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Development of an Automatic Soil Sampling Machine

Ibrahim Savas DALMIS[1] **Bahattin AKDEMIR[2]** **Nail TUREN[3]** **Korkmaz BELLITURK[4]**

[1]Namik Kemal University , Corlu Engineering Faculty, Department of Mechanical Engineering, Tekirdag, Turkey

[2]Namik Kemal University, Faculty of Agriculture, Department of Biosystems Engineering,

Tekirdag, Turkey

[3]Elektropro Otomasyon, Çorlu, Tekirdağ, Turkey

[4]Namik Kemal University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Tekirdag, Turkey

*Sorumlu yazar: E-mail: idalmis@nku.edu.tr

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Abstract: In this study, it was aimed to develop an automatic soil sampling machine. The machine consists of mechanics, hydraulics and electronical systems for taking soil sample. In addition, there is a GPS module in the system to determine the location of soil sampling point. The developed machine was attached to the tractor with three-point hitch system and can take samples from the depth of 30 cm up to the resistance of 4 MPa. In field tests, it was determined that the machine could take 40-162 gr soil sample in one stroke depending on soil penetration resistance. The effect of the machine operating speed on the amount of soil samples was also evaluated during the study. In the tests, the amount of soil samples taken at the operating speed of 0.6 m/s, 0.12 m/s, 0.22 m/s was analysed. Statistically, a significant difference wasn't found according to the one way anova analysis which was carried out on the samples (P>0.05). As a result of field tests, it ~~is~~ was proved that the machine can be used for the purpose of soil sampling. Besides, the sampling points were also recorded with the help of GPS module by georeferencing. The recorded geodata was in the form of being used to create topographic variability maps.

Keywords: Precision farming, soil sampling machine, GPS, soil penetration resistance

Otomatik Toprak Örnekleme Makinesi Geliştirilmesi

Özet: Bu çalışmada, otomatik bir toprak örnekleme makinesi geliştirilmesi hedeflenmiştir. Makine, toprak numunesi alımı için mekanik, hidrolik ve elektronik sistemlerden oluşmaktadır. Ayrıca sistemde örnek alınan yerin konumunu belirlemek amacıyla GPS modülü bulunmaktadır. Geliştirilen makine traktöre üç nokta askı sistemi ile bağlanmakta 4MPa toprak penetrasyon direncine kadar 30 cm derinlikten toprak örneği alabilmektedir.Makinenin tarla denemelerinde yapılan ölçümlerde bir strokta toprak penetrasyon direncine bağlı olarak 40-162 gr toprak örneği alabildiği saptanmıştır. Araştırmada makine çalışma hızının alınan toprak örneği miktarına etkisi araştırılmıştır. Denemelerde 0.6 m/s, 0.12 m/s, 0,22 m/s çalışma hızlarında alınan toprak örneği miktarları incelenmiştir. Örneklere uygulanan tek yönlü anova testine göre istatistiki açıdan önemli fark saptanmamıştır (P>0.05). Tarla testleri sonucunda; makinenin toprak örnekleme amacıyla kullanılabileceği saptanmıştır. Ayrıca, GPS modülü yardımıyla coğrafi konum belirlenerek örnekleme yapılabilmektedir. Alınan konum verileri yersel değişkenlik haritaları oluşturabilmek için kullanılabilecek yapıdadır.

Keywords: Hassas tarım, toprak örnekleme makinesi, GPS, toprak penetrasyon direnci

Introduction

In this study, an automatic soil sampling machine was developed and performance tests were carried out on the fields where plow pan was formed.

Soil testing is a useful tool for determining fertility requirements for crops. A regular sampling program can also track the trends and efficiency of a fertilizer program. A soil testing program should be coupled with feed or plant tissue testing for a more complete pool of information from which the producer can make crop management decisions *(Soilfactsheet, 2003)*.

According to *Suprem et al. (2013)*, soil sampling is the foremost process in the field of precision agriculture and about 60% of farmers in advanced countries such as USA, UK, Canada, Australia, etc. have already adopted it into their agricultural activities.

Adamchuk et al. (1999) reported on the development of an automated soil sampling system for rapid determination of soil pH. The system consisted of a lever situated below a soil shank, which collected soil and then rotated to press the soil slurry against the surface of a pH electrode.

Lutticken (2000) reported that the auger and its operation reduce the error in soil data caused by the sampling process itself. Properties such as sensor controlled sampling depth and improved emptying of the auger should allow a more consistent quality and therefore a better description of the spatial distribution of soil nutrients within a field. The system demonstrates the benefits of automation as time taken for sampling has been kept to a minimum. Digital data transfer between farm machinery and Office will not only reduce the risk of error, but also increase the efficiency of farm machinery. Real-time systems including on-board computers and DGPS provide the necessary tools for more standardised processes and automatic machinery controls.

An automated electro-pneumatic soil sampling method (EP) utilizing pressurized air for sample collection was developed and tested in a laboratory setting. Preliminary laboratory results suggest that pressurized air was effective in cutting and transporting soil samples for all soils studied in this experiment. In laboratory tests, the EP method was capable of obtaining a relatively consistent soil sample mass regardless of soil type and compaction level at fixed moisture contents *(Yildirim et al. 2006)*.

Most of soil sampling machines are used with an auger or soil probe for obtaining soil samples. According to *Wendt (2006)*, a soil probe cuts a uniform, unmixed soil core from a given soil surface area. It is the most accurate tool for obtaining soil samples at desired depth increments, and can likewise be used to sample soils on a soil mass basis. Whereas an auger must be re inserted for each depth increment sampled due to disturbance and mixing that can occur between different increments, a single soil probe core can be sectioned into several depth increments.

A good sampling process should consider field area per sample, procedural method including depth, time of sampling, tools, handling, information record form, and transportation. The American Society for Testing and Materials (ASTM) has developed a number of methods that have direct application to soil sampling. Taking soil samples may be done either by hand or by machine. A sampling probe, an auger or a shovel, either stainless steel or chrome-plated, is used for manual sampling (brass, bronze, or galvanized tools are not used because they contaminate with copper, zinc., etc.). However, several manufacturers have developed automated soil sampling equipment with latest techniques for in situ soil investigation *(Suprem et al.2013)*.

In the study, an automatic soil sampling machine was developed which can be integrated with precision farming solution with GPS. When the samples of probe typed soil sampling machines were analyzed, it was seen that sampling machine can work conveniently at the level of compaction resistance values. On the other hand, the information about the performances of this type of machines on the fields, in which plow pan was formed, wasn't encountered. In this study, machine performance tests were carried out on the fields where soil pan was formed.

Materials And Method

Design considerations

As the controlling unit of the machine requires resolute and high force, it is designed in a form in which hydraulic energy is to be used. The soil sampling machine takes the power from the tractor hydraulic power unit. In the hydraulic system solenoid valve and electrically operated limit switchers were used. A manometer in the capacity of 30 MPa was attached to the hydraulic system in order to follow the working pressure of the machine. The working pressure of the machine was adjusted with the pressure safety valve on hydraulic system. In order to be able to change the machine operating speed, flow controlling valve on the hydraulic machine was utilized. The system takes its movement from the hydraulic cylinder of Ø30*300 mm. The stroke of the 300 mm cylinder was increased to 600 mm with a sprocket mechanism.

The soil sampling machine can takes samples from the soil depth of maximum 30 cm in the resistance of 10 MPa._The depth can be adjusted between 10-30 cm by being changed with the help of limit switches. In order to take sample away from auger, a form of sonde was integrated with the auger. As a result of this, the soil samples taken from the adjusted hole were kept homogenous.

The machine can work with two different types of probes with 1,2 cm. and 2,4 cm inner diameter. Depending on the probe diameter, a sample with 34 cm^3 -136 cm^3 volume can be taken from one sampling. The required amount of sampling was reached by increasing sampling number. In Figure 1 the important parts of soil sampling machine and in Figure 2 the general dimensions of them were presented.

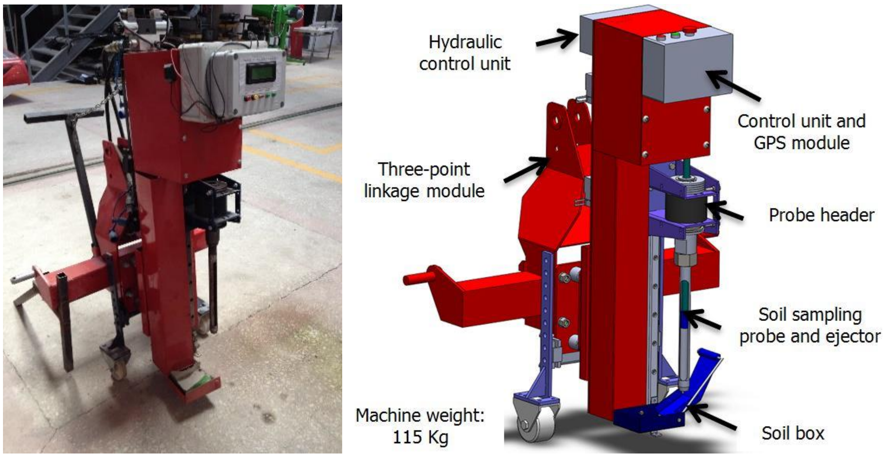


Figure 1. General view and important parts of soil sampling machine

Şekil 1. Toprak örnekleme makinesinin genel görünüşü ve önemli parçaları

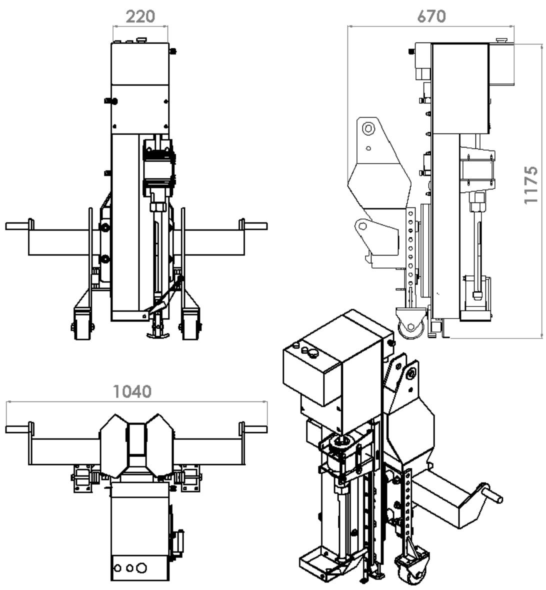


Figure 2. The general dimensions of soil sampling machine

Şekil 2. Toprak örnekleme makinesi genel ölçüleri

The required probe strokes for the machine's taking soil sample were supplied with a hydraulic unit used in the system. The limit switches S1, S2 used in the system and the controlling of 4/3 solenoid valve were supplied with a developed electronic circuit. The circuit diagram of the used hydraulic unit can be seen in Figure 3.

There are a main control unit of the machine, PIC micro controller, accumulator as a power supply, 2 relays for controlling solenoids, 2 switches for setting the limits of the machine, a start button and an emergency stop button in the system. There is also a GPS unit working independently from the main control unit in the system.

Preparing seperate programmes for both units in the application phase, the microcontrolling was loaded on the IC (integrated circuits).

There is a push rod on the developed soil sampling machine used for skimming the soil in the sampling probe. This push rod can be used in Ø10 mm and Ø18 mm of sizes depending on used probe. The pushers were produced in the length of 600 mm using transmission steel material. The pushers can be mounted on the machine by using bolted joint.

Three-point hitch system was used for the soil sampling machine's installing on tractor with three-point hitch system used as standard.

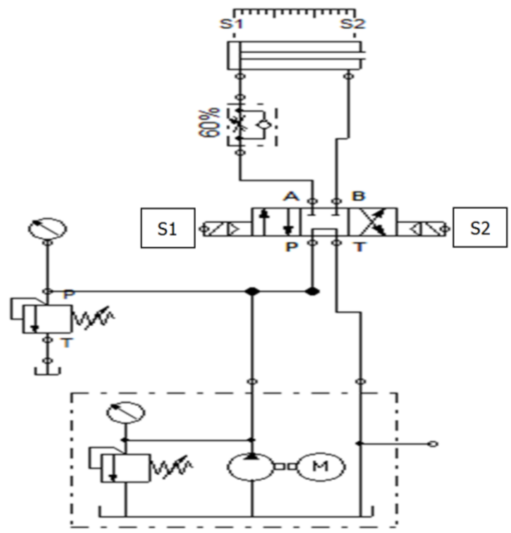


Figure 3. Hydraulic circuit of soil sampling machine

Şekil 3. Toprak örnekleme makinesinin hidrolik devre şeması

Sample Probes

The probe with 12 mm inner diameter was in the length of 600 mm and produced from a HSS material in 18 mm outer diameter and produced in the roughness of 56 HRC. In order to make sample taking easier, a channel in the length of 200 mm and in the width of 11.5 mm was opened from the edge of the probe.

The probe with 24 mm inner diameter was produced in the length of 400 mm, in 30 mm outer diameter, in 24 mm inner diameter and in the roughness of 40 HRC. As it was more economical, St 52 seamless drawn pipe was used as the material of the probe.

In Figure 4, the general 3D views and in Figure 5, the general sizes of the probes are presented.

Figure 4. Soil sampling probes in 12 mm and 24 mm inner diameters

Şekil 4. 12 mm ve 24 mm iç çap ölçülerindeki toprak örnekleme probları.

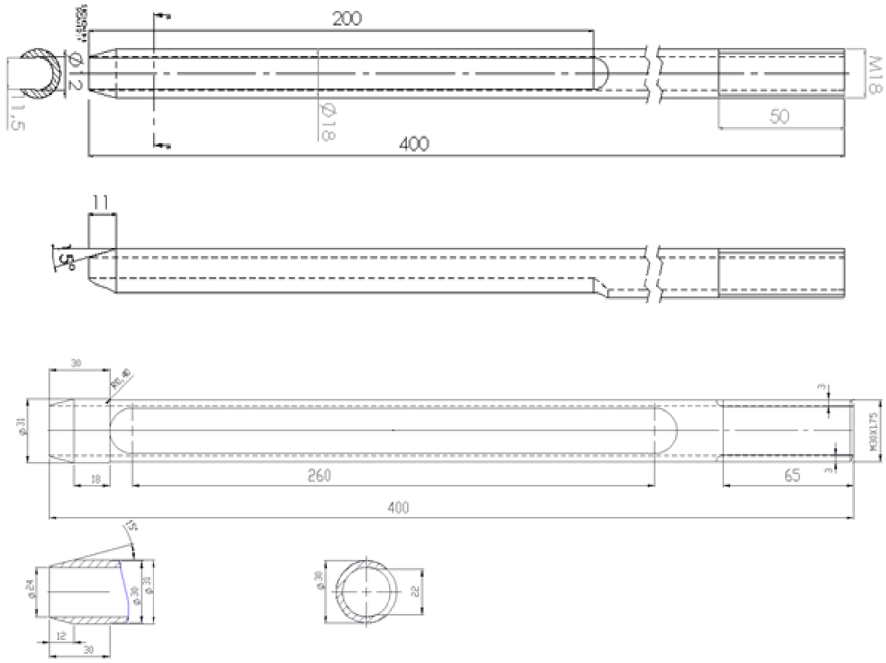


Figure 5. The dimensions of soil sampling probes in 12 mm and 24 mm inner diameters

Şekil 5. 12 mm ve 24 mm iç çap ölçülerindeki toprak örnekleme problarının genel boyutları

In Figure 6, the working algorithm of the machine was presented. As it is seen in the given flow diagram, the system performs emergency stop control when the start button is pushed. If the emergency stop button is pushed, the system quits the application and stops. Similarly, by performing emergency stop control during the working process, the system remains stable as soon as emergency stop button is pushed.

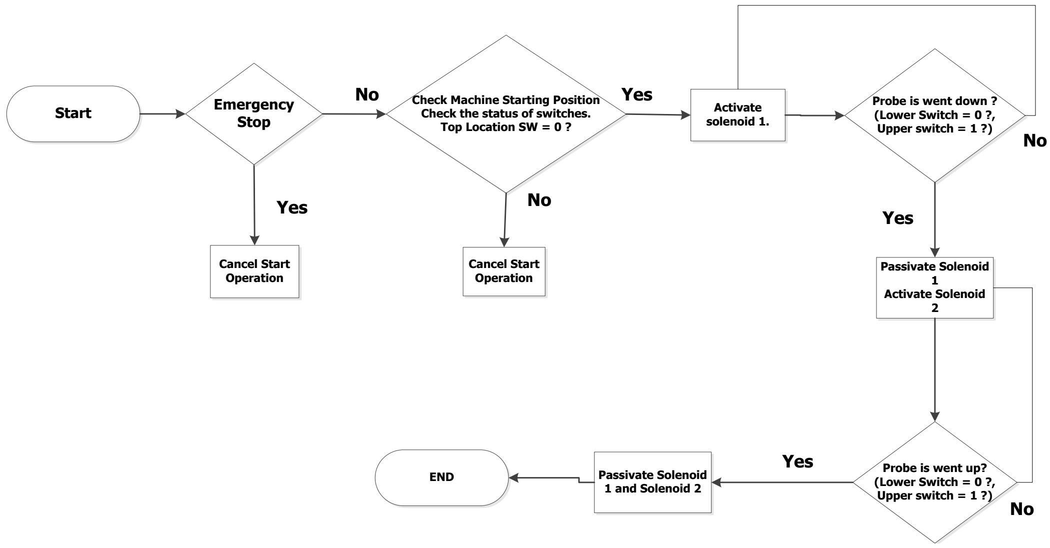


Figure 6. Working algorithm of soil sampling machine

Şekil 6. Toprak örnekleme makinesi çalışma algoritması

Figure 7. Soil sampling machine in field tests

Şekil 7. Tarla denemelerindeki toprak örnekleme makinesi

The sampling system can be installed on different types of vehicle, preferably light weight and low pressure units to ensure a minimum of soil compaction and allow sampling all year round. In Figure 7, soil sampling machine is shown installed on a tractor in field tests.

Arrangement of Field Tests

In order to determine the working performance, the machine was tested on the field in the Main Campus of Namık Kemal University. The tests were performed on two different fields, being close to each other, on whose grounds plow pans were formed. By this means, it was aimed to determine the effect of plow pan on the success of the machine. It is thought that plow pan has an important effect especially on the working performance of soil probe type soil sampling machines. According to Kilic et al. (2004) observations showed that plow pan was occurred about 20cm depths and it has higher soil penetration resistance than 5 MPa. A sample plow pan layer is shown in Figure 8. The soil samples were taken from the same axis being in the distance of 10 cm in case the soil penetration tests didn't have too much difference. Soil layers and soil sampling probe was shown Figure 9. In Figure 10, the soil samples on the probes were shown.

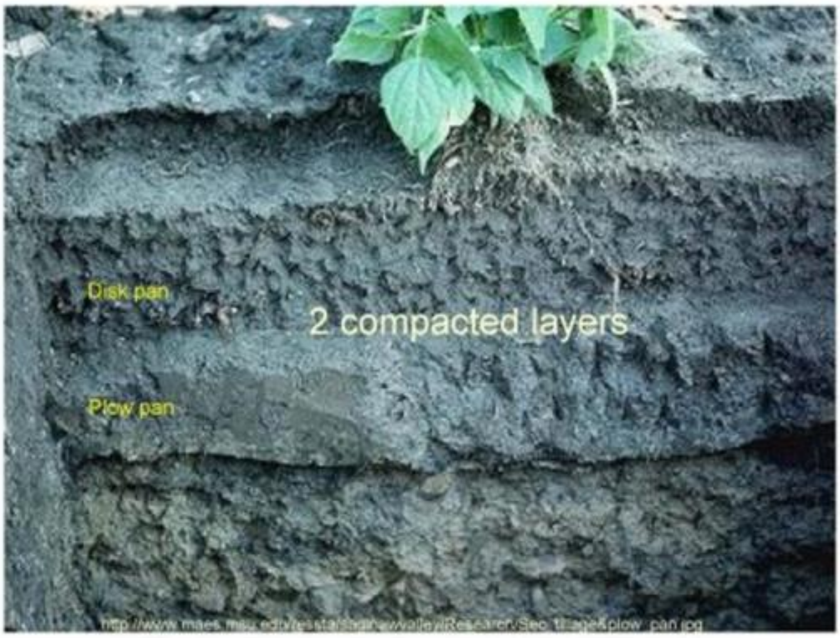


Figure 8. View of soil pan compaction formed in the soil (Gruver and Wander, 2013)

Şekil 8. Toprakta oluşmuş bir pulluk tabanı görünümü,

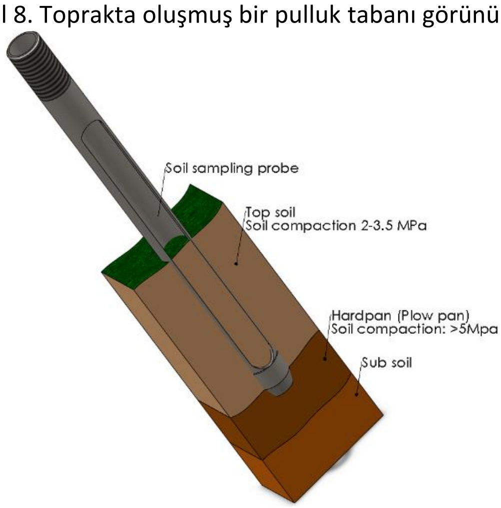


Figure 9. Illustration of soil sampling probe and soil layers.

Şekil 9. Toprak örnekleme probu ve toprak katmanlarının gösterimi

Figure 10. The soil samples on the type Ø12 and type Ø24 probes

Şekil 10. Tip Ø12 ve Ø24 problar üzerindeki toprak örnekleri

Performing 3 or 4 times repeating measurements in two different testing fields, the capacity of the machine was tested in experimental studies. Collected samples were placed in sealed polythene bags and labeled indicating date of collection, location and code number of soil sample (Podder et al. 2012). Scaling the samples taken from field experiments, the sampling capacity of the machine was determined.

Measuring soil penetration resistance in the fields where the experiments were carried out, the values of them were presented in the report. The penetration resistance was measured by using Eijkelkamp Penetrologger. Penetrologger working parameters are presented in Table 1.

Table 1. Eijkelkamp Penetrologger measurement parameters

Çizelge 1. Eijkelkamp Penetrologger ölçüm parametreleri

Cone	1.0cm^2 60^o
Penetrometer.Speed	2
Number Of Plots	2
Penetrometer./Plot	4

Operating pressure was adjusted as 17 MPa with the pressure safety valve on the machine. In the analysis, the probe with 24 mm diameter was damaged in the pressure applied to the probe over 17 MPa. The machine operating speed can be adjusted by the help of flow control valve on the hydraulic system. During the field experiments, the machine was operated at the speed of 0.2 m/s. The sampling depth was determined by the way of measuring penetration depth of the probe and the length of taken sample with the help of tape measure. In order to determine the effect of sampling speed on sampling amount, the sampling was conducted at 3 different operating speeds with the probe of 24 mm diameter. The sampling speed was determined depending on turning down sensibility of flow control valves. The operating speed used were 0.1 m/s, 0.16 m/s and 0.22 m/s. It was foreseen that weight differences between the samples could be determined more preciously with the probe of Ø24 mm which was preferred owing to the fact that the amount of sampling was higher.

In the stresses analysis of the probe edge, maximum von Mises stress criterion was used. This theory is also known as the Shear-energy theory or the Maximum distortion energy theory.

The von Mises stress is expressed as:

$$\sigma\ \text{vonMise} = \sqrt{\frac{(S1-S2)^2+(S2-S3)^2+(S1-S3)^2}{2}} \quad (1)$$

Where S1, S2 and S3 is the principal stresses.

In this conducted study, an electronic circuit was designed for the control of circuit components. Location information appropriate for precious farming can be saved by a GPS module integrated on this circuit.

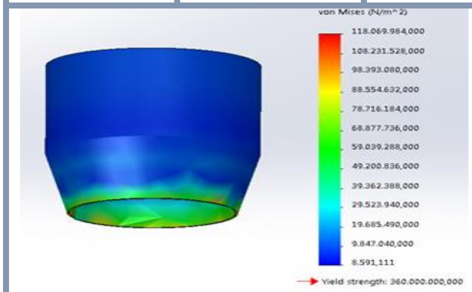
Results And Discussion

The results obtained from the field tests done with automatic soil sampling machine were presented in Table 2 and Table 3. When the Tables were analyzed, the GPS coordinates, sampling taken depth and its grammage were seen.

The plow pan soil resistance was higher than 5 MPa but it couldn't measure the exact value of it because of the buckling of penetrometer probe rod. The upper soil layer penetration resistance was measured with soil penetrometer as ≤3.5 MPa in the areas where the samples were taken. The machine could take samples from the depth of 10-25 cm at these values depends on the plow pan. When we look at the sampling depth, it is seen that the machine can't reach the depth of 30 cm in higher soil penetration resistances than 5 MPa. When the machine reaches the depth of plow pan, as a result of high pan soil penetration resistance, the machine completes its course by lifting itself on its suspension arms. It was thought that sampling depth could be increased by increasing the weight of the machine. 180 kg weight was put on machine suspension arms additionally, and again when the machine reaches plow pan depth, lifting itself on its suspension arms. In the probe analysis done by using Solidworks simulation, it was seen that the probe could exert >10 MPa pressure on the soil. The probe's incapability to take sample from plow pan shows us that this pressure wasn't enough to take sample from plow pan (Figure 11).

The field testing results were presented in Table 2 and Table 3.

Type	Min	Max
von Mises Stress	0.0086 MPa Node: 10695	118.07 MPa Node: 12849



Uç analiz-Static 1-Stress-Stress1

Figure 11. The sampling probe tip stress analysis.

Şekil 11. Örnekleme probu ucunda oluşan gerilme analizi

Table 2. Field 1 the experiment results

Çizelge 2. Tarla 1 deney sonuçları

Field 1	Date: 18.06.2013	Sample 1	Sample 2	Sample 3	Sample 4
	GPS Data Latitude Longitude	40°59'50.24" N 27°35'21.03" E	40°59'49.82" N 27°35'21.26" E	40°59'49.19" N 27°35'21.49" E	40°59'48.78" N 27°35'21.66" E
	Soil Layers Penetration Resistances				
Probe Ø12	Upper soil layer (Average) (MPa)	3.5	3.5	3.5	3.5
	Plow pan layer (MPa)	>5	>5	>5	>5
	Sampling depth (cm)	15	15	15	15
	Plow pan	15	15	15	15

	depth (cm)				
	Sample weight (gr)	25	18.5	22.6	26
Probe Ø24	GPS Data Latitude Longitude	40°59'48.90" N 27°35'22.43" E	40°59'49.43" N 27°35'22.15" E	40°59'49.98" N 27°35'22.04" E	40°59'50.51" N 27°35'21.82" E
	Soil Layers Penetration Resistances				
	Upper soil layer (Average) (MPa)	3.5	3	3.5	3.5
	Plow pan layer (MPa)	>5	>5	>5	>5
	Sampling depth (cm)	25	10	15	15
	Plow pan depth (cm)	25	10	15	15
	Sample weight (gr)	136.4	23.7	66.1	91

Table 3. Field 2 the experiment results

Çizelge 3. Tarla 2 deney sonuçları

Field 2	Date: 18.06.2013	Sample 1	Sample 2	Sample 3	Sample 4
Prop Ø12	GPS Data Latitude Longitude	40°59'49.19" N 27°35'19.54" E	40°59'48.48" N 27°35'19.90" E	40°59'47.93" N 27°35'20.08" E	40°59'47.33" N 27°35'20.34" E
	Soil Layers Penetration Resistances				
	Upper soil layer (Average) (MPa)	3.5	3.5	3.5	3.5
	Plow pan layer (MPa)	>5	>5	>5	>5
	Sampling Depth (cm)	20	20	20	20
	Plow pan depth (cm)	20	20	20	20
	Sample weight (gr)	28.3	31.8	29.3	33.5
Prop Ø24	GPS Data Latitude Longitude	40°59'47.19" N 27°35'19.37" E	40°59'47.79" N 27°35'19.06" E	40°59'48.45" N 27°35'18.81" E	40°59'49.28" N 27°35'18.47" E
	Soil Layers Penetration Resistances				
	Upper soil layer (Average) (MPa)	3.5	3.5	3.5	3.5
	Plow pan layer (MPa)	>5	>5	>5	>5
	Sampling Depth (cm)	20	25	20	20
	Plow pan depth (cm)	20	25	20	20
	Sample weight (gr)	83.1	162.6	99.1	89.5

The effect of soil sampling speed on the amount of sampling was studied. The machine sampling amount at different sampling speed was given in Table 4. In the tests, the amount of soil samples taken at the operating speed of 0.6 m/s, 0.12 m/s, 0.22 m/s was analysed. Statistically, a significantdifference wasn't determined according to the one way anova analysis which was carried out on the samples (P>0.05).

Table 4. The experimental results in different sampling speeds

Çizelge 4. Farklı örnekleme hızlarındaki deney sonuçları

Soil Sampling speed (m/s)	Coordinates	Soil Penetration Resistance (MPa)		Sample weight (gr)	Soil moisture (%)
		Upper soil layer (Average)	Plow pan		
1 (0,22 m/s)	40°59'70.72" N 27°35'14.07" E	3	>5	64.7	1,05
2 (0,16 m/s)		3	>5	45.0	1,05
3 (0,1 m/s)		3	>5	69.9	1,32
1 (0,22 m/s)	40°59'70.71" N 27°35'14.06" E	3	>5	48.6	0,96
2 (0,16 m/s)		3	>5	40.0	0,77
3 (0,1 m/s)		3	>5	43.7	1,08
1 (0,22 m/s)	40°59'70.70" N 27°35'14.04" E	3	>5	58.1	1,19
2 (0,16 m/s)		3	>5	40.3	0,62
3 (0,1 m/s)		3	>5	53.0	0,88

Conclusions

The followings were concluded from the study:

In the experimental study, it was found out that the mechanical and electronical parts of the machine operated successfully.

When the sampling depths were looked, it was seen that the aimed 30cm depth couldn't be reached. This situation was due to the fact that the soil penetration resistance of plow pan was too high (>5MPa). In the field where the soil sample was taken, the soil penetration resistance till the depth of plow pan was measured as 2-3.5 Mpa. Consequently this affected plow pan sampling depth formed on the field base and the machine was not able to take samples from plow pans due to higher pressure requirements. In the tests, it was seen that the soil penetration resistance must be at the values of 3-4.5 MPa in similar machines for ideal soil sampling operations. The machine could take samples from the depth of 10-25 mm range till to the plow pan.

The effect of machine operating speed on the capacity of soil sampling couldn't be determined. This was interpreted as an indicator about which the machine could take same amount of soil sample without being affected by the change in stated speed range.

When the difficulty of people's soil sampling with shovel/auger etc. is thought, they are going to be able to perform soil sampling in the whole farm easily and the costs are going to be reduced by enhancing the developed automatic soil sampling machine.

As the sampling amount collected with the 12 mm diametered probe was very low obviously the use of probes of 20 mm and above diameter will be more productive in general.

It was seen that the sampling depth of soil probe type-in the study changed depending on the depth of plow pan. it can be concluded that the use of hammer type or auger type soil sampling machines will be more appropriate for the depths below plow pan depth.

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