



Versatile electric prime mover for agriculture: A solution for small farmers

S P SINGH^{*1}, ADARSH KUMAR¹, H L KUSHWAHA¹, UTPAL EKKA¹, M K SINGH¹ and K K SINGH²

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 23 October 2020; Accepted: 22 December 2020

ABSTRACT

Amongst various sources of farm power, electrical power through stored electric energy is a potential source to meet the current challenge in agriculture. At ICAR-IARI, an attempt was made to use battery-power for developing a walk behind equipment with 250-800W DC/BLDCC motors for sowing, weeding, cutting and performing operations on a common platform during 2015-20. The study further led to developing a Versatile Electric Prime Mover for Agriculture (VEPMA) using 1.5 kW BLDC motor with the provision of various attachments that can meet the need of small farmers. The VEPMA is assessed to be an economically viable unit with a saving of 5-liter diesel fuel per ha and 5 to 10 times economical to tractor and power tiller operations. Its adoption in one percent cultivable area (1.4 million ha) in India can result in the net saving of approximately 32 million litres of diesel and reduce 85000 tons of CO₂ in the atmosphere.

Keywords: Battery-powered, BLDC motor, Electric power, Farm mechanization, Prime mover

Farm mechanization is a key input for enhancing farm productivity and drudgery reduction. The common form of power used on farms is mechanical and electrical, along with animate power sources. Nowadays, the agricultural system's current challenges are scarcity of labour, increasing share of female workers, high energy input cost, climate change, environment protection and enhanced income of farmers with high efficiency of input application. In a study conducted on air pollution from burning fossil fuels in India, an estimated loss of USD 150 billion annually (about 5.4% of the country's annual GDP). It is the third-highest cost from fossil fuel air pollution worldwide, followed by China with USD 900 billion and United States with USD 600 billion. Exposure to fossil fuels' pollution leads to around 490 million days of work absence due to illness (NDTV 2020, Farrow *et al.* 2020). A leading newspaper (Pushkar 2019) reported that The Automotive Industry Standards (AIS) studied the pollution caused due to agricultural equipment in India and suggested measures to reduce this pollution by around 30 percent with a viable option of electric vehicles and providing incentives to farmers.

The use of electricity through stored electrical energy (battery) started at the end of the 19th century before developing electric generators and electrical grids (Table 1).

The status of electrical power utilization on-farm across the country is at the research stage. Most of the reported studies are on electric tractor. There is a natural diversification in the size and shape of land available with the majority of farmers, the varied topography of fields, various type of new emerging commercial technologies (vertical farming, hydroponics, greenhouse cultivation, etc.). Under the present scenario, a Versatile Electric Prime Mover for Agriculture (VEPMA) may be an appropriate solution to cater to farmers' needs, especially in developing countries. The present investigation describes the scenario of power sources and the advantages and scope of VEPMA in India.

MATERIALS AND METHODS

The present study finds an appropriate solution to farm power for smallholders based on the present agricultural scenario in the country with varying mechanization levels in different operations. It includes aspects of energy use for farm operations, the status and advantage of electrical power utilization over the compression ignition engine, requirements of small land holders and a plan to cater to their needs in the present scenario of climate change. Diesel consumption was estimated as per the availability of present sources of farm power like 6.35 million tractors, 0.46 million power tillers, 0.04 million combine harvester and 11.48 million diesel engines. Correspondingly, the diesel consumption rate per hour was considered to 3.5, 1, 4 and 1 litre for operational use of 500, 100, 50, 50 h. The information is collected from secondary sources to assess the factors mentioned above (GOI, 2017, 2018a,b and Mehta *et al.* 2019). The cost of a walk-behind electric prime mover was also assessed as per earlier work at

Present address: ¹ICAR-Indian Agricultural Research Institute, New Delhi; ²Indian Council of Agricultural Research, KAB-II, Pusa, New Delhi. *Corresponding author e-mail: singhsp65@gmail.com.

Table 1 Use of electric power on farm

Place/organization	Development with salient outcome	Reference
GBPUAT, Pantnagar, India	Tractor development: 11kW induction motor replacing the engine with accessories of a common tractor	Rautaray and Singh (1982)
Federal University of Viçosa, Brazil	An alternating current motor, direct current motor and an internal combustion engine were evaluated for pluckingfruits of coffee. DC motor performed better than others in terms of the traction force, with 22.6% more power at the drawbar and lowest energy consumption per hour.	Rodrigues (1982)
Mediterranean region	A battery-powered electric vehicle for the light draft operations (intercultural), It is charged using a solar panel of10 kw. 10 ha area of the vineyard would save 4200-5200 litter of diesel fuel annually.	Redpath (2010)
Japan	An existing 10-kW conventional tractor converted to an electric tractor. The overall weight of the tractor increased, which had little adverse effect because of minor change in CG.	Ueka <i>et al.</i> (2013)
Under USAID	Motivo Hybrid Agriculture/Road Vehicles with Electricity Storage and Transformation (HARVEST) developed -an all-electric tractor. Power from solar panels, wind turbines, or intermittent electrical grids for storing power in an on-board battery, later delivers on-demand.	Motivo (2015)
America	John Deere developed the first fully powered system solely by a lithium-ion battery pack with brushless direct current motor using two electric motors, one for driving and the other for power takeoff that connects various farm equipment.	Hybrid (2016)
Mumbai, India	A 22kW Level 2 autonomous electric tractor can run around 150 km per charge and perform various functions like ploughing, tilling, disking, insecticide spraying and others, just like a conventional tractor. It uses a lithium ion-based battery technology.	AutoNext (2017)
Bangladesh	A 12V battery-powered reaper was developed for harvesting rice and wheat crops. The harvesting cost was 85% less as compared to manual harvesting.	Kiran <i>et al.</i> (2017)
USA	A fully electric tractor was developed with an output of 50kW, powered with a 650V lithium battery with a capacity of 100kWh. It is equipped with a standard PTO connection and a normal hydraulic system for implements.	Fendt (2017)
South Korea	The diesel engine and fuel tank are replaced with an electric motor and battery pack to power the 20kW electric motor for five hours work duration.	SIMA (2017)
IARI, New Delhi	250W DC motor operated battery-assisted weeder developed for weeding in wide row crops in light soil.	Singh <i>et al.</i> (2019a)
India	Performance of 6kW electric tractor matches a four times powered diesel tractor (about 16kW). It can attain speed up to 20km/h and the average running cost will be 4-7 times lower than its diesel engine.	Cellestial (2019)
Tamilnadu, India	An electrical rotavator (48V 1.5 kW BLDC motor) powered with four batteries of 12V, 50Ah was developed for weeding. The efficiency of the electric weeder was 80% of the existing weeder.	Mithan <i>et al.</i> (2019)
IARI, New Delhi	350W DC motor operated battery-assisted e-powered seeder was developed for sowing wheat, coriander and spinach.	Singh <i>et al.</i> (2019b)
California, USA	A 22kW HP diesel-equivalent eFarmer was developed with 28 kWh battery packs with 3-hour quick charge for one pack.	Solectract (2020)

IARI (Singh *et al.* 2019 a & b). The concept of VEPMA is based on the scenario and experience of the application of battery-powered electrical motors in mobile during 2015-20 and stationary farm operations, including domestic electrical needs (Chancellor 1969, Hunt 2007, Singh 2007, Prakash 2009, Sharma and Mukesh 2013, Singh and Ekka

2019, Singh *et al.* 2019 a & b and Singh *et al.* 2020). A thumb rule of one horsepower (hp) per ha land for a single cropping pattern (Prakash 2009) was considered for the design. The suitability of VEPMA for small land holders was also assessed based on the agricultural crop seasons, time available for each unit farm operations, area covered of

Table 2 Computation for suitability of VEPMA

Operation	Man-days available	Maximum area to be covered, ha	Potential hours covered by a VEPMA
Sowing	55	55	75
Intercultural operation	70	70	200
Spraying	40	80	100
Threshing/decortivating etc	30	5 to 10	125
Domestic lighting	365 (Five hours of lighting per day)		
Cost, ₹	Tractor	Power tiller	VEPMA
	4.75*	1.98**	1.06***
Cost of operation, ₹/h	800-1200	500-600	100

* only tractor, ** with rotavator, *** with proposed attachments

proposed VEPMA (Table 2). The cost of assessing proposed VEPMA was based on the standard cost of cultivation calculation and compared with the present sources of power, like, tractor and power tiller.

RESULTS AND DISCUSSION

Different farm operations for raising crops in different regions are being performed by human power, animal power, tractors, power tillers, combine harvesters, diesel engines and electric motors, etc. It was observed that the percentage of agricultural workers to total workers decreased from 59.1% in 1991 to 54.6% in 2011 and projected to be 40.6% in 2020, of which 45% will be women workers. Mechanization levels varied from 26 to 58% with varying standard deviations (Mehta *et al.* 2019). This indicates the effect of mechanization level in the cultivation of various crops. It may be due to land holdings, size of plots, topography, cropping pattern, soil conditions, lack of suitable machinery and adoption of new machines etc. As per estimate, out of the available power sources, it consumed about 11.74 million tonnes of diesel per year against total diesel consumption (83.5 million tonnes) of the country during 2018-19 (Anonymous 2019). The electricity consumption in the agriculture sector was 204 thousand GWh in the year 2018 (CSO 2018). Thus, total fuel consumption in agriculture and allied activities is estimated to a tune of 20495 million litres/year. The consumption pattern of both direct (electricity and diesel) and indirect energy (fertilizers and pesticides) inputs increased sharply from 2.5 to 16.5 thousand Mega Joules per ha during the last three decades (Jha *et al.* 2012).

Commonly, internal combustion (IC) engines are used as a prime mover for performing various farm operations. The agricultural operations require power and torque. An IC engine tractor also emits pollution, compromising the environment. There are well-designed transmissions to keep the IC engine in the center of the torque curve. Still, the reality is that most of the time, they are running at a range

that is outside their peak HP. A compact and quiet electrical motor yields 100% torque at zero rpm, without emissions making them environment friendly. Electric motors have almost no moving parts (other than the rotor). Electric motor can draw its power from power lines, whereas a diesel engine of the same rating has to carry its fuel and is heavier. Ketchell (2019) showed in the torque characteristics curve that maximum torque can be obtained with the electric motor even at starting rpm, while the same can be obtained only at rated engine rpm in the IC engine. Another important feature of a diesel tractor is the lugging ability, which is a measure of the amount of temporary overload the tractor can withstand. In other words, when the tractor is overloaded, engine rpm drops, but power increases. The feature of lugging-ability of diesel tractor, a factor of safety in the design of power requirement for an electric prime mover, is needed for compensation. Commercialization of e-rickshaw has provided availability of varying sizes of BLDC/DC motors, compact gear reduction units, controller and other essential parts.

Research initiated on a walk-behind electric-powered machines at ICAR-Indian Agricultural Research Institute, Pusa, New Delhi (2015). Study was conducted on developing variable height platforms using an 800W BLDC motor powered by 48V 32 Ah batteries (Singh *et al.* 2020). According to World Health Organization, the reduction in fossil fuel in India can be achieved with liquid petroleum gas and electricity, along with biogas and ethanol, as these are the clean energy alternatives. So, electric power use is one of the cleanest and viable option for powering Indian farms (WHO 2016).

Versatile Electric Prime Mover for Agriculture (VEPMA): Based on the study conducted at ICAR-IARI, New Delhi, a suitable battery-powered walk-behind Versatile Electric Prime Mover for Agriculture (VEPMA) is worked out (Fig 1) based on the following design considerations: The VEPMA is to substitute power on the animal operated farms; The draft requirement for bullock drawn 3-Tyne cultivator, 3-row seed-cum-fertilizer drill, is about 600N (Sharma and Mukesh 2013); Equipment to be attached to VEPMA is for secondary tillage, furrow making, sowing, weeding, spraying, paddy threshing, groundnut decortication, winnowing and domestic lighting; Power losses in the motor (15%), traction (20%) and 10% (power transmission) (Singh and Ekka 2019); The efficiency of the BLDC/DC motor is more than 75%; VEPMA should be operated for eight hours in a day.

With the standard formula, the power to operate the equipment mentioned above comes to 0.522 W. Considering factor of safety as two and utilizable power available from DC motor, a 1500 W motor would be sufficient to perform selected farm operations. An additional set of batteries will be provided for continuous full day working in the field. The command area for VEPMA can be for mobile operation-sowing four ha, furrow making- (four ha), intercultural activities (two times)-two ha, spraying (three times)- 4 ha. Under stationary operations: paddy threshing-5 ha

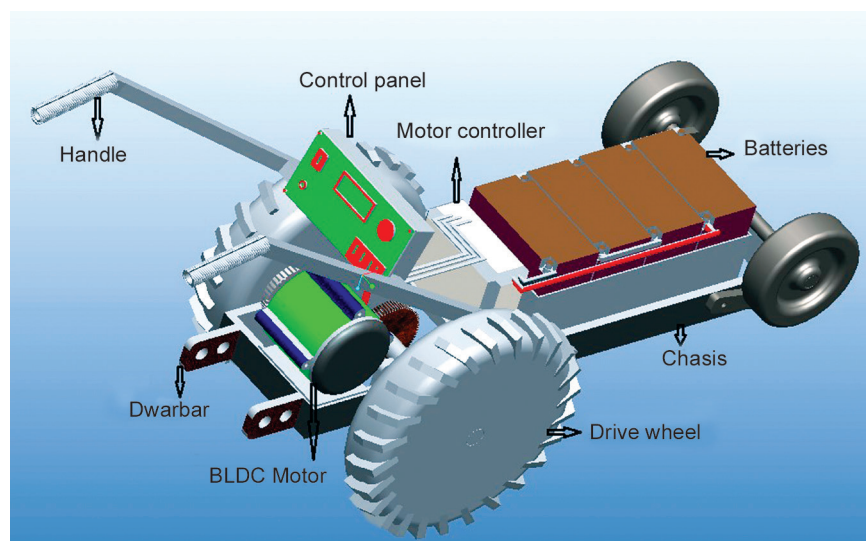


Fig 1 Design of Versatile and Gender-friendly Electrical Prime Mover for agricultural operations.

and groundnut decorticators-3 ha area. Moreover, being equipped with to AC converter it will enable users to run the domestic appliances and lights with this developed system. The operation hour in a year for selected activities will be 500 h, while the operation hours of tractor and power tiller are 1000h and 800h as per BIS, respectively. The total cost of VEPMA would be ₹ 106000 including attachments.

Considering its functional life of 10 years with annual use of 500 h (excluding domestic use), the interest rate of 12% on borrowing, the cost of operation per hour will be ₹ 100 per hour. This operational cost is lower than the power tiller drawn system (₹ 500-600 per h) and tractor (₹ 800-1200/h) with equipment (SMAM 2018). The use of VEPMA on farms will have the potential to save 22.5 litres of diesel per ha in sowing, spraying and paddy threshing operations. Considering the command area of VEPMA as 2 ha, the minimum saving of diesel will be around 45 l per year. Solar photovoltaic cells can be used for charging the batteries for mobile farm operations while they can be coupled directly for stationary operations. The addition of Solar Photo Voltaic Cells will initially add the cost to around 20%, but there would be very little dependency on the electrical grid. A very conservative estimate with 1% of the net cultivable area (140 million ha) adopted under VEPMA in the country, the net saving of diesel can be $(1.4 \times 22.5) \sim 32$ million litres per year. As one litre diesel produces 2.66 kg CO₂ (Auto Smart 2014), VEPMA has the potential to save approximately 85 thousand tonnes of CO₂ in the atmosphere for 1% cultivable area.

With the advantage of electric motor over internal combustion engine operated prime movers, walk-behind farm electric prime-mover unit will be a versatile power source available for mobile and stationary applications. The use of stored electricity for agricultural operations make it an eco-friendly prime mover with less impact on the environment compared to household farm power

source. VEPMA with attachments will act as the prime mover for both farm and family as this will also cater to household electric power needs. The operational cost per hour will be 5 to 10 times cheaper than the present power source (power tiller and tractor). A very conservative estimate with 1% cultivable area under VEPMA can result in a net saving of approximately 32 million litres of diesel per year. This will be a suitable option for small famers of India as well as other developing countries. This will enhance power availability at the family level for agricultural operations.

REFERENCES

- Anonymous. 2019. Economy- Petrol consumption up 8%, diesel up 3% in FY19. The Hindu Business Line, July 22.
- Auto Smart. 2014. Natural Resources, Canada. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oeef/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_6_e.pdf
- Auto Nxt. 2017. Auto Car-Indian start-up develops electric and autonomous tractor. <https://www.autocarpro.in/feature/indian-start-develops-electric-autonomous-tractor-28897>
- Celestial. 2019. E-mobility unveils new electric-tractor with battery swap & regenerative braking. <http://startuphyderabad.com/celestial-e-mobility-unveils-new-electric-tractor-with-battery-swap-regenerative-braking/>
- Chancellor W J. 1969. Selection of optimum sized tractor. *Transactions of A.S.A.E.*: 411-18.
- CSO. 2018. Energy statistics. 25th issue, Central Statistics Office Ministry of Statistics and Programme Implementation, Government of India, New Delhi. <https://data.gov.in/resources/state-wise-village-electrification-status-date.2020>; (accessed 22 April, 2020)
- Farrow A, Miller K A and Myllyvirta L. 2020. Toxic air: The price of fossil fuels. Seoul: Greenpeace Southeast Asia, February, 44 p.
- Fendt. 2017. Fendt e100 Vario: The battery-powered compact tractor. <https://www.fendt.com/int/fendt-e100-vario>.
- GOI. 2017. *Horticultural statistics at a glance 2017*. Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare, New Delhi, p 14.
- GOI. 2018a. *Horticultural statistics at a glance 2018*. Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare, New Delhi, p14.
- GOI. 2018b. *Annual Report 2017-18*. Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, New Delhi, p 3.
- Hunt Donell. 2007. Power selection, farm power and machinery management. 10th ed. Illinois: Waveland Pr Inc; 213-15p.
- Hybrid. 2016. John Deere Reveals a Battery-Powered Farm Tractor. HybridCARS. December 07, <https://www.hybridcars.com/john-deere-reveals-a-battery-powered-farm-tractor/>
- Jha G K, Pal S and Singh A. 2012. Changing energy-use pattern and demand projection for Indian agriculture. *Agricultural*

- Economics Research Review* **25**: 61-68.
- Ketchell Misha. 2019. Here's why electric cars have plenty of grunt, oomph and torque. *The Conversation*; April 16. <https://theconversation.com/heres-why-electric-cars-have-plenty-of-grunt-oomph-and-torque-115356> accessed on 27.6.20 at 17:39h.
- Kiran Imrul, Kaes Mirza, Awal Md. Abdul and Ali Md. Rostom. 2017. Development and performance evaluation of a battery-operated small-scale reaper. *Agricultural Engineering International: CIGR Journal* **19**(2): 217-23.
- Mathan M, Sathish Kumaraan B, Selvam T, Yuvarajan Babu P and Yogesh G. 2019. Design and analysis of battery powered weeder. *International Journal of Engineering Science and Computing* **9** (3): 21073-76.
- Mehta C R, Chandel N S and Jena P C. 2019. Indian agriculture counting on farm mechanization. *Agricultural Mechanization in Asia, Africa and Latin America* **50**(1): 84-89.
- Motivo. 2015. Motivo HARVEST electric tractor. <https://www.engineeringforchange.org/solutions/product/motivo-harvest-electric-tractor>
- NDTV. 2020. Air Pollution From Fossil Fuels Costs India USD 150 billion annually, reveals a new report. *NDTV- India News*, February 07. <https://swachhindia.ndtv.com/air-pollution-from-fossil-fuels-costs-india-usd-150-billion-annually-reveals-a-new-report-41704/>
- Prakash A. 2009. Determination of optimum sized tractor and optimum field capacity for some selected farms. M Tech thesis, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India.
- Pushkar Banakar. 2019. Agricultural pollution in India. *The Sunday Standard*, The New Indian Express, 07 July.
- Rautaray S K and Singh K N. 1982. Effect of lug angle of cage wheels on tractive performance of dual wheels under submerged soil conditions. *Agricultural Mechanization in Asia, Africa and Latin America* **13** (1): 27-32.
- Redpath D A G, McIlveen-Wright D, Kattakayam T, Hewitt N J H, Amsartt E L, Gehaff D, Karams F, Karlowski J and Griffiths P. 2010. Battery operated electrical vehicles developed for light agricultural duties in remote areas in the southern Mediterranean region. *International Journal of Ambient Energy* **37** (3): 115-32.
- Rodrigues Denilson E, Teixeira Mauri M, Ruas A, Renato A, Fernandes Haroldo C and Herrera Prat Mario Ignacio. 2006. Evaluation of micro-tractor worked with different energy alternatives in turning of coffee in yard. *Revista Ciencias Técnicas Agropecuarias* **15**(4): 8-15. Available from <https://www.redalyc.org/articulo.oa?id=93215402>.. Accessed: June 23, 2020.
- Sharma D N and Mukesh S. 2013. *Farm Machinery Design-Principles and Problems*, 3rd ed. Jain Brothers, New Delhi, p374.
- SIMA. 2017. Profi- The Farm Machinery Magazine. <https://www.profi.co.uk/news/sima-2017-tym-electric-tractor-prototype>.
- Singh M K, Singh S P, Singh M K and Ekka U. 2019a. Battery assisted four-wheel weeder for reducing drudgery of farmers. *Indian Journal of Agricultural Sciences* **89**(9): 1434-38.
- Singh S P and Ekka U. 2019. Battery-assisted farm machines for smallholders. *Proceedings of International Conference on 'Sustainable Agricultural Development in Changing Global Scenario'* at BHU Varanasi from October 11-13, 55-58.
- Singh S P, Kumar Adarsh and Kushwaha H L. 2020. Sugar cane canopy spraying: A perspective solution with ergonomics and mechatronics approach. *Sugar Tech* **22** (2): 203-07, <https://doi.org/10.1007/s12355-019-00766-1>
- Singh S. 2007. *Farm Machinery- Principles and Applications*. DIPA, ICAR, New Delhi.
- Singh S P, Singh Mukesh K, Ekka U and Singh M K. 2019b. E-powered multi-purpose two-row seeder for smallholders. *Indian Journal of Agricultural Sciences* **89**(12): 2091-95.
- SMAM. 2018. *Final Report on Monitoring, Concurrent Evaluation and Impact Assessment of Sub-Mission on Agricultural Mechanization (SMAM)*. Mechanization & Technology Division, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, GOI. May. WAPCOS, Gurugram, Haryana, India, 4-67p. <https://farmech.dac.gov.in/SMAM/Evaluation%20Report%20SMAM/Final%20Report%20M&E%20SMAM%20.pdf>(assessed on 11.6.2020 at 11h IST)
- Solectrac. 2020. The future of farming- Compact electric tractor. <https://www.solectrac.com>
- Ueka Yuko, Yamashita Jun and Sato Kazunobu and Doi Yoshinori. 2013. Study on the development of the electric Tractor: Specifications and traveling and tilling performance of a prototype electric tractor. *Engineering in Agriculture, Environment and Food* **6**(4): 160-64.
- WHO. 2016. India takes steps to curb air pollution. *Bulletin of the World Health Organization* **94**:487-488. doi: <http://dx.doi.org/10.2471/BLT.16.020716>