Development of an electric hand tractor (e-Tractor) for agricultural operations

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Abstract. The development of an e-Tractor for agricultural operations was conducted in response to innovative and environment-friendly technologies utilizing non-fossil fuel as a source of energy. Design considerations were taken from the Needs and Design Assessment (NADA) of the intended beneficiaries such as transport of agricultural product and/or for human mobility requirement and for plowing operations. The e-Tractor was designed with a 3-kW direct current electric motor as prime mover and 5.76 kWh battery system as the power source. The machine was tested for transport with trailer attachment using three speed settings (low -2 kph, medium -5 kph, high -7 kph) and three load settings (0 kg, 200 kg, and 400 kg). Test results showed that the e-Tractor can operate at an optimum setting of 7 kph with 287.8 kg load resulting in an operational time of 127.5 minutes and a travel distance of 14.33 km. The obtained field efficiency for the plowing operation using three trials was about 92.29\% with a theoretical field capacity of 0.11 ha/h. The development of an operational electric hand tractor facilitates agricultural product mobility as an alternative RE Technology for plowing operation with minimal negative environmental impact.

1. Introduction
In recent years, the promotion and utilization of agricultural mechanization technologies (AMTs) have been purposively implemented by the government and by different stakeholders in the food value chain to propel agricultural production. With the advancement of technology, most of the Research and Development Institutions (RDIs) and Higher Education Institutions (HEIs) involve in the agricultural sector in the country have been focusing on innovative technologies to cope up with the demand of the ever-growing population.

Among the AMTs that are widely adopted and utilized in the agricultural production systems is the hand tractor or two-wheel tractor powered by small internal combustion engines. It is a single-axle machine powered by a 3 hp to 15 hp small internal combustion engine. It is commonly utilized for land preparation, planting, cultivating, harvesting, and transport. It was revealed that among the farmer-operator of hand tractors in Laguna, Philippines, 68\% used the machine for land preparation operation while the other 32\% utilized the machine for weeding and/or hauling and transport [1].

Hand tractors can be classified as either traction or pull type; rotary type; or general-purpose type. The traction type hand tractor has a drawbar which provides a pulling power for implements. Rotary
type tractors make use of rotating blades to cut through and pulverize the soil. General-purpose type, on the other hand, makes use of both the drawbar for traction and the power take-off (PTO) shaft for doing rotary work. The power from the engine on these hand tractors is transferred to the wheels or to the PTO shaft through the transmission system which can be in the form of belt and pulleys assembly, chain and sprockets, gears or direct drive [5].

The hand tractor becomes a necessary machinery in today’s agriculture. Its utilization primed with gasoline and diesel engines dominate the mobile operations in the agricultural production systems. However, its utilization has become more and more expensive because of the rising costs of fossil fuels. Moreover, the use of small internal combustion engines has been contributing to gas emissions polluting the air and the environment. To address these problems, researches were focused on the utilization of renewable energy or green energy as alternative source of power in the farm.

This study focuses on the development of an innovative technology utilizing green energy to power hand tractors which are intended for agricultural operations while preventing the emission of harmful gases that contribute to the pollution and degradation of the environment. The development of the electric hand tractor (e-Tractor) is seen as an innovative substitute for the conventional hand tractor which utilizes internal combustion engines. It uses an electric motor as a prime mover and a battery system as the power source. The use of electric motors is perceived for stationary operations in the agricultural production systems. Hence, this innovation will serve as a starting point for the use of electric motors for mobile applications in Philippine agriculture.

The main objective of the study is to develop an electric hand tractor (e-Tractor) for transport. Specifically, it aims to:

a. establish the design parameters for the e-Tractor through the conduct of Needs and Design Assessment (NADA) of the intended beneficiaries;
b. design and fabricate an e-Tractor for agricultural operations;
c. evaluate the performance of the designed e-Tractor for transport and plowing; and
d. determine the optimum working condition (speed [kph] and load [kg] settings) of the e-Tractor for transport.

2. Materials and Methods

The development of the e-Tractor is part of the Green Spark Project for un-energized communities implemented through the collaboration of the Institute of Agricultural Engineering and the Civil Engineering Department, College of Engineering and Agro-Industrial Technology (CEAT), University of the Philippines Los Baños and funded by the National Grid Corporation of the Philippines (NGCP).

2.1 Conduct of Needs and Design Assessment (NADA)

The Green Spark project site identified by NGCP is in Brgy. Macabud, Rodriguez, Rizal, Philippines where the Needs and Design Assessment (NADA) was conducted. The project site is basically an agricultural-based area with no supply of electricity from the grid of NGCP. A questionnaire was formulated based on the needs of the intended beneficiaries on the utilization of hand tractor for agricultural applications. A total of 70 respondents were identified for the NADA survey taken from stratified random sampling calculated using Equation 1:

\[
ssf = \frac{sso}{1 + \frac{sso - 1}{pop}} ; \quad sso = \frac{n^2(P)(1-P)}{(C.I.)^2}
\]

where:
ssf is the sample size for finite population
sso is the sample size for considerably infinite population
pop is the population number
z is the z-value for a given confidence level (2.576 for 99% C.L.)
C.I. is the confidence interval
z is the z-value for a given confidence level (2.576 for 99% C.L.)
P is the percentage (0-1)

2.2 Design and Fabrication of the e-Tractor
Using the data obtained from the NADA, the e-Tractor was designed using a computer-aided design software, AutoCad ®. The main design consideration is the type and load of agricultural product to be transported. The prime mover power rating was based from the conventional small hand tractor primed with small internal combustion engine and was computed using Equation 2:

\[ Motor \ Power = \left( \frac{z}{\sqrt{2}} \right) \times (Internal \ Combustion \ Engine \ Power) \]  

(2)

The e-Tractor was fabricated at the CEAT Shop, CEAT, UPLB. The fabrication materials were acquired from local suppliers while the electric motor components were imported from foreign suppliers.

2.3 Testing of e-Tractor
The e-Tractor was tested in transport mode using three different speed and load settings as independent variables with distance and duration of travel as dependent or response variables. The test was conducted at Pili Drive, CEAT, UPLB, College, Laguna, Philippines. The speed of the e-Tractor varied from 2 kph (low), 5 kph (medium), and 7 kph (high). The load was varied from 0 kg, 200 kg, and 400 kg. A total of nine (9) trials was done for the different speed and load settings. For the plowing operation, a two-bottom disc plow was attached to the e-Tractor and was tested at the test area of the Agricultural Machinery Testing and Evaluation Center (AMTEC), UPLB, Los Baños, Laguna.

2.4 Data Analysis
The data obtained from the transport test was analyzed using the Design Expert 11. The optimum speed and load settings were determined by maximizing the distance and time of travel for the e-Tractor. For the plowing operation, the actual (Equation 3) and theoretical field capacities (Equation 4) were computed including the field efficiency (Equation 5).

\[ Actual \ Field \ Capacity = \left( \frac{Distance \times Effective \ width}{Time \times 10,000} \right) \]  

(3)

where:
Distance is the distance travelled by the e-Tractor in meters
Effective width is the width of cut of the disc plow in meters
Time is the duration of travel in hours

\[ Theoretical \ Field \ Capacity = \left( \frac{Theoretical \ Speed \times Effective \ Width}{10,000} \right) \]  

(4)

where:
Theoretical Speed is the speed of the e-Tractor in meters per second
Effective width is the width of cut of the disc plow in meters

\[ Field \ Efficiency = \left( \frac{Actual \ Field \ Capacity}{Theoretical \ Field \ Capacity} \right) \times 100 \]  

(5)
3. Results and Discussion

3.1 Needs and Design Assessment (NADA)

NADA was first conducted at Brgy. Macabud, Rodriguez, Rizal. Residents from the four sitios of the barangay (Proper I, Proper II, Udiongan, and Calumpit) served as the sampling population. A total of 70 respondents were interviewed for the survey. They were randomly selected and identified from the sampling population of the four sitios. The distribution of respondents was based on the population ratio for each sitio.

From the NADA, the project site is an agricultural-based community with 39% of the respondents as farmers and others were housewives (23%), laborers/skilled workers (11%), entrepreneurs (11%), government officials or employees (9%), while the rest had no occupation (3%) (Figure 1). The data indicates that agriculture plays a vital role for the whole community. Food crops such as rice, banana, cassava, and corn comprise 50% of the main crops planted in the area (Figure 2). Other respondents do not have main crops, while 10% had horticultural crops.

![Figure 1. Main occupation of the respondents in Sito Proper I, Proper II, Udiongan, and Calumpit, Brgy. Macabud, Rodriguez, Rizal, Philippines, October 2018.](image1)

![Figure 2. Main crops planted by the respondents in Sitio Proper I, Proper II, Udiongan, and Calumpit, Brgy. Macabud, Rodriguez, Rizal, Philippines, October 2018.](image2)

On the introduction of the need of the e-Tractor, the intended users in the project area gave an initial positive response. They responded that the machine can be used for hauling of agricultural products, particularly from the remote farm areas or for human transport and may even be utilized for farming operations, especially for land preparation (plowing) operation. Figure 4 shows the
willingness of the respondents to use the e-Tractor for transport purposes. Thirteen percent of the residents strongly agreed to use the e-Tractor for transport and 24% agreed to do so. There were 7% who said that they may or may not use the e-Tractor while 16% were unwilling. A total of 40% of the respondents were undecided. Those who agreed on the use of the e-Tractor for transport noted the weight of the products that they wanted to load. The respondents agreed to use the e-Tractor for hauling of agricultural products such as rice (200 kg), cassava (200 to 500 kg), banana (40 kg, 300 kg, and 1000 kg), and other vegetables (ranging from 20 to 500 kg). Out of those who would use the e-Tractor for hauling, 56.25% had loads of at most 200 kg, while 43.75% had a load of more than 300 kg. It is then necessary to design the e-Tractor to accommodate a minimum load of 200 kg.

Figure 3. Availability of tractors in Sitio Proper I, Proper II, Udiongan, and Calumpit, Brgy. Macabud, Rodriguez, Rizal, Philippines, October 2018.

Figure 4. Willingness of the respondents to use the e-Tractor for transport in Sitio Proper I, Proper II, Udiongan, and Calumpit, Brgy. Macabud, Rodriguez, Rizal, Philippines, October 2018.
3.2 Design and Fabrication of the e-Tractor

Figure 5 shows the rendered design using AutoCad ®. Table 1 shows the specifications of the e-Tractor. It has three main components, namely the hand tractor, the prime mover, trailer as the load carrier, and a two-bottom disc plow. The trailer is designed based on the Philippine Agricultural Engineering Standards (PAES) 136:2004: Agricultural Trailer Specifications [4]. The overall length of the trailer is 3120 mm while the overall width is 1470 mm. The overall platform dimension is 860 mm by 1680 mm. The height of the seats is 0.3 m and the backrest for the passengers is 0.23 m. The backrest can be dropped down while the rear cover is completely removable for easier loading of products. Similar to the common hand tractor-trailers in the Philippines, the driver’s seat also serves as a toolbox. The trailer also has a roof which makes it possible to accommodate passengers, especially during rainy seasons.

![Figure 5. Rendered design of the e-Tractor using AutoCad ®.](image)

| Item            | Specification          |
|-----------------|------------------------|
| **Trailer**     |                        |
| Overall length, mm | 3120                   |
| Overall width, mm  | 1470                   |
| Overall height (including roof), mm | 2400 |
| Ground clearance, mm | 430                    |
| Seat height, mm  | 300                    |
| Backrest height, mm | 230                   |
| Gross Weight, kg | 342.4                  |
| **Hand Tractor**|                        |
| Overall length, mm | 2200                   |
| Overall height, mm  | 1625                   |
| Overall width, mm  | 900                    |
| Ground clearance, mm | 150                   |
| Gross weight, kg  | 372.2                  |
| Implement type    | Two-bottom disc plow   |
| Disc Diameter, mm | 406.6                  |
| **Prime Mover**  |                        |
| Type             | Direct current electric motor |
| Power, kW        | 3                      |
| Rated speed, rpm | 2500                   |
| Power source     | Battery                |
| Voltage, V       | 48                     |
| Battery Capacity, Ah | 120                  |
The e-Tractor’s prime mover was matched based on the conventional hand tractors used in the Philippines. A small hand tractor has at least 5-hp gasoline engine equivalent to 3.73 kW. An electric motor can produce a delivery rating of about 2/3 of the power of a small internal combustion engine. A 3.73 kW internal combustion engine is then as efficient as an electric motor with a power of 2.4867 kW or 2.5 kW power. Hence, the hand tractor was matched with a 3 kW electric motor to compensate for the transmission and other losses. The wiring of the electrical components of the e-Tractor is shown in Figure 6. The electric motor was connected to the motor controller, which commands voltage and current drawn from the battery system. The battery system is composed of four 12-V, 120-Ah sealed lead-acid batteries connected in a series configuration. The battery system provides a total power of 5.76 kWh but only 50% of this power was utilized to prolong the battery systems’ useful life. The motor speed can be changed by the motor controller through the speed controller lever. The speed control lever can be directly manipulated by the operator to the desired e-Tractor speed.

The transmission system of the e-Tractor was adopted from the original design of the UPLB Hand Tractor with Steering clutch Mechanism [2] as presented in Figure 7. This design utilizes a surplus automotive differential. Two differentials were used as transmission system for the e-Tractor where the upper differential was oriented vertically with respect to the ground and is connected to the belt and pulley transmission system powered by the electric motor. The lower differential connected to the vertical positioned differential was horizontally aligned serving as the axle of the wheels that provide traction. The upper and lower differentials are connected to each other such that the speed ratio from the electric motor is reduced by 47 times with respect to the wheel speed. Simple costings on the fabrication of the e-Tractor including the trailer, disc plow, lugged wheel, and cage wheel incurred a total cost of around Php 215, 543.45 (USD 4,311 @ USD 1=PhP50). The fabricated e-Tractor with trailer is presented in Figure 8 while the e-Tractor with the disc plow is presented in Figure 9.
Figure 7. Rendered UPLB design for hand tractor transmission system.

Figure 8. Fabricated e-Tractor with trailer.

Figure 9. Fabricated e-Tractor with disc plow.
3.3 Data Analysis

Testing the e-Tractor for transport mode was done at the Pili Drive, University of the Philippines Los Baños, Laguna, Philippines. A total of nine (9) runs was done where different speed and load settings were considered. Table 2 shows the results of the e-Tractor test for transport. The e-Tractor was limited to three main speeds: low speed at 2 kph, the medium speed at 5 kph, and the high speed at 7 kph. Three settings for the load was used namely no load, 200-kg load, and 400 kg load. Based on the data obtained, different speed and load settings resulted in a varying distance and time of travel. The maximum distance that the e-Tractor can travel is 21.533 km which is attained at 7 kph with no load. Without load, there is lower current draw which also results to a lower power consumption. The minimum distance travelled is 7.475 km recorded at 2 kph with a load of 400 kg. The maximum duration of travel was 299.7 minutes attained at 2 kph with no load. The minimum duration of travel was 73 minutes attained at 7 kph with 400 kg of load.

Table 2. Results of the test for the e-Tractor.

| Run | Load (kg) | Speed (kph) | Distance travelled (km) | Operation time (min) |
|-----|-----------|-------------|-------------------------|----------------------|
| 1   | 0         | 2 (Low)     | 14.186                  | 299.7                |
| 2   | 0         | 5 (Medium)  | 9.872                   | 126.0                |
| 3   | 0         | 7 (High)    | 21.533                  | 178.0                |
| 4   | 200       | 2 (Low)     | 7.511                   | 158.7                |
| 5   | 200       | 5 (Medium)  | 9.374                   | 112.3                |
| 6   | 200       | 7 (High)    | 21.503                  | 181.4                |
| 7   | 400       | 2 (Low)     | 7.475                   | 157.9                |
| 8   | 400       | 5 (Medium)  | 12.678                  | 145.7                |
| 9   | 400       | 7 (High)    | 8.514                   | 73.0                 |

The data was optimized using Design Expert 11 with speed and load setting as the independent variables and distance and travel time as the responses. The speed was set in range and limited to 2 kph, 5 kph, and 7 kph while the load was set and ranged from 0 to 400 kg. The distance and duration of travel are the response variables that were both maximized to obtain the optimum condition of the performance of the e-Tractor. Three solutions were presented with different desirability, as presented in Table 3. In the first solution, the load is 287.793 kg at the speed of 7 kph, which will result in 14.326 km distance and 127.519 minutes of operation with the desirability of 0.391. The desirability presented is the combined desirability of the dependent or response variables. For every trial, the expected distance and operation time will occur 39.1% of the time. The second solution has 372.506 kg of load and 5 kph speed. This will result in 11.851 km and 95.353 minutes of operation with the desirability of 0.300. The third solution is a load of 247.891 kg and a speed of 2 kph, which will result in 8.921 km and 196.363 minutes of operation and desirability of 0.204. The first solution has the highest desirability. Figure 10 shows the location of the points obtained in the first solution.

Table 3. Obtained solutions using Design Expert 11.

| Solution | Load (kg) | Speed (kph) | Distance travelled (km) | Length of operation (min) | Desirability |
|----------|-----------|-------------|-------------------------|---------------------------|--------------|
| 1        | 287.793   | 7 (High)    | 14.326                  | 127.519                   | 0.391        |
| 2        | 372.506   | 5 (Medium)  | 11.851                  | 95.353                    | 0.300        |
| 3        | 247.891   | 2 (Low)     | 8.921                   | 196.363                   | 0.204        |
For plowing operation, the obtained results are shown in Table 4. A 15 m distance was plowed for three trails and the resulting width and depth of cut and operation time varied for each trial. The longest time of travel for a 15-m distance was 31.36 seconds while the fastest was 26.53 seconds. The depth of cut was recorded at 60 mm and the widest cut obtained was 650 mm. The average time was 29.26 seconds while the average depth and width of cut were 5.33 cm and 56.33 cm, respectively. The theoretical field capacity was 0.11 ha/h while the actual field capacity was 0.1 ha/h. The resulting field efficiency was 92.29% which is acceptable.

**Table 4.** Data gathered from the plow test of the e-Tractor.

| TRIAL | DISTANCE (m) | TIME (s) | DEPTH OF CUT (cm) | WIDTH OF CUT (cm) |
|-------|--------------|----------|-------------------|-------------------|
| 1     | 15.00        | 29.88    | 5.00              | 65.00             |
| 2     | 15.00        | 31.36    | 6.00              | 55.00             |
| 3     | 15.00        | 26.53    | 5.00              | 54.00             |
| Average | 15.00        | 29.26    | 5.33              | 56.33             |

4. Conclusion

An electric hand tractor (e-Tractor) was developed for agricultural operations, specifically the transport of agricultural products and plowing operations for farm production. The e-Tractor was designed with a trailer based on PAES 136:2004 [4] and a load requirement of 200 kg based on the NADA conducted. It was also designed to pull a two-disc plow implement for tillage operation. The e-Tractor was matched with a 3kW electric motor coupled with a 5.76-kW sealed lead acid battery system as prime mover equivalent to an internal combustion engine power of 5 hp or 3.73 kW. The transmission system was based on the design of the UPLB Hand Tractor with a steering clutch mechanism [2].

The test for the e-Tractor in transport mode was conducted with a total of nine (9) runs. The speed settings were varied from 2 kph, 5 kph, and 7 kph while the load settings were set at no load, 200 kg load, and 400 kg load. The distance and duration of travel were obtained as response variables. Results showed that the maximum and minimum distance traveled were 21.5327 km and 7.4754 km with a maximum and minimum duration of 299.7 minutes and 73 minutes, respectively. The load, distance, and duration of travel were maximized, and the speed was set in range to obtain the optimum setting. The optimum setting of the e-Tractor was obtained at load 287.793 kg and speed of 7 kph resulting in
a distance traveled of 14.3256 km and a duration of 127.519 minutes with combined desirability of 39.10%. For plowing operation, a total of three trials were done in a 15-m field. The obtained field efficiency was 92.29%, which is highly acceptable based on PAES.

The study also shows the potential use of electric motor in mobile applications as exemplified in the development of the e-Tractor. An electric motor as a prime mover for on-farm operations counters the notion that they are only good for stationary applications. The electric motor could enhance operational efficiencies because of the higher delivery ratings compared to fossil-fueled engines. The utilization of the e-Tractor can also mitigate further degradation of the environment because of the non-emission of harmful gases as contributed by fossil fuels. The development of the innovative e-Tractor could contribute to the modernization of the agriculture and fisheries sector by utilizing a more efficient and environment-friendly technology in the agricultural production systems.

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References
[1] Amongo RMC, Zubia OF, Petingco MC and Garcia PS 2011 Design Improvement of the Local Two-Wheel Tractor using Anthropometry. Poster paper presented during the 61st Philippine Society of Agricultural Engineers (PSAE) Annual Convention, 9th International Conference and Exhibition and the 22nd Agricultural Engineering Week, 25-29 April 2011, Dapitan City, Zamboanga del Norte, Philippines.
[2] Amongo RMC, Yaptenco KF, Saludes RB, Larona MVL, Paras, Jr FO, Delos Reyes RB, Castro MLY, De Ramos JD, R. Pangan RS, Rodulfo, Jr VA, Estrada MDG, and Valencia RC 2017 Diffusion and Utilization of UPLB Corn Mechanization Technologies for Food Security. Technical Paper presented during the 14th International Conference and 67th PSAE Annual National Convention. 23-29 April 2017. Legazpi City Convention Center, Legazpi City, Albay, Philippines.
[3] Philippine Agricultural Engineering Standards (PAES) 109:2000. Agricultural Machinery-Walking-type Agricultural Tractor-Specifications Part1: Pull-type.
[4] Philippine Agricultural Engineering Standards (PAES) 136:2004- Agricultural Machinery-Agricultural Trailer- Specifications.
[5] Resurreccion AN 2006 Agricultural Machinery Lecture Notes. Institute of Agricultural Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, Laguna, Philippines.