Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi
Journal of Agricultural Faculty of Gaziosmanpasa University
http://ziraatdergi.gop.edu.tr/

Araştırma Makalesi/*Research Article*

JAFAG
ISSN: 1300-2910
E-ISSN: 2147-8848
(2017) 34 (2), 81-90
doi:**10.13002/jafag4267**

Monitoring Sunflower and Maize Canopy Under Alternative Nitrogen Regimes with Lidar and Optical Sensors

Chris CAVALARIS[1]* Bahattin AKDEMİR[2] Chris KARAMOUTIS[1] Theofanis GEMTOS[1]

[1]University Of Thessaly, Faculty Of Agricultural Sciences, Department Of Agriculture, Crop Production And Rural Environment, Greece
[2]Namik Kemal University Faculty Of Agriculture Department Of Biosystems Engineering, Turkey
*e-mail: chkaval@uth.gr

Alındığı tarih (Received): 17.03.2017 Kabul tarihi (Accepted): 21.06.2017
Online Baskı tarihi (Printed Online): 18.08.2017 Yazılı baskı tarihi (Printed): 09.09.2017

Abstract: Crop fertilization is an important part of cost and energy inputs in agriculture. The opportunity to apply the variable rate of nitrogen fertilizers according to the plant needs in each part of the field is a promising practice to increase the fertilizer use efficiency. An experiment was conducted in 2016 in the University of Thessaly farm, Central Greece in order to evaluate the use of lidar and optical sensors to monitor the crop canopy for sunflower and maize. The canopy development can serve as a good indicator for the nutrition state of the crops regarding especially the nitrogen, and it can be used as an indicator for variable rate application systems. In order to obtain plants with different canopy development, a field experiment was established with treatments receiving the normal, farmer's practice, nitrogen rates (100%N) at basic fertilization, treatments receiving 50% reduced nitrogen fertilizer (50%N) and treatments with no nitrogen application (0%N). During growing, the crop canopy was monitored with a lidar and an optical sensor. Manual measurements of plant height and weight were also made. The manual measurements revealed the effect of variable fertilizer rates to plant development. The plots with higher nitrogen rates had higher and more vigor plants. The lidar sensor depicted more clearly these differences compared to the optical sensor. Plant height was sufficiently assessed for both the sunflower and maize crop by lidar. Plant volume though was assessed only for the sunflower. A problem with the lidar sensor was the small sampling rate (almost 2Hz) but this can be compensated by its ability to scan simultaneously more than one crop rows (4 to 6) and obtain multiple sample information.

Keywords: Canopy height, crop monitoring, lidar sensor, precision fertilization

1. Introduction

The fertilization of arable crops is one of the main components of the production costs. Moreover, the production of the chemical fertilizers, especially the nitrogen ones, is a high energy consuming process for the industry and creates a pathway of massive energy inputs for farm production. Even though agriculture today is highly dependent on fertilizers their use efficiency is not the maximum possible. Fertilization is still based on the 'field average". This means that the decision of what, when and how much fertilizer should be used is based on the average conditions of the fields. Most of the fields, however, even the smaller ones, present high variability on soil texture, structure, topography, soil moisture and water capacity, pH and many others parameters. These are all factors affecting crop needs and the absorption of the. Applying fertilizers based on the average conditions means that some parts of the fields may be over fertilized and some other under fertilized. This issue comes to great importance when considering the nitrogen, a highly mobile nutrient which requires timing and spatial regulation.

The solution to cope with the above-mentioned problem is to develop spreaders capable to modify the application rate according to the plant's needs. And to be able to recognize the plant's needs, the appropriate sensors should be used to detect soil and crop properties and use them to spatially differentiate application rates. These sensors should be able to detect characteristics related to crop nutrition. Optical sensors monitoring the reflectance of the canopy by utilizing indexes like NDVI, RVI etc are widely used and today there are some commercial products in the market. But the information provided by vegetation indices is not always solely related to the nutrition state of a plant. For example, a pale color of the leaves may be the result of nitrogen deficit as well as of a disease infestation. A low NDVI index may be owed to pale leaves, restricted vegetation or bare ground. Satellite imagery is also utilized in the same manner. Additional sensors could be used to interpret the information.

Crop height measurement can contribute towards this direction. This measurement can be carried out by laser scanners or ultrasonic sensors. Ehlert et al. (2009) measured crop height by two different laser scanners of three different crops (rapeseed, winter wheat and winter rye). Crop height was highly correlated (r^2=0.75 to r^2=0.99) with the biomass measured manually. Static and dynamic (on-the-go) measurements of miscanthus height were carried out using laser scanner and correlated with manually measurements of biomass with an average error 5.08% for static and 3.8% dynamic measurements (Zhang & Grift, 2012).

For applying site, specific spraying, sonar and laser scanning were used to construct three-dimensional canopy model of vineyards and orchards (Gil et al., 2006; Llorens et al., 2011). In pear orchards, canopy volume and foliage density was obtained from laser sensor measurements and highly correlated with canopy height and canopy cross-section measurements (r^2=0.86) (Escola et al., 2009). Ultrasonic sensors were used to detect weeds and bare spots within blueberry fields (Swain et al., 2009).

Laser scanning and ultrasonic sensors were used for measuring and describing the canopy characteristics of tree orchards. Laser scanner measurements were correlated to crop parameters such as Leaf Area Index, tree height, canopy density with high correlation (Arno et al., 2009). They were used to obtain a three-dimensional model of tree canopy (Rossell et al., 2009). In Florida, citrus orchards tree canopies were measured with a laser scanner and correlated with manual measurements with a high correlation (r^2=0.85) (Tumbo et al., 2002). A three-dimensional laser scanner was used to estimate tree height, the crown height and crown width of olive trees (Moorthy et al., 2010). The sensor's measurements showed very high correlation for all the tree parameters (r^2=0.97, r^2=0.99 and r^2=0.76 respectively).

Another characteristic often related to the nutrition of the crop is the plant's growth. This can be expressed as plants' height, plants volume or leaf area. Plants with nutrient deficits are normally shorter with smaller canopy. They might require more nutrients or they might not be able to use the nutrients provided from the soil.

Lidar sensors are developed to measure a distance to a target by illuminating that target with a laser light. They are highly utilized in industry and landscaping. There appear however great opportunities to introduce such sensors on the agricultural production. A lidar sensor can roughly monitor the shape of a plant giving useful information about plant's growth. As mentioned, growth may be related to crop nutrition.

An experiment was established in 2016 at the University of Thessaly Farm, Greece in order to evaluate the perspective to use lidar sensors to monitor crop development for two arable crops, sunflower and maize. Based on the hypothesis that fertilization affects the crop development, the lidar data could be utilized, alone or in combination with data from optical sensors, to adjust the nitrogen rates in precision agriculture systems. The experiment included low fertilization plots to simulate plants growth under nitrogen deficiency and conduct measurements with lidar and optical sensors in order to recognize growth changes. The results of the experiment are presented in the present paper.

2. Methodology

A laser scanner sensor (SICK LMS200) was used to scan the crop canopy in order to obtain geometrical information about the crops like plants Height (Hls) and Canopy Vertical Surface (CVSls) which is the surface area delineated by the edge points of the scanned canopy (Fig 4).

The sensor was carried by a special vehicle equipped with a horizontal mast extending at one side for placing the sensor above the crop canopy (Figure 1a). The sensor was mounted at the edge of the mast, right above the top of one row, at a height of 1.6 m from the soil surface. The sensor was configured to monitor the distance at an angle of 180^o (90^o to the right and 90^o to the left) at 0.5^o intervals. Each scan consisted of 360 laser hits (measurements). Sampling was performed at 1.96 s time intervals. The forward speed of the vehicle was 0.31 m/s. The vehicle also carried the power supply for the sensor and a laptop PC for recording the data using the sensor's software (SICK LMS/LMI User Software).

Estimation of NDVI was done with an optical sensor (Crop Circle ACS 210 - Holland Scientific Inc). Measurements were taken by handling the sensor at a height of approx. 30 cm from the top of the plants and walking along the lines of the crops.

Plant samples were cut manually from 20m of row, taken and weighed to assess biomass production.

Both crops (Maize and Sunflower) were sown at 18/5/16 with a pneumatic planter at a row distance of 0.75m. The distance of the seeds at the row was 15.7 cm for sunflower and 12.6 cm for maize. Maize variety was Dekalb DKC5276 and sunflower Pioneer P63LE75. Three fertilization regimes were established for each crop (Table 1).

Table 1. The three fertilization treatments applied to the sunflower and maize

	Sunflower	**Maize**
F1 = 100% N	160 kg/ha N	300 kg/ha N
F2 = 50%N	80 kg/ha N	150 kg/ha N
F3 = 0%N	-	-

On both crops, the fertilizer was applied at 17/6/16.

The plots were 3x20 m long comprising four rows of sunflower or maize. Three rows of 3 m each were measured at each plot. Measurements conducted on 12/7/2016. At that period, sunflower was at the beginning of flowering while the maize was still at the vegetative stage. These are the normal stages, for both crops, for a second nitrogen application.

The preliminary data obtained from the instrument are shown in Figures 2 & 3. It is clear (Figure 2), that the vertical measurements at the left are owed to the detection of the carrying mast and the vehicle while the horizontal measurements at the top, become from the cables connecting the sensor (Fig1.b). The horizontal measurements at the bottom of Figures 2 & 3 indicate the ground level. Finally, especially in Figure 2 for sunflower, there are distinct two adjacent row crops, one right below the sensor and another one on the right. It is also clear that the vertical mast was unstable at the maize measurements resulting in a bias of the data. For estimating the plant's height a filter was established to recognize and exclude the data from the adjacent left row of the crop (Figure 2 & 3 inside the frames). The right and left limits were set artificially. Another filter with artificial upper where incidentally on an 180^o set of scans, no data were obtained from the ground (due to the presence of plant tissues), the mean value from adjacent measurements was used.

Plant's height (Hls) was estimated from the restricted set of data inside the frames (Figure 2 & 3) according to the formula:

$$Hls = \sum_{1}^{n}[max\{x_1, x_2, x_3 \dots x_i\} - min\{y_1, y_2, y_3 \dots y_i\}]/n$$

Where n = the total number of 180^o scan sets obtained from each plot

$x_1, x_2 \dots x_i$ = the filtered data set (for each 180^o scan) regarding the ground level

$y_1, y_2 \dots y_i$ = the filtered data set (for each 180^o scan) regarding the crop canopy

Another parameter obtained from the Lidar sensor was the Canopy Vertical Surface (CVSls).

For every 180^o scanning set, the edge points detected by the sensor were used to delineate a contour line starting / ending from the ground and surrounding the crop canopy (Figure 4). The surface area delineated from this contour and the ground level was estimated as the CVSls. For each plot, a mean value of CVSls was estimated from all the scans. This index can also represent the crop canopy volume expressed as m^3 if it is multiplied per 1 m of row crop.

The index is a more precise representative of crop growth than plant's height as more vigorously growing plants are not necessary the taller ones.

Plant's height (Hm) was also measured manually for each plant of the plots in order to verify the Lidar measurements. Then each plant was cut from its base and the fresh weight (FWm) was measured in the field with a carried balance.

The data were subjected to a statistical analysis (two-way analysis of variance and analysis of covariance) by using the SPSS package.

Figure 1. The vehicle with the vertical and horizontal mast carrying the laser scanner (lidar) (left) and the alignment of measurements (right).

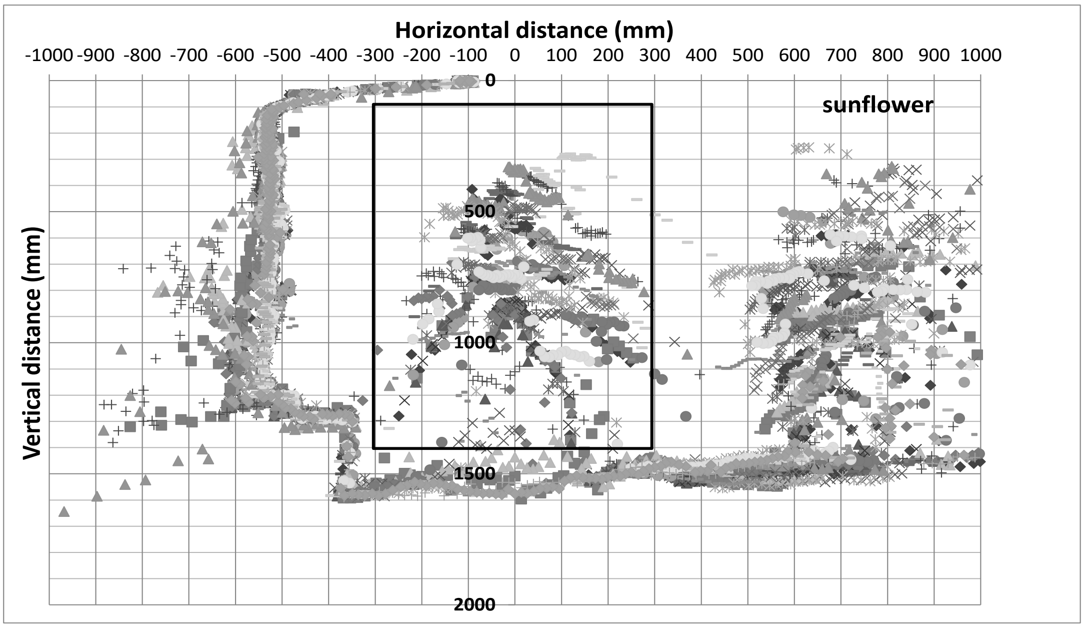


Figure 2. Laser scanner (lidar) measurements on the sunflower crop

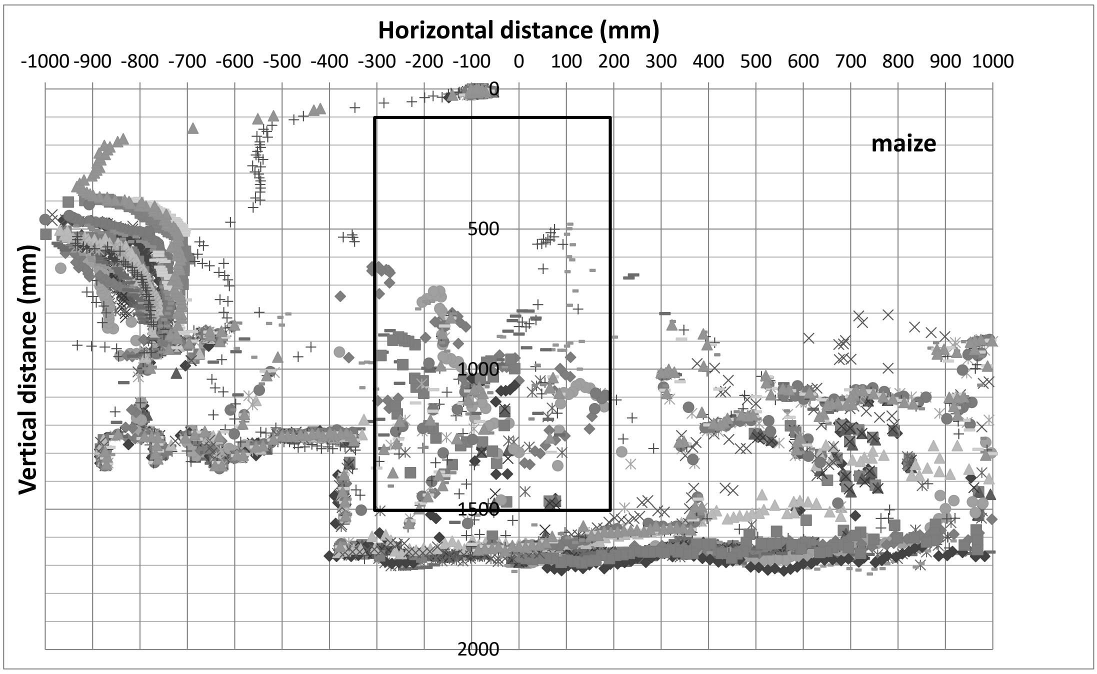


Figure 3. Laser scanner (lidar) measurements on the maize crop

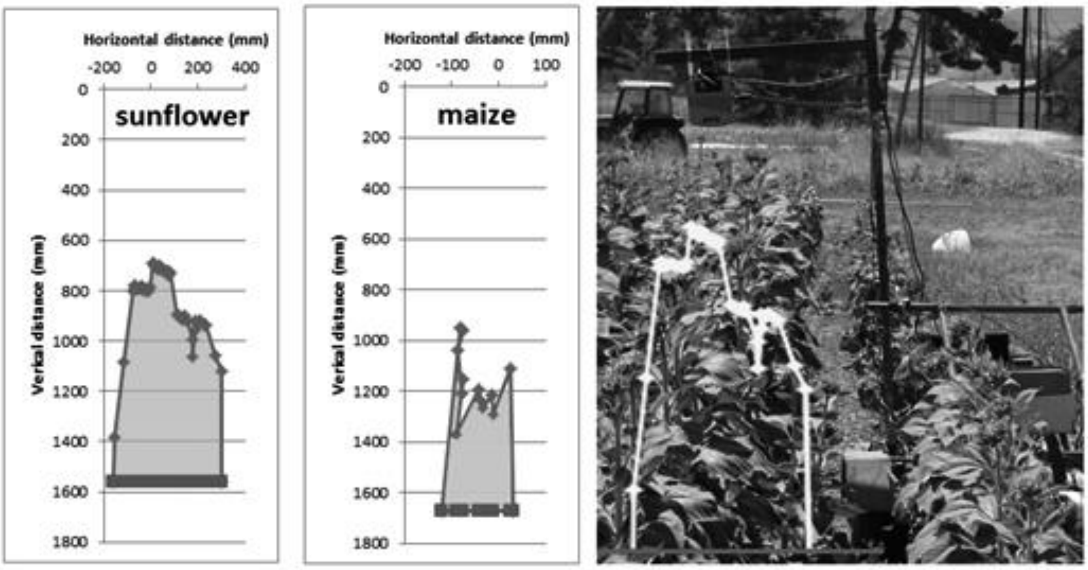


Figure 4. Representative 180^o set of scans for sunflower (left) and maize (center) and the surface area calculated to estimate the Canopy Vertical Surface (CVSls). A graphical depiction of what that area represents for sunflower is shown at the right.

3. Results and Discussion

The parameters measured are presented in Tables 2 & 3. The tables present the mean values obtained from each plot and the total means for the three levels of fertilization. As shown in Table 2, manual measurements of sunflower's height highlighted significant differences among the fertilization treatments with the best-fertilized treatment presenting the highest plants, as expected. The laser scanner detected these differences even though not on a statistically significant level (Table 2).

This is attributed to the highest coefficient of variation for the laser scanner measurements. The same applies for the maize crop. Actually, for maize, even the manual measurements did not reveal any statistical significant effect on plant's height from the variable fertilization (Table 3).

Table 2. Summary results of the lidar, optical and manual measurements (mean values for each replication plot) for sunflower

sunflower		**Plant's height (Hm) (mm)**	**Plant's height (Hls) (mm)**	**Fresh Weight (FWm) (kg)**	**Canopy Vertical Surface (CVSls) (m^2)**	**NDVI**
100% N	R1	1037	868	0.29	0.268	0.634
	R2	1091	829	0.40	0.360	0.595
	R3	1118	1045	0.54	0.458	0.680
	mean	*1082*	*914*	*0.41*	*0.362*	*0.636*
50% N	R1	921	862	0.21	0.290	0.552
	R2	999	796	0.29	0.206	0.669
	R3	988	978	0.34	0.309	0.528
	mean	*969*	*878*	*0.28*	*0.268*	*0.583*
0% N	R1	877	871	0.24	0.323	0.381
	R2	861	717	0.27	0.234	0.561
	R3	1016	834	0.34	0.290	0.562
	mean	*918*	*807*	*0.28*	*0.282*	*0.501*
replication effect		ns	*	*	ns	ns
fertilization effect		*	ns	*	ns	ns
CV%		4.4	6.3	12.7	21.1	13.6

*ns = non signifficant diference, * = signifficant difference at P=0.05*

Table 3. Summary results of the lidar, optical and manual measurements (mean values for each replication plot) for maize

maize		**Plant's height (Hm) (mm)**	**Plant's height (Hls) (mm)**	**Fresh Weight (FWm) (kg)**	**Canopy Vertical Surface (CVSls) (m^2)**	**NDVI**
100% N	R1	917	709	0.21	0.158	0.661
	R2	889	943	0.15	0.579	0.578
	R3	1001	827	0.22	0.291	0.480
	mean	*936*	*826*	*0.19*	*0.342*	*0.573*
50% N	R1	658	661	0.11	0.171	0.491
	R2	845	733	0.15	0.222	0.511
	R3	880	395	0.18	0.105	0.511
	mean	*794*	*596*	*0.15*	*0.166*	*0.504*
0% N	R1	841	892	0.17	0.453	0.541
	R2	846	753	0.15	0.156	0.491
	R3	733	304	0.10	0.020	0.479
	mean	*807*	*650*	*0.14*	*0.210*	*0.504*
replication effect		ns	ns	ns	ns	ns
fertilization effect		ns	ns	ns	ns	ns
CV%		11.2	25.6	26.3	79.9	9.7

*ns = non significant difference, * = significant difference at P=0.05*

But it is noticed again a trend for highest plants at the sufficient fertilized treatments and this was fairly depicted also from the laser scanner measurements.

Table 4 shows the correlations among the parameters measured in the two crops. Manual measurements of plants height (Hm) and fresh plant weight (FWm) are closely related for the maize crop but sparser for the sunflower as also shown in Figure 7. This was observed also in the ,field during the measurements for sunflower; thicker plants presented greater weight even though the height was the same. In that case, the Canopy Vertical Surface (CVSls) would be expected to give better correlations to (FWm). Indeed in Table 4, it is shown an r equal to 0.799 which is quite well. On the other hand, the CVSls index was very poorly correlated with FWm for the maize (r= 0.176). The CVSls index was closely related to the Hls as both parameters were obtained from the same sensor (Table 4 & Figure 8).

Table 4. Lidar, optical and manual parameter correlations for sunflower and maize crop (Hm = Plant's height manual, Hls = plant's height with lidar, FWm = fresh weight manual, CVSls = canopy vertical surface with lidar, NDVI = Normalized Difference Vegetation Index with optical sensor)

	Sunflower					Maize				
	Hm	***Hls***	***FWm***	***CVSls***	***NDVI***	***Hm***	***Hls***	***FWm***	***CVSls***	***NDVI***
Hm	1.000					1.000				
Hls	0.532	1.000				0.416	1.000			
FWm	0.515	0.637	1.000			0.861	0.372	1.000		
CVSls	0.576	0.809	0.799	1.000		0.345	0.792	0.176	1.000	
NDVI	0.689	0.116	0.522	0.067	1.000	0.336	0.323	0.437	0.299	1.000

Regarding the NDVI measurements (Table 4), it appears to be a weak relation with the fresh matter for both crops and a slightly better for the manually measured height for the sunflower plants. There was no significant correlation however between the NDVI and the CVSls index as would be expected.

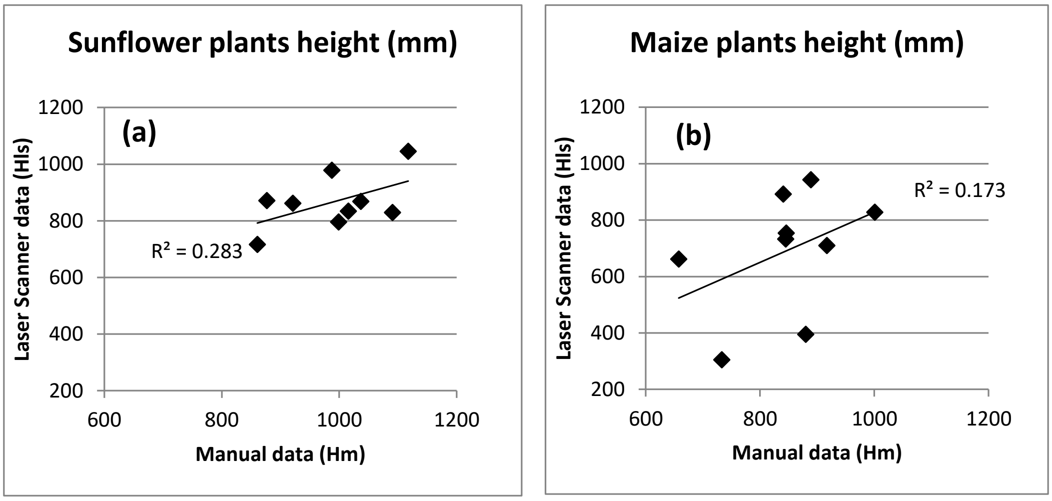


Figure 5. Correlation between manual obtained plant's height and height estimated with the laser scanner instrument. (mean values from each plot).

In general, the values obtained by the laser scanner appear to be more valuable for sunflower crop than for maize. This is probably due to the shape of the plant's canopy. Sunflower plants are broader with leaves extending to a horizontal or downward position and so the laser radians have a greater probability of hitting a plant tissue. Maize plant grows to a narrower space with narrower leaves of which the younger ones are shooting vertical upwards and so, there is a much less probability to be hit by the laser radians. As shown in Figure 8, the manually obtained parameters tend to decrease with the reduction in the nitrogen availability. This general trend was also more or less true for the lidar and optical sensor obtained parameters.

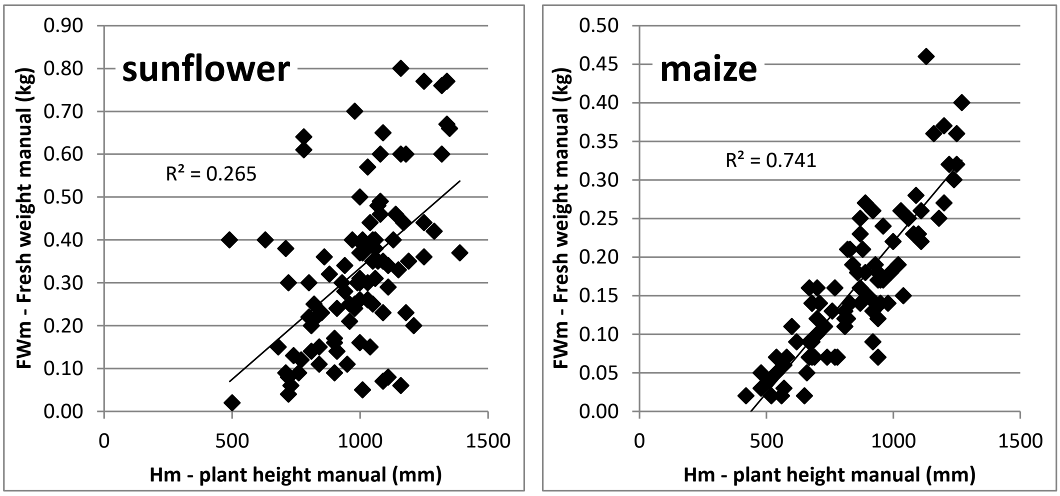


Figure 6. Correlations between manual obtained plant height (Hm) and fresh plant weight (FWm) for sunflower and maize

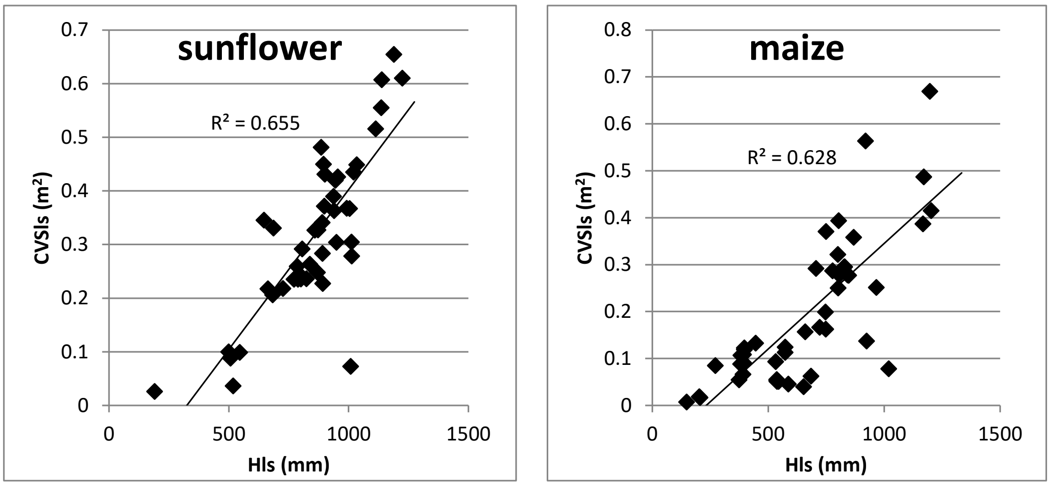
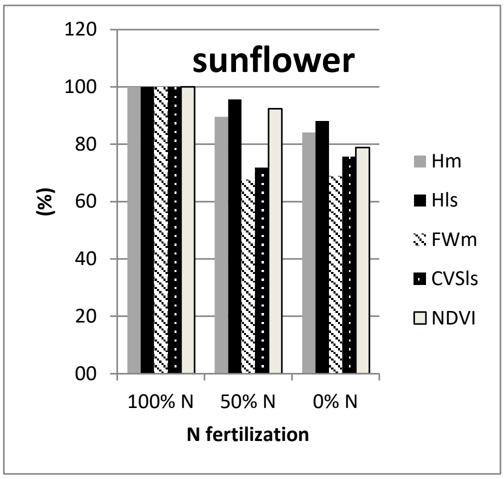


Figure 7. Correlations between plants height (Hls) and Canopy Vertical Surface (CVSls) for the data obtained with the laser scanner sensor for sunflower and maize.

The aim of the present work was to investigate possible relations of sensor obtained crop parameters with manually measured properties of the crops, such as plant weight and plant height, trying the verify the hypothesis that the last two are affected by the nutrition regime. Indeed the statistical analysis on the manually obtained data proved this effect on sunflower. In maize, although the effects were not significant, there was also the same trend for the less fertilized plants to be shorter and less developed.



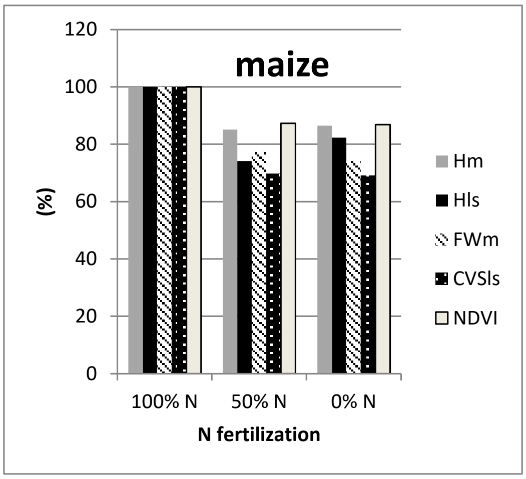


Figure 8. Manual (Hm) and laser scanner (Hls) measurements of plants height, Fresh weight (FWm), Canopy Vertical Surface (CVSls) and NDVI for three levels of fertilization. (Values expressed as % of the fully fertilized treatment).

The integration of the lidar data showed that plants height could be sufficiently monitored with the laser scanner sensor. Also for sunflower, the fresh weights were closely correlated to the Canopy Vertical Surface an index that also can represent the Canopy Volume if expressed in m^3/m of row. The height obtained with the laser scanner sensor was about 10-15% from that measured manually to the sunflower and up to 27% for maize. This is probably attributed to the fact that the laser radians may not always hit the taller part of the plants.

Considering the forward speed of the carrying vehicle 0.31m/s and the frequency of the sensor sampling frequency (1.6s for each 180^o angle set of measurements) it is estimated that each set was taken at distance intervals of 0.6 m. The plant spacing in the row for sunflower was 15.7 cm and for maize 12.6 cm. This means that at the 0.6 m distance there were only 4 sunflower plants or 5 plants of maize. So, the probability of hitting the highest part of the plant was low.

This is also a limitation for obtaining the Canopy Vertical Surface. Furthermore, the 0.31m/s speed of the vehicle is considered extremely low for performing field operations. Fertilizer spreaders normally work on the field at speeds of 2.2 - 3.3 ms/s. This means that the sampling intervals would range from 4.3 to 6.5 m. Assuming also that a greater number of samples (at least 5) are required to obtain reliable information, fertilization range could not be altered at a distance less than 20-30 m. As though, no on-the-go sensor could be built in that case.

There seem to be some technical limitations for the sensors to perform sampling at the higher frequency (each set consists of 360 samples). Nevertheless a solution could be to put the sensor higher to monitor more crop lines. As shown in Figures 2 & 3, even though the sensor was placed at the top of the row, it was able to detect also an adjacent row to the right. By placing the sensor higher and certainly not near to the vehicle, it could monitor 4 to 6 rows. This means that sampling intervals could be reduced 4 to 6 times falling again below the 1m of forwarding distance. And if more than one sensor would be used, the intervals would decrease further to a reasonable length.

The second sensor used in the present study was an optical NDVI sensor. The data obtained were generally poor correlated with the manually measured plant parameters (except for a medium correlation of NDVI with the manual measured height of sunflower). There was also a weak relation between the parameters measured with the two sensors. Some technical limitations seem to appear also for the use of the NDVI sensor. The sampling frequency of the optical sensor was 1Hz which means that at a normal working speed of 3 m/s it would take only one sample every 3m. Moreover, the sensor covers a much narrower section area (when placed at a maximum allowed height of 1m it covers only a 0.57m wide section). Therefore the lidar sensor may be more convenient to be used as an on-the-go sensor with the precondition of creating an algorithm to relate the differences in crop height with the nitrogen needs.

4. Conclusions

- The lidar sensor was able to detect the position of the canopies both on sunflower and maize crops. Actually, the sensor is able to recognize more than one crop rows according to the height it is positioned.
- Even though with less accuracy plant height can be reasonably monitored with the lidar sensor at both crops. A much greater sampling frequency is required to improve the accuracy.
- Fertilization affected the plant height. Therefore the height could be a useful indicator for regulating fertilizer dressing with spreaders capable to apply variable rate dose.
- Another parameter to be exploited is the Canopy Vertical Surface which can express the canopy volume. The parameter was related to the plant fresh weight for sunflower.
- Comparing with the optical sensor, the lidar provides more capabilities to monitor the crop.
- Sampling frequency for the lidar should be increased either by placing the sensor higher to monitor more crop rows or by using more sensors.

References

Arnó, J., Escolà, A., Vallès, J.M., Sanz, R., Masip, J., Palacín, J. and Rosell, J.R. 2009. Use of a ground-based LIDAR scanner to measure leaf area and canopy structure variability of grapevines. 7th European Conference on Precision Agriculture, Wageningen, The Netherlands, pp.177-184.

Ehlert, D., Adamek, R. and Horn, H-J. 2009. Laser rangefinder-based measuring of crop biomass under field conditions. Precision Agriculture vol. 10, pp 395-408.

Escolà, A., Arnó, J., Sanz, R., Camp, F., Masip, J., Solanelles, F. and Rosell, J.R. 2009. Sensing tree canopy parameters in real time for precision fructiculture/horticulture applications: methodology set-up and first results. 7th European Conference on Precision Agriculture, Wageningen, The Netherlands, pp.185-191.

Gil, E., Escola, A., Rosell, J.,Planas S. and Vald, L. 2007. Variable rate application of plant protection products in vineyard using ultrasonic sensors. Crop Protection vol. 26, pp. 1287–1297

Llorens, J., Gil, E., Llop, J. and Queraltó, M. 2011. Georeferenced LiDAR 3D Vine Plantation Map Generation. Sensors, volume 11, pp. 6237-6256

Moorthy, I., Millera, J., Jimenez J., Zarco-Tejadac, P., Hub, B. and Chend, J. 2011. Field characterization of olive (Olea europaea L.) tree crown architecture using terrestrial laser scanning data. Agricultural and Forest Meteorology vol. 151, pp. 204–214.

Rosell, J.R., Llorens, J., Sanz, R., Arno´, J., Ribes-Dasi, M., Masip, J., Escola`, A., Campc, F., Solanelles, F., Gracia, F., Gil, E., Val, L., Planas, S. and Palacin, J. 2009. Obtaining the three-dimensional structure of tree orchards from remote 2D terrestrial LIDAR scanning. Agricultural and Forest Meteorology, 149, pp. 1505-1515.

Swain, K.C., Zaman, Q.U.Z., Schumann A.W. and Percival, D.C. 2009. Detecting Weed and Bare-spot in Wild Blueberry Using Ultrasonic Sensor Technology. 2009 ASABE Annual International Meeting. Reno, Nevada, June 2009.

Tumbo, S. D., Salyani, M., Whitney, J., Wheaton T. and Miller W. 2002. Investigation of Laser and ultrasonic ranging sensots for measurements of citrus canopy volume. Applied Engineering in Agriculture. Vol. 18(3), pp. 367–372.

Zhang, L. and Grift, T. 2012. A LIDAR-based crop height measurement system for Miscanthus giganteus. Computers and Electronics in Agriculture vol. 85, pp. 70–76.