residue divided by the total pixels within the frame gives the percent residue cover. This value is then stored in a data file along with the code number for the individual slide.

The preceeding simplified example illustrates some of the problems in formulating decision rules. Even though the lowest color for a pixel representing soil was 4294, it was assumed that any pixels with a lower value (which would be approaching black) would also be soil. Thus, a color value of 0 was chosen as the lower limit. Similarly, the upper limit color value of corn residue is set at 32,766. This is done to allow white (color value = 32,767) to be used as a "mask" for areas of the frame not to be analyzed, if so desired.

Overlapping color values, between 11,625 and 14,800 in this example, create the most problems in formulating decision rules. In this case, the division was made at the midpoint of the overlap range, with color values of 13,213 or greater assigned as residue, and color values less than this assigned as soil. However, for certain groups of slides, other divisions of this range may be more appropriate. If the majority of the overlapping values were determined to have been from pixels designated as soil, the decision rules would be adjusted so that larger color values would be classified as soil.

It is also possible to formulate additional decision rules based on the intensity values of the red, green, and/or blue components, as these values generally tend to be 14 or less for soil, and 15 or greater for residue. More work remains to be done in perfecting the process of formulating decision rules. However, the number of pixels with overlapping color values is generally relatively small.

3 SUMMARY AND CONCLUSIONS

A procedure which uses readily-available microcomputer-related hardware and standard slide projection and video equipment has been developed to estimate percent crop residue cover from 35-mm photographic slides. This technique is relatively rapid, eliminates the tedious nature of the standard photographic grid determination method, and has given excellent correlation with this standard method.

Classification of residue cover using computer imagery provides considerably more analysis points than the standard grid technique, and eliminates many of the subjective decisions of a human observer. Thus, it should be a more accurate and consistent system.

Color imagery worked better than black and white in all cases for determining percent residue cover from photographic slides. Variations within the projection lighting system are a particular problem with black and white systems. The red band of the visible light spectrum provided the greatest separation of light intensity between soil and residue for the color system, while the near-infrared band provided the greatest separation for black and white. Color systems may require careful tuning of the video camera to obtain faithful color renditions.

For certain applications, direct video tape input may be the preferable alternative. However, much data is presently contained on 35-mm slides, which have a much greater resolution than current video systems.

For each set of different residue and/or lighting conditions, pixel contents of sample frames first need to be carefully analyzed. The pixel classification and decision rules can then be adjusted accordingly, thus fine-tuning the system.

4 ACKNOWLEDGEMENTS

This work was part of a research project partially funded by the Nebraska Soybean Development, Utilization, and Marketing Board. Special thanks are given to former student programmers Anthony Stepanek and John Van Brocklin, video technician Bruce Sandhorst, and Charles Burr, Missouri Cooperative Extension Service, St. Joseph, MO, for their assistance on the project.

REFERENCES

Biere, D.A., C.D. Yonts, and J.A. Smith. 1984. Distribution of surface residue in reduced tillage systems. ASAE Paper No. 84-2555. Am. Soc. of Ag. Eng. St. Joseph, MI.

Burr, C.A. 1986. Tillage influences on soybean residue reduction. Unpublished M.S. Thesis, Univ. of Nebraska. Lincoln, NE.

Conservation Tillage Information Center (CTIC). 1986. 1985 National survey-conservation tillage practices. Fort Wayne, IN.

Dickey, E.C., P.J. Jasa, and D.P. Shelton. 1986. Estimating residue cover. Cooperative Extension Service, Univ. of Nebraska. NebGuide G86-793.

Dickey, E.C., D.P. Shelton, P.J. Jasa, and T.R. Peterson. 1984. Tillage, residue and erosion on moderately sloping soils. TRANSACTIONS of the ASAE 27(4): 1093-1099.

Dickey, E.C., D.P. Shelton, P.J. Jasa, and T.R. Peterson. 1985. Soil erosion from tillage systems used in soybean and corn residues. TRANSACTIONS of the ASAE 28(4): 1124-1129, 1140.

Dickey, E.C., G.A. Wicks, D.E. Eisenhauer, and L.E. Lucas. 1989. Agricultural energy conservation project: impacts of a five-year educational program. Final Report to the Nebraska State Energy Office. Univ. of Nebraska. Lincoln, NE.

Laflen, J.M., M. Amemiya, and E.A. Hintz. 1981. Measuring crop residue cover. J. of Soil and Water Conservation. 36(6): 341-343.

Meyer, G.E., A. Stepanek, D. P. Shelton, and E.C. Dickey. 1988. Electronic image analysis of residue cover for erosion control on soil. TRANSACTIONS of the ASAE 31(3): 968-973.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc. (6): 80-92.

Nicol, K.H., E.O. Heady and H.L. Madsen. 1974. Models of soil loss, land and water use, spatial agricultural structure and the environment. Center for Agr. and Rural Develop., CARD Rpt. 49T. Iowa State Univ., Ames, IA.

Pierson, B.J., C.E. Lewis, and C.A. Birklid. 1988. Observer differences in determining crop residue cover in the Alaskan subarctic. J. of Soil and Water Conservation 43(6):493-495.

Seay, E.E. 1970. Minimizing abatement costs of water pollutants from agriculture. A parametric linear programming approach. Ph.D. Thesis, Iowa State Univ., Ames, IA.

Shelton, D.P., P.J. Jasa, and E.C. Dickey. 1986. Soil erosion from tillage and planting systems used in soybean residue: part I - influences of row spacing. TRANSACTIONS of the ASAE 29(3): 756-760.

Stone, D.A., B. Lancashire, R.A. Sutherland, K.B. Niendorf, and R.B. Sampson. 1988. A low cost microcomputer-based image analysis system for the measurement of percentage ground cover. Research and Development in Agriculture 5(2): 65-70.

USDA/SCS. 1985. Estimating crop residue - using residue to help control wind and water erosion. United States Department of Agriculture. Soil Conservation Service. NE Leaflet No. 3. Lincoln, NE.

Yonts, C.D., J.A. Smith, J.E. Bailie, and M.D. Rath. 1987. Frequency distribution and percent cover for corn, sugarbeet, and dry edible bean residue. ASAE Paper No. 87-2511. Am. Soc. of Ag. Eng. St. Joseph, MI.

New & recent publications

Vincent A.Dodd & Patrick Grace (eds.) 90 6191 980 0
Agricultural engineering – *Proceedings of the 11th international congress, Dublin, 4–8 September 1989*
1989, 25 cm, 3000 pp., 4 vols, Hfl.385 / $170.00 / £118.50
A broad coverage of basic & applied research projects dealing with the application of engineering principles to both food production & processing. *Land and water use.* Use of peatland; Traffic & transportation systems; Environmental aspects of soil water; Soil/water engineering. *Agricultural buildings.* Modern & future design of buildings for animal production; Design considerations of agricultural buildings; Environmental control in animal housing. *Agricultural mechanisation.* Soil cultivation & seed-bed preparation; Harvesting & handling of agricultural products; Application of plant nutrients & pesticides. *Power & processing.* Energy operated processes in agriculture; Processing agricultural products for industrial purposes; Tractors & their fuels. *Management & ergonomics.* Management & decision making systems; Ergonomic standards in agriculture; New systems of reaching, research & development in agriculture. About 450 papers from over 50 countries worldwide. Editors: University College, Dublin.

Alekseeva, T.V., K.A.Artem'ev, A.A.Bromberg, R.I.Voitsekhovskii & N.A.Ul'yanov 90 6191 447 7
Machines for earthmoving work: Theory and calculations
(3rd edn.) (M.M.Sivaramakrishnan, transl.)
(Russian translations series, 30) (No rights India)
1985, 24 cm, 529 pp., Hfl.175 / $85.00 / £54
Theory & design of highway construction machines such as bulldozers, scrapers, motor graders, high-performance continuous operation machines & soil compactors.

Khachatryan, Kh.A. (ed.) (K.S.Dhillon, transl.) 90 6191 545 8
Operation of soil-working implements in hilly regions
(Russian translations series, 37) (No rights India)
1985, 24 cm, 239 pp., Hfl.125 / $65.00 / £38.50
Equilibrium of soil-working implements working on slopes; Soil deformation by implements working on slopes; Tractive resistance of soil-working implements; Bibliography.

Nartov, P.S. (ed.) 90 6191 443 4
Disk soil-working implements
(M.M.Sivaramakrishnan, transl.)
(Russian translations series, 27) (No rights India)
1985, 24 cm, 156 pp., Hfl.125 / $65.00 / £38.50
Design of plows for continuous & furrow plowing, stubble-breakers, cultivators, harrows, rippers & cover strippers. Recommendations for optimum parameters of working parts of disks meant for different purposes.

Rudnev, V.K. (M.M.Sivaramakrishnan, transl.) 90 6191 450 7
Digging of soils by earthmovers with powered parts
(Russian translations series, 32) (No rights India)
1985, 24 cm, 144 pp., Hfl.95 / $45.00 / £29
Design features & operation of earthmovers. Problems in planning & conducting investigation of digging processes.

Gyachev, L.V. (ed.) (C.B.Malvadkar, transl.) 90 6191 459 0
Theory of surfaces of plow bottoms
(Russian translations series, 38) (No rights India)
1986, 24 cm, 310 pp., Hfl.135 / $70.00 / £41.50
Mechanics of motion of slice; Spherical representation of surfaces of plow bottoms; Design of surfaces; etc.

Wijk, A.L.M.van & J.Wesseling 90 6191 639 9
Agricultural water management
1986, 25 cm, 335 pp., Hfl.95 / $45.00 / £29
Drainage & reclamation of soils with low permeability; Effects of drainage and/or irrigation on agriculture; Installation & maintenance of drainage systems; Regional & local water management systems; Effect of agriculture on its environment.

Ageikin, Ia.S. (A.Jaganmohan, transl.) 90 6191 931 2
Off-the-road wheeled and combined traction devices – *Theory and calculation*
(Russian translations series, 59) (No rights India)
1988, 24 cm, 219 pp., Hfl.125 / $65.00 / £38.50
Mechanical properties of soil and snow-covered surfaces for vehicular transport; Wheel-soil interaction; Effect of wheel parameters on performance; Analysis of multiwheeled and combined traction vehicles; Determination of the principal parameters of off-the-road vehicles.

Ageikin, Ia.S. (V.S.Kothekar, transl.) 90 6191 495 7
Off-the-road mobility of automobiles
(Russian translations series, 56) (No rights India)
1987, 24 cm, 245 pp., Hfl.125 / $65.00 / £38.50
Nature of surfaces; Interaction of wheel with soil; Movement on soft soil & uneven surfaces; Analytical & experimental methods of evaluating mobility; Structural elements & accesoires; Calculation of basic structural parameters; References.

Severnev, M.M. (ed.) (S.K.Kaila, transl.) 90 6191 454 X
Wear of agricultural machine parts
(Russian translations series, 36) (No rights India)
1985, 24 cm, 271 pp., Hfl.125 / $65.00 / £38.50
Results of theoretical as well as experimental investigations on the wear & corrosion. Problems concerning wear resistance & corrosion resistance of materials, & the pattern of wear of agricultural machine parts are examined in detail.

Klenin, N.I., I.F.Popov & V.A.Sakun (eds.) 90 6191 448 5
Agricultural machines – *Theory of operation, computation of controlling parameters and the conditions of operation*
(A.Jaganmohan, transl.) (Russian translations series, 31)
1985, 24 cm, 650 pp., Hfl.175 / $85.00 / £54 (No rights India)
A textbook describing the various working parts. Soil-working machines & equipment; Seeders, planters & machines for fertilizer application; Plant protection equipment; Components of harvesting machines; References.

Bocharov, A.P. (ed.) 90 6191 426 4
A description of devices used in the study of wind erosion of soils (S.C.Dhamija, transl.) (Russian translations series, 14)
1984, 24 cm, 98 pp., Hfl.95 / $45.00 / £29 (No rights India)
Instruments used to measure soil surface parameters; Equipment & instruments used to determine the physical state of soil; Methods & instruments used to measure the extent of erosion; Instruments to measure wind speed & turbulence; Instruments to tap solid particles from airflow; Wind tunnels; References.

Zelenin, A.N., V.I.Balovnev & I.P.Kerov (eds.) 90 6191 451 5
Machines for moving the earth – *Fundamentals of the theory of soil loosening, modeling of working processes and forecasting machine parameters* (C.B.Malvadkar, transl.)
(Russian translations series, 33) (No rights India)
1986, 24 cm, 566 pp., Hfl.175 / $85.00 / £54
Interaction of soil working tools of machines; Cutting unfrozen soils; Mechanical loosening frozen soils; Analytical theory.

All books available from your bookseller or directly from the publisher:
A.A.Balkema Publishers, P.O.Box 1675, Rotterdam, Netherlands
For USA & Canada: A.A.Balkema Publishers, Old Post Rd, Brookfield, VT, USA