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Research article

Drone application with low-cost remote-controlled earth-drilling machine for modern agriculture

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Abstract

Importance of the work: Drilling can be modeled using an up-and-down drive algorithm, controlling an 18 V, wireless, hand-held drill. When the radio-controlled drill rotates counterclockwise, the earth drilling machine moves downward along the spiral axis, creating a drill hole.

Objectives: To design and fabricate a drone with a low-cost, remote-controlled, earth-drilling machine for use in modern agriculture.

Materials & Methods: A drone was designed and created with a body and driving system using an Arduino board and motor drive module design. A system was developed to control the up and down movement of the drill to make holes remotely. The working speed (in kilometers per hour) and its impact on working capacity (in hectares per hour) were assessed, including fuel consumption (in liters per hour) and electricity consumption (in kilowatt hours)

Results: With an increase in working speed, both fuel and electricity consumption increased. At a working speed of 0.04 km/hr, the fuel consumption was 0.5 L/hr, resulting in electricity consumption of 0.541 kWhr and a working capacity of 0.05 ha/hr. A cross-comparison of the readings from the soil compaction meter revealed a good correlation between the working capacity trend for clay soil and loamy soil.

Main finding: The developed specially designed earth-drilling machine for modern agriculture could drill holes in real time with a system for controlling the drilling up and down position using a remote control. Soil compaction maps at (3 mth and 6 mth) were developed using the ArcGIS® software.

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Introduction

A remote-controlled system has recently become an essential component of modern engineering processes, ensuring high productivity, accuracy, quality and low production costs (Samseemoung et al., 2011). Work in the field of electronics in agriculture has included smart machines (Samseemoung et al., 2012; Jayasuriya and Sangpradit, 2014), geographic information system (GIS) application mapping (Sammseemoung et al., 2016), unmanned aerial vehicles (Soni and Salokhe, 2016), plant disease monitoring (Samseemoung et al., 2017a, b) and precision agriculture (Sirikun et al., 2021) to support local farmers and to raise the output per area (Jarimopas and Jaisin, 2008; Indarto et al., 2022).

Nowadays, commercial forest plantations have become increasingly more popular (Holl and Brancalion, 2020). Besides providing timber and fuel, trees are now recognized for their roles in carbon storage and sequestration as important mitigation steps for global warming (Nowak et al., 2013). Labor represents a major cost in tree planting (Godoy, 1992) including the digging the hole for the seed or seedling (Fig. 1). Therefore, the current study conceived, constructed, and tested a low-cost, remote-controlled earth digger that works with drones to survey the whole area before digging. This technology should not only save cost and time but also make modern agriculture more interesting to younger generations of workers, as well enabling both the elderly and disabled to engage in agriculture.

The field of study of reducing vibration for drilling machines has been the subject of research globally. Le and Dang (2020) introduced a fuzzy compensation control algorithm based on fuzzy logic to control the rotational speed of a C-250T drilling machine. Their proposed solution used an artificial neural network instead of a vibration-measuring sensor to identify the amplitude and vibration frequency of a rotary drill. The vibration amplitude, vibration frequency and setpoint of the drilling speed were used as the input variables for the fuzzy logic unit.

The main goal was to develop a drone containing a cheap, remote-controlled, earth-drilling machine for use in modern agriculture by identifying the external factors affecting the accuracy of low altitude imagery, to explore the capabilities of integrating the camera, location, soil compaction, working capacity, electricity and fuel consumptions details in clay and loamy soils (Fig. 2).

(A) (B)

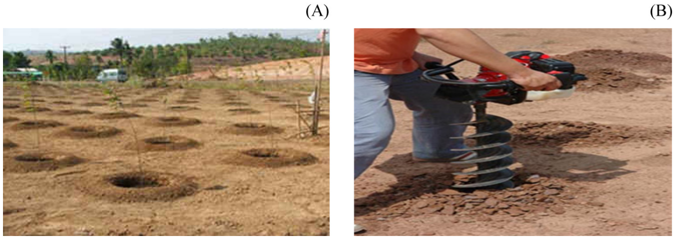

Fig. 1 (A) *Dipterocarpus alatus* Roxb. Ex G. Don aged 7 mth transplanted to holes with 40 m × 40 m spacing; (B) Traditional hand-held drilling method

Materials and Methods

Experimental field and setup arrangements

The experimental field was located at Bang Luk Suea, Ongkharak, Nakhon Nayok province, Thailand (14.0924°N, 101.0934°E). The distance between the planted *Dipterocarpus alatus* Roxb. Ex G. Don seedlings aged 7 mth was 4 m and the distance between rows was 4 m (625 trees/ha) in an experimental area of 40 m × 40 m. Fertilizer was applied at a rate of 59–91 kg/ha for nitrogen, 27–40 kg/ha for phosphorous and 85–131 kg/ha for potassium. Table 1 presents the physical characteristics of the soil on the site.

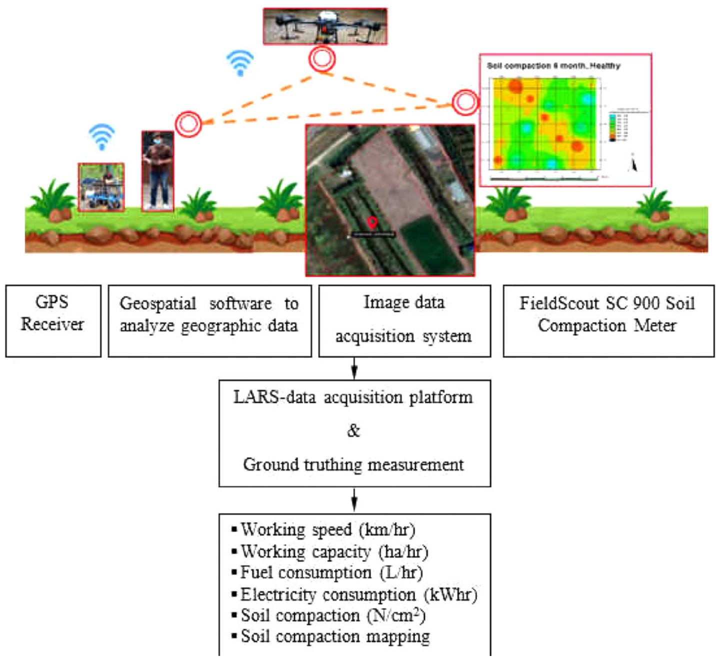

Fig. 2 Schematic overview of system for low-cost drone with remote-controlled, earth-drilling machine

Table 1 Physical characteristics of the soil and how fertilizer is used in *Dipterocarpus alatus Roxb. Ex G. Don (Yang)* plantations

Yang age (yr)	Rate of fertilizer 15-15-15 (kg/m^2)	Magnesium sulfate, $MgSO_4$ (kg/m^2)	Dolomite, CaMg $(CO_3)_2$ (kg/m^2)
3	1	0.1	1
4	2	0.1	2
5	3	0.1	3
Soil depth (cm)	0–20		
pH	6–7		
Soil Texture	Clay		
Sand (%)	15		
Silt (%)	30		
Clay (%)	60		
Organic matter (%)	1.64		
Particle density (g/cm^3)	2.44		
Bulk density (g/cm^3)	1.39		
Moisture content (%) d.b.	25		

Design of body and driving system

The soil drill blade (Drill bit 4-inch diameter depth 900 mm 35:1 ratio 170 rev/min; Japan), solar cell (2 Solar panel 12 V 30 W Polycrystalline; DoHome.co.th; Thailand), power transmission system (Mitsubishi TL52 5 hp 7000 rev/min; Japan) and radio-controlled digger structure were the four basic parts of the developed unit. The design process involved gathering study data and applying knowledge and technical principles to enable the remote-controlled digger to function as envisioned. The fabrication of the remote-controlled earth drilling machine was carried out at the Faculty of Engineering, Agricultural Machinery Engineering Laboratory building, Rajamangala University of Technology Thanyaburi, Pathum Thani province, Thailand.

Arduino board and motor drive module design

The Arduino board (Uno R3; Shenzhen Shanhai Technology Ltd.; China) in the radio control system was used to instruct the digger's motor drive (AC magnetic motor 2RK6GN-AMw/2GN60K gear head; Oriental Motor Co. Ltd.; Japan) to go forward and backward using a remote control (FS-i6X Flysky fsi6x i6x Radio; 2.4 GHz 10 ch with remote receiver ia6b x 6b; Mode 2; Thailand). The Microcontroller Unit (MCU, Shenzhen Shanghai Technology Ltd.; China) was programmed to operate other electrical equipment by controlling the transmission of electrical signals in accordance with various conditions.

System design for remotely controlling the up and down position of drilled holes

The vertical tree planting hole was generated using the algorithm of driving up and down resulting from the operation of the 18 V wireless hand-held driller (NASH Cordless Drill No. LI-ION; DoHome.co.th; Thailand) and the 40 mm bevel gear (40 mm bore, 40 teeth, 1.0 Module; RS Components Co., Ltd; Thailand). When the wireless driller rotated counterclockwise, the digger engine (TL52 5 hp 7000 rev/min; Mitsubishi; Japan) moved down the threaded shaft and caused the digger to spin up. The thread shaft downward/upward speed was 10 m/s.

Slip test

An earth-drilling machine wheel was marked to facilitate recording complete revolutions. The estimated ground digger's theoretical range when operated remotely was calculated as five wheel revolutions multiplied by the circumference. Steel markers at the starting and ending points and a measuring tape were used to determine the actual trip distance. For each plot, the test was carried out three times. The loaded distance was the distance that the earth drilling machine could move while the blade was still turning; unloaded distance was the distance that the earth drilling machine could move while the blade was not turning. The percentage slip was calculated using Equation 1:

$$\%\ \text{Slip} = \frac{\text{Unloaded distance - Loaded distance}}{\text{Unloaded distance}} \times 100 \qquad (1)$$

where all distances are measured in meters.

Working speed

The working speed of the machine was determined by placing two poles 10 m apart and measuring the time it took for the machine to move between the two poles. This was repeated five times for each plot and the results were averaged.

Fuel consumption

The fuel tank was filled completely before commencing the experiment. A volumetric beaker was used to measure the amount of fuel used per plot for a covered distance of 10 m. Competency, fuel and energy usage rates were determined based on Equations 2–4 (Samseemoung et al., 2017a):

$$\text{Actual working performance} = \frac{\text{Actual working area}}{\text{Total time}} \qquad (2)$$

where the actual working performance is measured in hectares per hour, the working area is measured in hectares and the total time is measured in hours.

$$\text{Fuel consumption rate} = \frac{\text{Total oil consumed}}{\text{Total time}} \quad (3)$$

where the fuel consumption rate is measured in liters per hour, the total oil consumed is measured in liters and the total time is measured in hours.

$$\text{Electricity consumption rate} = \frac{\text{I x V x t}}{1{,}000} \quad (4)$$

where I is the electrical current measured in amperes, V is the electromotive force measured in volts and t is the working time measured in hours.

Statistical analysis

Each measurement was made in triplicate and the experimental data were analyzed using the SPSS 11.5 software (SPSS Inc; USA). Analysis of variance was used to determine the significance between treatments and Duncan's multiple range test was used to compare the means at the 95% confidence level. Regression analysis was carried out using the Excel software (Microsoft Inc; USA).

Mapping and geostatistical analysis

A linearly weighted combination of a set of sample points was combined with the inverse distance weighted interpolation procedure to calculate cell values for geostatistical analysis. The inverse distance was used to determine weights, where the interpolated surface represented a location-dependent variable. A low-cost drone (model #GCS-9, Lipo Battery 6S1P 14,000 mAh 22.2 V; Kaset Genn Y Co. Ltd., Thailand) platform simultaneously captured field images and the GPS output. The method integrated the plot-based images from the drone camera with data manually collected through on-ground surveying (Samseemoung et al., 2011). Prior to mapping, excess areas outside the ground limits were masked, trimmed and corrected for altitude. The actual ground coordinates of reference locations were utilized to merge all the photos into a matrix and create a combined image. The final land image was transformed into GIS map layers using the ArcGIS® software (Esri (Thailand) Co., Ltd.; Thailand), and then used for additional analysis. Soil data were gathered in the field using a soil compaction meter (FieldScout SC 900; Spectrum Technologies, Inc., USA).

Results and Discussion

Design of algorithm, direction and position controlling system and remote monitoring system for low-cost, remote controlled, earth-drilling machine

The time it takes to dig holes for planting trees could be halved by integrating the design, prototyping, testing and assessing a low-cost, remote-controlled, earth-drilling machine. The final prototype machine had a 101.6 mm diameter soil auger and a 5 Hp motor powered by a 12 V battery. The small engine, solar panels, drill blade, drive motor, steel shaft, bevel gears, wheels and chassis comprised the primary structure. The advantages of the construction included the ability to apply a low-cost, remote-controlled, earth-drilling machine on a domestic or commercial scale (Figs. 3 and 4). Based on the test findings and depending on the soil conditions (Table 1), up to 1,000 holes could be drilled daily, with an average drilling time of 3–4 min per hole and a hole size of 203.2 mm in diameter and 304.8 mm deep. The technique was designed to be simple and practical. The machine was sent to the location by the control system after turning on the power. The machine needed to be operated to lift the drill blade once the desired hole had been made and to move on to the next drilling site. Engineering expertise particularly in the area of agricultural machinery engineering, was used in the structural analysis and design of the prototype. Numerous testing phases are anticipated to refine the original prototype in response to feedback from farm workers (Samseemoung et al., 2017b; Sirikun et al., 2021).

Effect of soil compaction values and working capacity on clay and loamy soils

The results based on the readings from the soil compaction meter revealed (Fig. 5 and Table 2) a good correlation between the working capacity trends for clay soil and loamy soil with the soil compaction values (R^2 values of 0.7038 and 0.8615, respectively) (Samseemoung et al., 2017a; Sirikun et al., 2021).

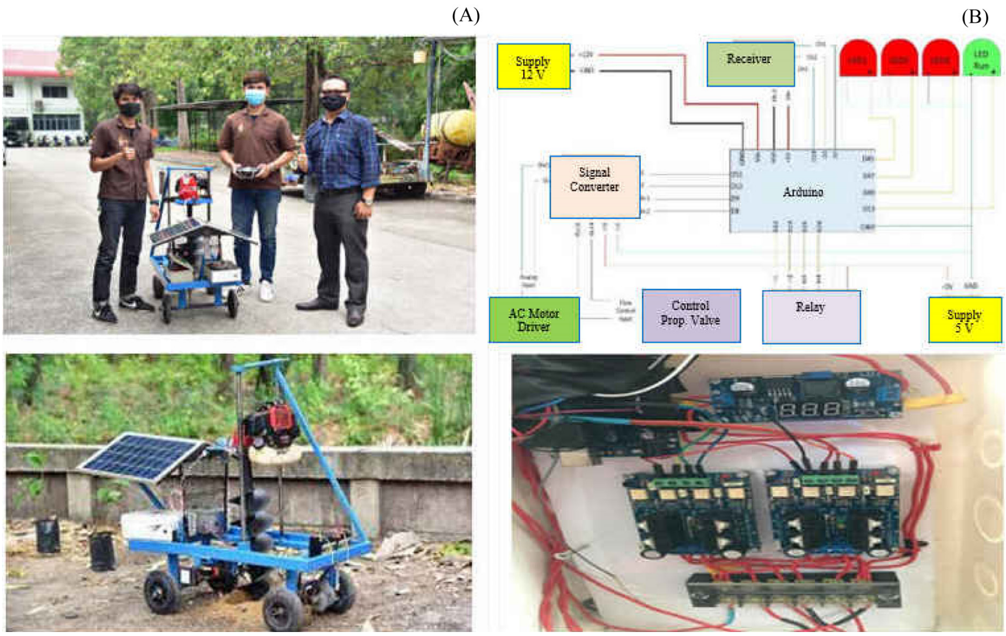

Fig. 3 (A) Low-cost remote controlled earth drilling machine; (B) Schematic diagram of direction and position controlling system

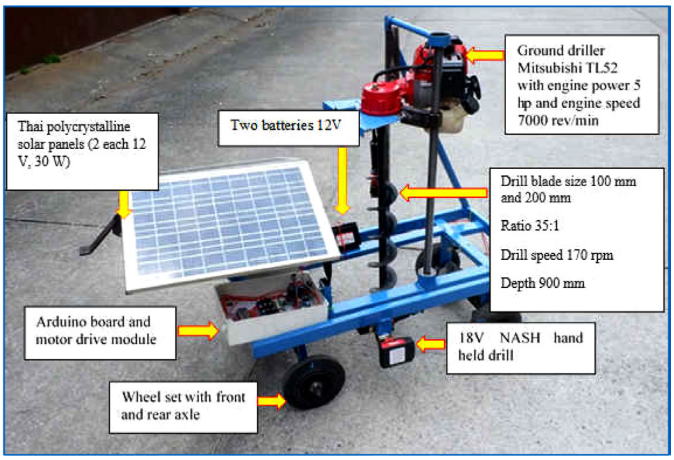

Fig. 4 Configuration for low-cost, remote-controlled, earth-drilling machine

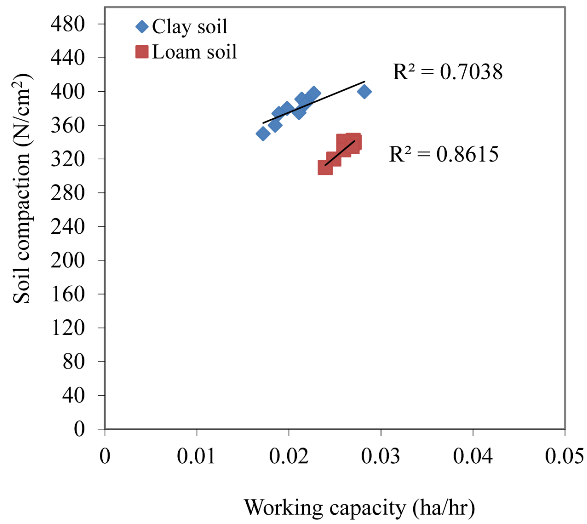

Fig. 5 Correlation between working capacity and soil compaction for clay and loamy soils

Table 2 Type of soils, actual performance, soil compaction rate, and working speed (Moisture content [%db], 25)

Type of soil	Slip test (%Slip)	Working speed (km/hr)	Working capacity (ha/hr)	Soil compaction (N/cm^2)
Clay	20.58	0.01	0.025±0.001[a]	350.00±2.00[d]
Clay	24.70	0.02	0.030±0.010[ab]	374.00±4.58[e]
Clay	32.93	0.03	0.040±0.010[bc]	391.00±2.00[f]
Clay	41.17	0.04	0.050±0.010[cd]	400.00±2.52[g]
Loamy	22.23	0.01	0.027±0.001[a]	310.00±2.65[a]
Loamy	27.99	0.02	0.034±0.001[ab]	320.00±3.00[b]
Loamy	39.52	0.03	0.048±0.001[cd]	335.00±5.57[c]
Loamy	43.64	0.04	0.053±0.001[d]	340.00±2.65[c]

Data were reported in mean ± standard error. Means for each characteristic superscripted by different lowercase letters are significantly ($p < 0.05$) different.

Effect of actual performance, fuel consumption rate, electricity consumption rate and working speed of prototype machine

The results showed that the speed had a direct relationship with fuel consumption, with expected movement at speeds of 0.01 km/hr, 0.02 km/hr, 0.03 km/hr and 0.04 km/hr having fuel consumption rates of 0.25 L/hr, 0.298 L/hr, 0.446 L/hr and 0.500 L/hr, respectively, with working capacity levels of 0.025 ha/hr, 0.03 ha/hr, 0.04 ha/hr and 0.05 ha/hr, respectively. The working capacity increased as the soil compaction decreased. The electrical consumption was 0.498 kWhr, 0.542 kWhr, 0.624 kWhr and 0.641 kWhr, respectively, at the four speeds tested as shown in Fig. 6 (Samseemoung et al., 2012).

Soil compaction mapping

The study's findings revealed that when measuring soil compaction in *Dipterocarpus alatus Roxb. Ex G. Don (Yang)* plantation plots with the FieldScout SC 900 Soil Compaction Meter, test plots measuring 40 m × 40 m should be divided into smaller sections measuring 5 m × 5 m in order to collect data on soil compaction and GPS coordinates for latitude and longitude (Garmin Legend H Handheld GPS Navigator, 24 MB of internal memory, High-sensitivity, WAAS-enabled GPS receiver; Garmin Ltd.; USA). Later, a GIS application mapping of soil compaction (3 mth and 6 mth) that included spatial data on the fields was created using the ArcGIS® software (Astanakulov et al., 2021).

Figs. 7 and 8 show that high compaction was evident and that the plotted soil compaction values had a uniform distribution. The soil condition being reclaimed for 3 mth, (orange-colored in Figs. 7 and 8) was scattered along the perimeter of the test site; however, after 6 mth, the dispersion of compacted soil was high along the diagonal of the test area.

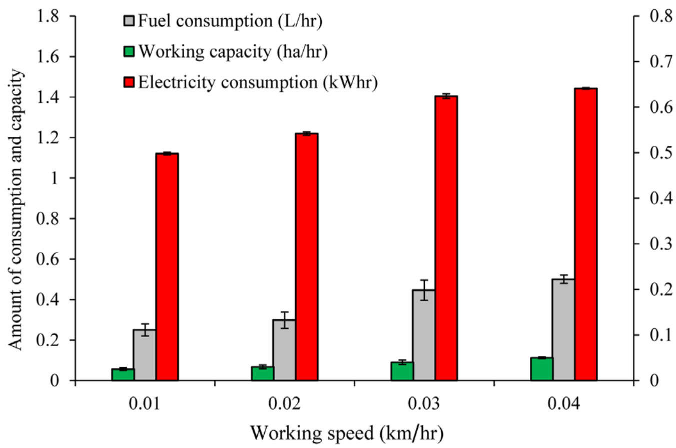

Fig. 6 System field performance for low-cost, remote-controlled, earth-drilling machine

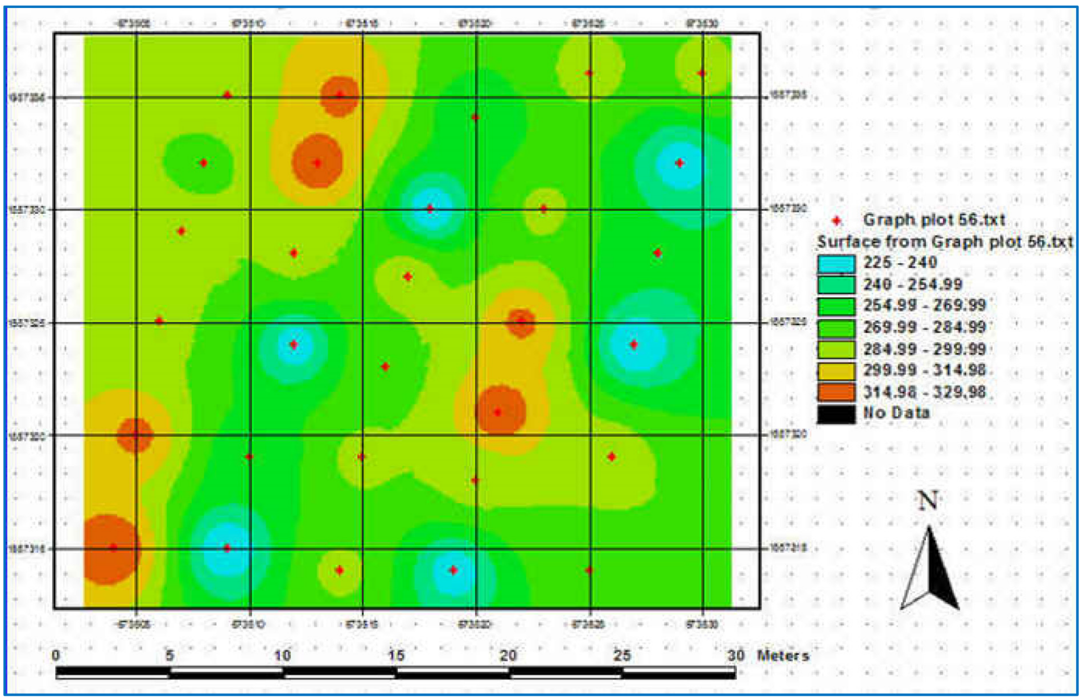

Fig. 7 Soil compaction map (3 mth) created using ArcGIS® software

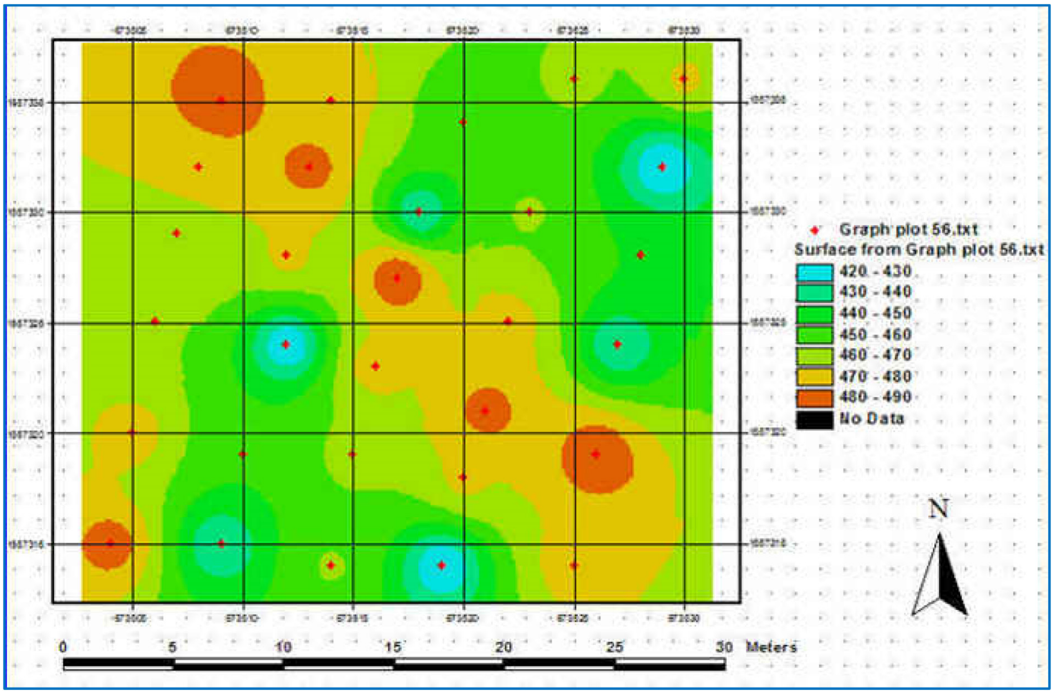

Fig. 8 Soil compaction map (6 mth) created using ArcGIS® software

Conclusions

The main components involved in the design and fabrication of a low-cost, remote-controlled, earth-drilling machine for modern agriculture consisted of the vehicle's wheels, drilling component, power transmission system and the radio-controlled unit. The working speed had an impact on all the attributes when the influence of working capacity was assessed, including fuel consumption and electricity consumption. An increase in working speed increased both fuel and electricity consumption. At a working speed of 0.04 km/hr, the fuel consumption was 0.5 L/hr, which resulted in electricity consumption of 0.641 kWhr and a working capacity of 0.05 ha/hr.

Cross-comparison of the readings from the FieldScout SC 900 Soil Compaction Meter revealed a good correlation between the working capacity trends for the clay and the loamy soils, with soil compaction R^2 values of 0.7038 and 0.8615, respectively. The ArcGIS® software application successfully produced soil compaction maps at 3 mth and 6 mth.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

A local farmer in Bang Luk Suea, Ongkharak, Nakhon Nayok provided the experimental site. Financial support was provided by Rajamangala University of Technology Thanyaburi (RMUTT), Faculty of Engineering, Agricultural Engineering, Thanyaburi, Pathum Thani, Thailand.

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