ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 4 [November]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.]İlker ÜNAL, [2.]Mehmet TOPAKCI, [2.]Murad ÇANAKCI,
[2.]Davut KARAYEL, [1.]Önder KABAŞ

REAL TIME STUBBLE COVER RATIO DETERMINATION BY USING AN AUTONOMOUS ROBOT

[1.] Technical Science Vocational School, Akdeniz University, Antalya, TURKEY
[2.] Agricultural Machinery & Technologies Engineering, Faculty of Agriculture, Akdeniz University, Antalya,TURKEY

Abstract: Stubble cover is one of the most important field parameters to protect the soils. Also, it is a decisive criterion for conventional, no-till and reduced tillage systems. In this study, the stubble cover ratio on the field under three different tillage systems was determined and mapped using the online image processing method. The developed system includes the GPS guided autonomous robot, digital camera, and the image processing software. To determine the stubble cover ratio, binary images which were converted from colored stubble images were evaluated by developed software. Also, line transect method was used to make comparison with image processing algorithm. As a result, average stubble cover ratios were calculated as 5.42%, 35.68% and 89.55% respectively for three tillage systems after image processing method. There were no statistical difference between the image processing and line transects method for stubble cover ratios of each tillage systems (P>0.05).
Keywords: stubble cover; tillage systems; image processing; autonomous robot

1. INTRODUCTION

Stubble, traditionally considered as “trash” or agricultural waste, is increasingly being viewed as a valuable resource. Corn stalks, corn cobs, wheat straw, paddy straw and other leftovers from grain production are now being viewed as a resource with economic value (Bahadur, 2015). Stubble is one of the most important tillage factors for improving soil’s physical and chemical properties (Busari, 2015). Stubble helps reduce surface runoff and soil loss (Dickey et al., 1985), conserving soil moisture and improving soil microorganism populations (Peigne et al., 2007), soil organic matter content (Brady & Weil, 2002), and soil hydraulic/physical properties (Agostini, 2012). The effectiveness of stubble is linked to the soil topography and soil slope (Bricchi, 2004), as well as other factors that affect the sustainability of the stubble on the soil surface. Relatively flat fields can be protected against water erosion with 12 to 20 percent stubble cover (Dickey et al., 1985).

Tillage has been an integral component of crop production systems since the beginning of agriculture. The process of tilling or preparing the soil was greatly refined with the invention of the first plow by the Chinese in the sixth century B.C., and since then, various types of tillage equipment and systems have been developed for seedbed preparation and cultivation (Mitchell et al., 2009). Tillage is normally classified as primary or secondary tillage. Primary tillage is deep tillage (> 15 cm) that loosens and fractures soil for weed control and incorporation of stubble, fertilizer, lime, and manure. Secondary tillage (< 15 cm) kills weeds, cuts and covers stubble, incorporates herbicides, and prepares a seedbed. In-crop tillage for weed control or injecting fertilizer or manure it is considered tertiary tillage. Also, tillage systems included under stubble management are no-till, ridge-till, mulch-till, and reduced-till. In this study, the stubble cover ratio on the field under conventional, no-till and reduced tillage systems was determined. Conventional tillage is a multiple tillage pass system that disturbs 100% of the soil surface (full width), including moldboard plowing, that leaves less than 15% stubble on the soil surface after planting. Reduced tillage is a full width tillage system that leaves 15 to 30% stubble cover after one to three tillage passes. No-till is a system with a minimal amount of soil disturbance (> 70% stubble cover) with a row cleaner, coulter, seed opener, or another planter attachment to help establish a good crop stand.

The evaluation of the stubble covering rate and its spatial distribution are important to the scientists who are involved in erosion modelling and surface water flow and to authorities aiming to adopt new legal regulations regarding stubble conservation on arable lands (Arsenault & Bonn, 2005). Several procedures for determining and mapping stubbles exist in the literature, namely visual estimation (McNairn & Protz, 1993), line transect (Morrison et al., 1993), point intercept (Daughtry et al.,1995), meter stick (Hartwig & Laflen, 1978), spiked wheel (Morrison et al., 1995), photographic techniques (Morrison & Chichester, 1991), spectral detection (McMurtrey et al., 2005) and the remote sensing (Bannari et al., 2006). In fact, methods employed to date can be grouped in traditional manual-visual methods and image analysis methods. Ideal method to estimate percent ground cover of stubble mainly includes following procedures: 1. Cheap and easily manipulated equipment should be adopted. 2. The in-situ data should be accurately and objectively treated. 3. The method should save time mostly and be restricted the least when measuring in field. 4. The process should be scarcely disrupted by the operator. The method to take pictures of stubble by digital camera, divides the image to soil and residuals two classes, and calculates percent ground cover of stubble in two-value image arithmetic could be a good choice among other methods. (Zhou & Robson, 2001). Several image processing methods in the literature have been described to estimate stubble cover ratio.

Riberio et al. (2011) proposed the application of genetic algorithms employed during the fine tuning of the segmentation process of a digital image with the aim of automatically quantifying the stubble coverage. The RGB images were used come from a sample of images in which sections of terrain were photographed with a conventional camera positioned in zenith orientation at top of a tripod. The images were taken outdoors under uncontrolled lighting conditions. Researchers reported that up to 92% similarity was achieved between the images obtained by the segmentation process proposed in their paper and the templates made by an elaborate manual tracing process.

Pforte & Hansel (2010) developed the prototype of an online-capable camera sensor for measuring percent stubble cover, appropriate image acquisition equipment and exposure conditions were investigated and different image processing algorithms for segmenting images into stubble and soil were written with the help of commercial software. In study, the camera was mounted onto an all-terrain vehicle (ATV) and the stubble cover of three test fields was analyzed. A large number of observations were obtained using an online camera sensor, and was made evaluation of its correct functioning by means of visual standard methods for estimating stubble cover questionable. Researchers reported that the Pearson correlation between the two measurement approaches was 0.967 for the cover rate observations taken on the three fields.

Jimenez et al. (2013) developed a methodology for estimating the quality of soil coverage by pruning stubble by determining the soil cover percentage, distribution and size of the pruning stubble in olive orchards by image analysis using the threshold segmentation tool in RGB and the block analysis tool. Researchers reported that the percentage of soil coverage after chopping was 39% higher in the high quantity pruning stubble treatment (2.04 kg m^{-2}) but was not significantly influenced by the chopping speed (2.4 to 3.1 km h^{-1}).

2. MATERIAL AND METHOD

The objective of this study was to determine and map the stubble cover ratio of the fields under conventional, no-till and reduced tillage systems using the online image processing method.

Design of the system

The main aim of the designed system is to determine the real time stubble cover ratio and map it. The system involves three main components:

a. Autonomous robot: a remote-controlled and GPS-guided autonomous robot which can be controlled via the 3G internet and is suitable for image processing applications was used to take pictures of stubble.
b. Data acquisition system: the system is used to collect and process the data from a GPS receiver and the camera for determining stubble cover ratio and mapping operations.
c. Image processing algorithm: the system is used to convert to grayscale images and thereafter convert to binary images from colored stubble images. Finally, the stubble cover ratios were calculated by evaluating the binary images with this system.

Autonomous robot

Autonomous robot is able to steer point to point both autonomously and under manual control (Figure 1). It was developed in our previous study (Ünal & Topakci, 2015). The robot chassis was made of U-steel profile, and the body structure covered with sheet metal with a thickness of 2 mm. The robot was powered by two 24 V – 0.5 kW – 1440 rpm DC motors. Two reducers with 1:30 transmission rate were used to reduce rpm and increase torque. Four 4.00x8 agricultural rubber wheels were chosen to operate in open field conditions. A Roboteq AX3500 (Roboteq Inc., Arizona, USA) motor controller with two channel outputs was used to power and steer the robot by varying the speed and direction of the motors at each side of the chassis. The controller's two channels can be operated independently or combined to set the forward/reverse direction and steering of a robot by coordinating the motion on each side.

A Promark 500 GPS (Magellan Co., Santa Clara, CA, USA) receiver was used to navigate the robot. Two software based on client/server architecture were developed to control and monitor the mobile robot. The server software was run on the robot computer to collect GPS data to perform steering and to collect stubble images by the digital camera. The client software was run on the remote computer to manually control the robot and monitor the process data. In the server software, the image-processing algorithm was coded for determination of stubble cover. All functions of the digital camera could be controlled by both the server software and the client software. The stubble images obtained by the server software were recorded to the robot computer.

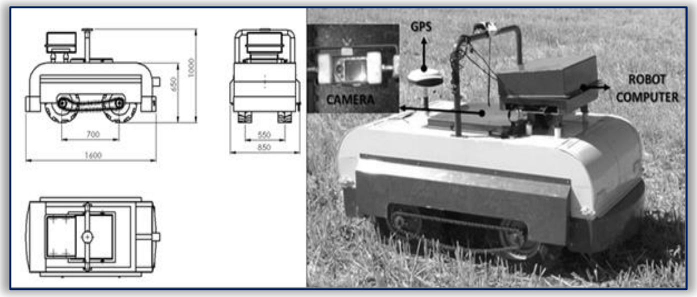

Figure 1 - Remote controlled and GPS guided autonomous robot

Data acquisition system

GPS receiver was used to transfer data such as geographic coordinate, working speed, etc. on a robot computer. Promark 500 GPS receiver owned by Magellan Co. was used in the study. The receiver has 75 channels and up to 20 Hz data output rate. It is the most flexible GNSS surveying system available, offering multiple operating modes, configurations and communication modules (UHF, GSM/GPRS, EDGE) and protocols. It can connect to CORSE-TR (Continuously Operating Reference Stations - Turkey) via phone data card (SIM Card) for receiving correction signals (Figure 2).

Latitude and longitude data received from a GPS receiver in the NMEA-0183 format are in units of ddmm.mmmm, where dd equals degrees, mm equals minutes, and .mmmm is decimal minutes. For many purposes, position information in this format is more than adequate. However, when plotting position information on maps or carrying out supplemental calculations using the position coordinates, it can be advantageous to work instead with the corresponding grid coordinates on a particular map projection. One of the most widely used map projection and grid systems is the Universal Transverse Mercator (UTM) system (Topakci et al., 2010).


Figure 2 - Promark 500 GPS receiver

For this reason, data received from GPS receiver was converted to UTM format, and stored to the database by the server software. GPS data must be transferred on the maps to better analyze in the office. Many GPS manufacturers have developed different software packages to create GPS data files for mapping software such as ArcGIS, Surfer, etc. However, these GPS data files are unsuitable for special purpose application software. So, integration of these files into the special purpose software is very difficult. Generally, database files such as .mdb, .dbf, .mdf etc. can be integrated to mapping software. In addition, excel files (.XLS), tab delimited text files (.CVS), comma separated text files (.TXT) can be integrated to mapping software. Developed server software for the study can collect GPS data and create suitable GPS data files for mapping software. In this study, obtained stubble cover data was mapped by using ArcGIS 9.3 software.


Figure 3 - Digital camera mounted in sealed box on the autonomous robot

Canon PowerShot SX100 IS (Canon Inc., Tokyo, Japan) digital camera was used to take pictures of the stubble. The SX100 IS is designed with 8.0MP sensor, a 10x zoom, optical image stabilization and a comprehensive range of manual photographic controls.The digital camera mounted in sealed box on the autonomous robot. The base area of the sealed box was 45x50 cm. The digital camera is placed at a height of about 60 cm above the soil surface (Figure 3).

Therefore a box was constructed to completely prevent the camera's field of view from being directly changed by outdoor illumination conditions in order to meet the required minimum image uniformity. All functions of the digital camera can be controlled by the developed server software. The stubble images obtained by the server software were transferred to the client software. During the study, the obtained data was stored into the SQL Server 2005 database.

Image processing algorithm

The image processing software was developed in VB.NET 2005. We used two-value arithmetic images to determine stubble cover ratio (Figure 4). Firstly, the colored stubble images were collected in JPEG format with an image size of 2,592 by 1,944 pixels. The field images were taken with only camera flash inside robot sealed box. Each image sampled a surface of 0.225 m². Secondly, the colored stubble images have been converted to grayscale images to create a monochromatic image as is regularly done in digital image processing. The red filter was used to perform segmentation of the various components (stubble, vegetation, and soil) because this approach allows for the best visualization of the stubble and separation of the plant coverings and soil. Thirdly, grayscale images with red filter calibration converted to binary images by the software and the binary histograms of the stubble images were obtained. Finally, the stubble cover ratios were calculated by evaluating the binary histograms. In the resulting binary image, stubble appeared white and soil appeared black. White pixels inside binary image were counted to determine number of white pixel (WPS) for each image. The stubble cover ratio (SCR) in each image was determined using Equation 1.

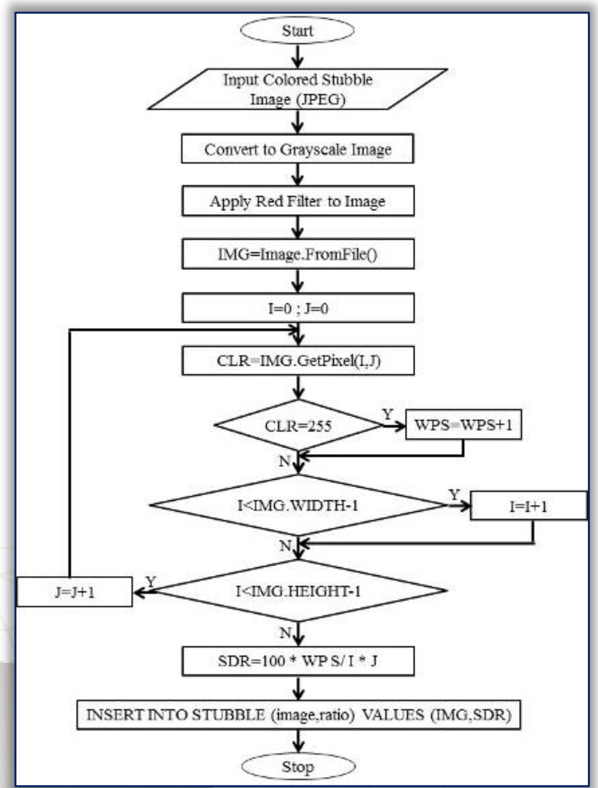

Figure 4 - Flowchart of image processing algorithm

$$\mathrm{SCR}(\%) = \frac{100*\mathrm{WPS}}{\text{Image Resolution } (2592*1944)} \qquad (1)$$

In addition to image analysis, stubble cover ratio was also estimated using the line transect method. In line transect method; count the number of times a marked line intersects with a piece of stubble. Use a 50 to 100 cm tape measure (or a rope with marks spaced at 1cm intervals). Stretch the tape (or rope) between two stakes placed diagonally (at a 45 degree angle) of the stubble rows. Looking directly from above the tape (vertically), count the number of times where a "foot" mark intersects with stubble. Make consistent judgments use only the left or right side of the foot mark on the tape (or rope) to avoid over counting stubble. The resulting count converts directly into the percentage of stubble remaining in that sample area. (Example: 47 occurrences of intersection equal 47 percent stubble remaining). In this study, we used steel rule at a 45 degree angle mounted inside 45 x 50 cm rectangle frame (Figure 5).

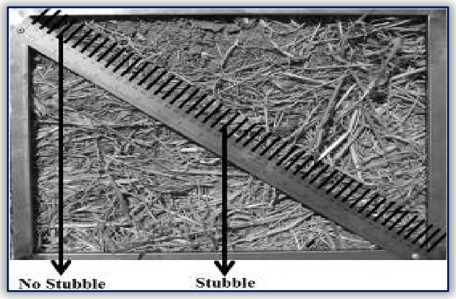

Figure 5 - Stubble cover ratio determinations with line transect method

Figure 6 - Experimantal field

Experimental field

The field experiments were carried out in the agricultural experiment field of Batı Akdeniz Agricultural Research Institute, in Aksu, Antalya, located in the West Mediterranean region of Turkey. The research area is located approximately 15 km from Antalya between the coordinates of 36º 56′ 34.46” N and 30º 53’ 04.10” E. Experimental field has an area of 12 ha with corn silage was planted in June 2012. The crop was harvested with a combine harvester in September 2012. Experimental field was divided to three equal parcels (Figure 6). The treatments included three tillage methods including conventional, no-till and reduced tillage. The stubble images were taken from 24 different spots of the each parcel by the autonomous robot.

Data collection

The digital map of the studied field was transferred into the ArcGIS 9.3. In this way, the GPS waypoint file for the autonomous robot was prepared in the office environment. A total 72 different waypoints were selected by the help of ArcGIS 9.3 software. We selected 24 different waypoints for each parcel. For each parcel, autonomous robot was steered to take colored stubble images and calculated stubble cover ratio for each point. All collected and calculated data was stored into the SQL Server 2005 database by the server software. Also, we collected stubble cover ratio using line transect method for each point to make a comparison between image processing and line transect methods.

3. RESULTS

During the experiment within the 12 ha field, geographical coordination and progress values for 72 waypoints (24 waypoints for each parcel) stubble cover ratios were collected. All collected and calculated data was stored into the SQL Server 2005 database. Stubble cover ratios for conventional tillage, reduced tillage and no-tillage parcels were presented in Tables 1, 2 and 3 respectively.

No faults were detected either in the mechanical or software parts of the system during operation. The obtained data was stored in a format adaptable to the mapping software in the Microsoft

Table 1. Stubble cover ratio for conventional tillage

CONVENTIONAL				
ID	UTMX (m)	UTMY (m)	Image Processing Stubble Ratio (%)	Line Transect Stubble Ratio (%)
1	311587.43958575	4090445.59745670	9.45	8.00
2	311588.78989651	4090466.28897305	9.58	9.00
3	311592.64633438	4090492.84526968	0.58	1.00
4	311598.22981597	4090523.61852750	5.59	4.00
5	311605.18190164	4090555.84150662	4.63	6.00
6	311608.71679931	4090581.29486803	5.55	6.00
7	311616.77688887	4090623.29896298	6.62	5.00
8	311622.10033766	4090655.74312695	4.00	5.00
9	311626.48332920	4090692.64849608	6.23	6.00
10	311632.67605257	4090730.80878132	1.60	3.00
11	311637.75658769	4090759.00303756	4.69	4.00
12	311641.56766760	4090783.52521124	3.91	4.00
13	311654.44240964	4090788.23474503	1.28	2.00
14	311649.71556592	4090769.28330038	9.13	8.00
15	311642.42931725	4090742.06307526	2.75	4.00
16	311634.26270448	4090695.25097860	7.89	8.00
17	311629.42972347	4090664.83106732	6.67	8.00
18	311623.13779633	4090628.89314825	9.05	8.00
19	311616.29664186	4090601.66305724	6.70	7.00
20	311611.91555022	4090544.77620442	9.19	9.00
21	311604.46960952	4090503.68354406	3.11	2.00
22	311597.86360042	4090473.67304183	0.08	1.00
23	311593.84297772	4090439.71985438	3.71	3.00
24	311590.12956374	4090426.29633272	8.16	8.00
		Average	5.42	5.38
		Standard Mean	2.935	2.568

Table 2. Stubble cover ratio for reduced tillage

REDUCED				
ID	UTMX (m)	UTMY (m)	Image Processing Stubble Ratio (%)	Line Transect Stubble Ratio (%)
1	311599.62394921	4090432.56098397	33.13	35.00
2	311611.94197124	4090485.75634827	31.66	36.00
3	311619.40085796	4090520.74328382	37.68	34.00
4	311623.10810539	4090553.96338338	31.09	30.00
5	311628.91031377	4090581.21654480	39.87	41.00
6	311636.29043073	4090619.35046769	33.62	35.00
7	311643.38529764	4090664.70625012	35.47	38.00
8	311651.64008151	4090695.42022959	33.09	32.00
9	311657.91409236	4090743.93947172	39.80	40.00
10	311660.30727557	4090764.79285868	37.01	39.00
11	311664.26328097	4090782.46632565	37.33	36.00
12	311668.19601231	4090785.70926579	32.06	30.00
13	311662.11427351	4090752.54186120	32.33	30.00
14	311656.67542097	4090721.58034896	39.82	42.00
15	311653.65161267	4090699.07584227	39.90	39.00
16	311649.61758387	4090677.88885678	31.75	34.00
17	311646.70523433	4090653.71675734	31.82	33.00
18	311645.58966239	4090636.90530548	39.11	41.00
19	311640.85110191	4090610.73860264	38.03	40.00
20	311638.07550043	4090579.34794868	38.20	39.00
21	311631.53188012	4090545.45076159	37.62	36.00
22	311627.91085510	4090516.11402699	31.08	30.00
23	311623.25562308	4090480.32478714	34.81	38.00
24	311619.86851100	4090461.52862382	39.93	41.00
		Average	35.68	36.21
		Standard Mean	3.328	3.934

SQL Server 2005 database. The database was transformed into the ArcGIS 9.3 mapping software. For the creation of the stubble cover ratio map, ordinary kriging interpolation was applied. Figure 7 illustrates image processing based stubble cover ratio map for each parcel in the experimental field.

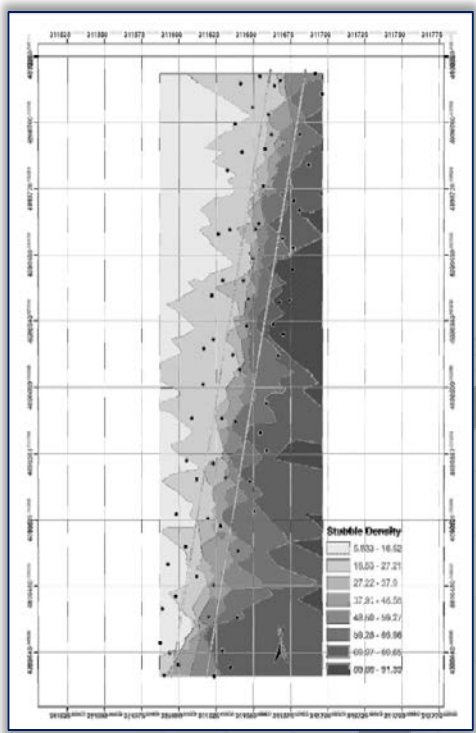

Figure 7 - Stubble cover ratio map for three tillage methods

Table 3. Stubble cover ratio for no-till tillage

NO-TILL				
ID	UTMX (m)	UTMY (m)	Image Processing Stubble Ratio (%)	Line Transect Stubble Ratio (%)
1	311663.28041258	4090637.80768411	86.49	90.00
2	311669.63644382	4090690.02537524	91.78	90.00
3	311681.27254985	4090752.67163190	88.49	85.00
4	311667.74805646	4090651.76952780	92.79	95.00
5	311658.66776451	4090590.54665800	92.66	98.00
6	311654.70758780	4090572.68827240	92.94	91.00
7	311647.52451880	4090543.43060534	87.38	85.00
8	311623.67751137	4090425.73648267	87.25	86.00
9	311629.21299955	4090440.96969810	86.99	90.00
10	311639.75317765	4090501.05005475	91.80	90.00
11	311666.72077450	4090618.85995489	94.19	93.00
12	311677.26530431	4090712.61267984	87.24	90.00
13	311691.59607884	4090789.63017615	86.55	90.00
14	311696.22715629	4090777.50151976	94.48	98.00
15	311687.25241386	4090734.40759287	88.27	91.00
16	311681.14951623	4090706.97606332	86.79	85.00
17	311676.78999553	4090684.50120029	87.27	91.00
18	311676.35023050	4090671.37501384	94.36	93.00
19	311674.60410537	4090652.91243737	89.55	93.00
20	311670.13306282	4090632.10517250	88.75	85.00
21	311658.92221860	4090561.86394189	85.62	90.00
22	311650.68857623	4090525.41407316	93.98	90.00
23	311639.31608746	4090461.28189057	85.36	88.00
24	311634.63559014	4090431.04360955	88.16	89.00
		Average	89.55	90.25
		Standard Mean	3.105	3.627

As a result, average stubble cover ratios for conventional, reduced and no tillage parcels were 5.42% (±8.615), 35.68% (±11.077) and 89.55% (±9.641), respectively after image processing method. In line transect method, average stubble cover ratios for conventional, reduced and no tillage parcels were 5.38% (±6.592), 36.21% (±15.476) and 90.25% (±13.152), respectively. Data were subjected to statistical analysis using the t- test for each tillage system. There were no statistical difference between the image processing and line transects method for stubble cover ratio of each tillage system (P>0.05) (Table 4).

Table 4. T-test analyses

	Image Processing Stubble Ratio (%)	Line Transect Stubble Ratio (%)
Conventional Tillage		
Average	5.424	5.375
Standard error of the mean	8.615	6.592
Number of Point	24	24
Pearson Correlation	0.945	
Sig. (2-tailed)	0.810	
Reduced Tillage		
Average	35.676	36.208
Standard error of the mean	11.077	15.476
Number of Point	24	24
Pearson Correlation	0.862	
Sig. (2-tailed)	0.204	
No-till Tillage		
Average	89.548	90.250
Standard error of the mean	9.641	13.152
Number of Point	24	24
Pearson Correlation	0.624	
Sig. (2-tailed)	0.257	

The Conservation Technology Information Center (CTIC) has defined conservation tillage as any tillage and planting system that has more than 30% residue cover after planting; reduced-tillage as 15–30% residue cover; and intensive or conventional tillage as less than 15% residue cover (Daughtry, 2001). Stubble cover estimation is not only useful in planning field operations to maintain erosion control, but is sometimes needed to determine if a particular field qualifies for certain federal, state, or local conservation programs. For this reasons, stubble cover ratio should be determined to make effective management decisions. There are several methods for measuring stubble cover ratio. One of these methods is line transect. Laflen et al., (1981) reported that the line transect method has emerged as the preferred method for field use. Shelton & et al. (1991) reported that the line-transect method is one of the easiest method to use in the field to determine the percent residue cover on the surface. Currently, the most reliable technique for determining soil coverage is image analysis.
Among the different image analysis techniques, fractal image analysis (Velázquez-García et al., 2010), the use of fluorescent images (Daughtry et al., 1997), and computer-assisted analysis of images (Olmstead et al., 2004) are clear examples of the possibilities of image analysis (Jimenez et al., 2013). Korucu and Yurdagül (2013) were to use imaging method to determine of residue cover as affected by different soil tillage practices. Line transect and imaging technique were used to determine the amount of residue cover after each tillage application. T-test resulted in a high correlation (R^2=0.91) between line transect and imagery data in primary soil tillage. Pforte et al. (2012) compared various manual methods and image analysis methods, and obtained higher Pearson correlation coefficients of between 0.86 and 0.92. Image analysis has demonstrated its usefulness in determining the stubble cover ratio in comparison with visual estimation. Image processing may provide a more accurate, quick and extensive estimate of the stubble cover ratio. Also, image processing and GIS technologies are proving to be efficient tools for addressing problems of environment. In fact, image processing method is similar to the visual estimation method. Advantages of the image processing methods are fast, precision and reliability. But, image processing system should be mounted on the autonomous vehicle.

4. CONCLUSION

As final conclusions, this study determined and mapped the stubble cover ratio of the fields under conventional, no-till and reduced tillage systems using the online image processing method. High values of stubble cover ratios were obtained for the no-till tillage whereas low values for the conventional tillage system. The experimental results showed that the designed system works quite well in the field and the system is a practical tool for providing on-line stubble cover measurements. Maps are regarded as tools for processing coordinate data and also for data analysis and representation. Another important factor of the maps is their contribution in aiding users in making quick and reasonable decisions, for which the quality of the data gains importance. In this respect, to improving the map quality, number of spots should be increased (more than 24). This study contributes to further research for the development of on-line stubble cover measurements and mapping within the precision farming applications.

References

[1] Agostini MA, Studdert GA, San-Martino S, Costa JL, Balbuena RH, Ressia JM, Mendivil GO, Lázaro L, 2012. Crop residue grazing and tillage systems effects on soil physical properties and corn (Zea mays L) performance. J Soil Sci Plant Nutr 12: 271-282.

[2] Arsenault E, Bonn F, 2005. Evaluation of soil erosion protective cover by crop residues using vegetation indices and spectral mixture analysis of multispectral and hyperspectral data. Catena 62(2-3): 157–172.

[3] Bahadur I, Sonkar VK, Kumar S, Dixit J, Singh AP, 2015. Crop residue management for improving soil quality & crop productivity in India. Indian Journal of Agriculture and Allied Sciences 1(1): 52-58.

[4] Bannari A, Pacheco A, Staenz K, McNairn M, Omari K, 2006. Estimating and mapping crop residue cover in agricultural lands using hyperspectral and IKONOS images. Remote Sens Environ 104: 447 459.

[5] Brady NC, Weil RR, 2002. The Nature and Properties of Soils. Prentice Hall, Upper Saddle River, NJ, USA. 960 pp.

[6] Bricchi E, Formia F, Esposito G, Riberi L, Aquino H, 2004. The effect of topography, tillage and stubble grazing on soil structure and organic carbon levels. Span J Agric Res 2(3): 409-418.

[7] Busaria MA, Kukal SS, Kaur A, Bhatt R, Dulazib AA, 2015. Conservation tillage impacts on soil, crop and the environment. International Soil and Water Conservation Research 3(2): 119-129.

[8] Daughtry CST, McMurtrey JE, Chapelle EW, Dulaney WP, Irons JR, Satterwhite MB, 1995. Potential for discriminating crop residues from soil by reflectance and fluorescence. Agron J 87: 165–171.

[9] Daughtry CST, McMurtrey JE, Kim MS, Chappelle EW, 1997. Estimating crop residue cover by blue fluorescence imaging. Remote Sens Environ 60: 14-21.

[10] Daughtry CST, 2001. Discriminating crop residues from soil by shortwave infrared reflectance. Agron J 93: 125–131.
[11] Dickey EC, Shelton DP, Jasa PJ, Peterson T, 1985. Soil Erosion from Tillage Systems Used in Soybean and Corn Residues. T Asae 28(4): 1124-1129.
[12] Hartwig RO, Laflen JM, 1978. A meterstick method for measuring crop residues cover. J Soil Water Conserv 33(2): 90–91.
[13] Jiménez-Jiménez F, Blanco-Roldán GL, Márquez-García F, Castro-García S, Agüera-Vega J, 2013. Estimation of soil coverage of chopped pruning residues in olive orchards by image analysis. Span J Agric Res 11(3): 626-634.
[14] Korucu T, Yurdagül FC, 2013. Using the Image Processing Method to Obtain the Residue Cover on the Soil Surface after Different Tillage Practices. Journal of Agricultural Faculty of Gaziosmanpasa University 30(2): 6-17.
[15] Laflen JM, Amemiya M, Hintz EA, 1981. Measuring crop residue cover. J Soil Water Conserv 36(6): 341-343.
[16] McMurtrey JE, Daughtry CST, Devine TE, Corp LA, 2005. Spectral detection of crop residues for soil conservation from conventional and large biomass soybean. Agron Sustain Dev 25: 25-33.
[17] McNairn H, Protz R, 1993. Mapping corn residues cover on agricultural fields in Oxford County, Ontario, using thematic mapper. Can J Remote Sens 19(2):152–159.
[18] Mitchell J, Pettygrove G, Upadhyaya S, 2009. Classification of Conservation Tillage Practices in California Irrigated Row Crop Systems. Oakland, USA. Technical Report 8364, UC ANR.
[19] Morrison JE, Chichester FW, 1991. Still video image analysis of crop residues covers. Soil Sci Soc Am J 34: 2469–2474.
[20] Morrison JE, Huang C, Lightle DT, Daughtry CST, 1993. Residues cover measurement techniques. J Soil Water Conserv 48: 479–483.
[21] Morrison JE, Lemunyon J, Bogusch HC, 1995. Source of variation and performance of nine devices when measuring crop residues cover. T Asae 38: 521–529.
[22] Olmstead MA, Wample R, Greene S, Tarara J, 2004. Nondestructive measurement of vegetative cover using digital image analysis. Hortscience 39(1): 55-59.
[23] Peigné J, Ball B, Roger-Estrade J, David C, 2007. Is conservation tillage suitable for organic farming? A Review. Soil Use Manage 23: 129-144.
[24] Pforte F, Hensel O, 2010. Development of an algorithm for online measurement of percent residue cover. Biosyst Eng 106(3): 260-267.
[25] Pforte F, Wilhelm B, Hensel O, 2012. Evaluation of an online approach for determination of percentage residue cover. Biosyst Eng 112(2): 121-129.
[26] Ribeiro A, Ranz J, Burgos-Artizzu XP, Pajares G, Sanchez del Arco MJ, Navarrete L, 2011. An Image Segmentation Based on a Genetic Algorithm for Determining Soil Coverage by Crop Residues. Sensors-Basel 11(6):6480-6492.
[27] Shelton DP, Dickey EC, Kanable R, Melvin SW, Burr CA, 1991. Estimating Percent Residue Cover Using The Line-Transect Method. Biological Systems Engineering: Papers and Publications. Paper 254.
[28] Topakci M, Unal I, Canakci M, Yiğit M, Karayel D, 2010. Improvement of field efficiency measurement system based on GPS for precision agriculture applications. J Food Agric Environ 8(3&4): 288-292.
[29] Ünal İ, Topakci M, 2015. Design of a Remote-controlled and GPS-guided Autonomous Robot for Precision Farming. Int J Adv Robot Syst 12: 1-10.
[30] Velázquez-García J, Oleschko K, Muñoz-Villalobos JA, Velásquez-Valle M, Martínez-Menes M, Parrot J, Korvin G, Cerca, M, 2010. Land cover monitoring by fractal analysis of digital images. Geoderma 160(1): 83-92.
[31] Zhou Q, Robson M, 2001. Automated rangeland vegetation cover and density estimation using ground digital images and a spectral–contextual classier. Int J Remote Sensing 22(17): 3457-3470.

ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering