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Combined and Multifunctional Implements: A Promising Approach for Modern Farm Mechanization

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ABSTRACT: The growing population and reducing land available for agriculture is insisting mechanised agriculture to meet the food demand. The higher energy requirements of modern agricultural implements and the increasing cost of energy is making farmers look for implements/machines that have lower energy demand to reduce the overall cost of production. Thus, implements/machines which combine consecutive field operations (called as combined implements) are gaining attention as they can save time, energy and reduce soil compaction as a result of lesser number of field operations. As the total emissions are also reduced, the combined implements are also environment friendly. In addition, combining active and passive tools have a favourable impact on reducing draft and energy required by the total system. Further, implements/machines having provisions to combine consecutive field operations and carry out other major field operations are called as multifunctional implements (MFI's). MFI's were found to be superior to combined implements as they additionally help the farmer in reducing the overall cost of mechanisation by reducing the number of implements/machines required. Hence the present study proposes that, research activities on the development of MFI's have need to be intensified.

Keywords: Agricultural mechanisation, Combined tillage implements, Active-active tool combination, Active-passive tool combination, Negative draft, Multifunctional implements.

INTRODUCTION

It is estimated that the global population will reach an alarming high of 10.4 billion by 2050 and will push about 820 million people to starvation (Tedla *et al.*, 2019; Debrezion *et al*., 2020). This will put tremendous pressure on the agricultural sector to produce more so as to meet the growing food demand and supply agricultural products at affordable cost (Athira *et al.*, 2020a). The major challenges will be, limited land available for farming, scarcity and cost of labour force (Athira *et al*., 2020b) and reducing the overall cost of production (Tarighi *et al.*, 2015). These challenges can be tackled through mechanisation as it reduces the operational cost, enables more crops per year by reducing the time required in land preparation (Maslov *et al*., 2020) and results in increased production and productivity (Jat *et al*., 2020). But the modern machines available are making agriculture more energy-demanding (Chen *et al.*, 2020; Jat *et al*., 2020; Kumar *et al*., 2021). Their increased energy cost and its associated environmental effects are now diverting farmers' thoughts on technologies that consume lesser energy without affecting the crop production (Prem *et al*., 2016; Ceylan, 2020).

The cost to be invested and the time required for various operations is a matter of serious concern in modern agriculture (Prem *et al*., 2016). Using specialized implements/machines for every agricultural operation, increases the capital investment required, field traffic, fuel, time, energy, environmental effects and compaction of soil. Implements/machines that can combine consecutive operations in a single pass will save cost, time, fuel and energy (Taheri and Shamabadi 2013; Prem *et al*., 2016; Al-khafaji, 2020; Maslov *et al*., 2020). In addition, these types of implements/machines effectively use the tractor capacity and increases the loading coefficient (Prem *et al*., 2016). Studies have shown that combining consecutive operations can have labour saving up to 25%, energy savings up to 50% and lesser time requirements and compaction rates as added benefits of (Aldoshin *et al*., 2020). This paper analyses the use of implements that can combine consecutive field operations and the added benefits of multi-functional implement (MFI) which can both combine consecutive field operations and also be used for other field operations.

COMBINED AND MULTI-FUNCTIONAL IMPLEMENTS

There are a number of field operations starting from land preparation to harvesting and some operations are performed in a consecutive manner (e.g., primary tillage, secondary tillage, fertilizer application and planting), some performed based on need (e.g., Inter cultural and plant protection operations) and operations like harvesting, though mandatory stands as a separate operation. There is a possibility of combining operations like primary and secondary tillage (Babu *et al.*, 2020; Upadhyay & Raheman 2020a; Usaborisut *et al*., 2020), tillage and planting (Abo-Habaga *et al*., 2017; Quasim *et al*., 2019), fertilizer application and spraying plant protection chemicals (Channapur *et al*., 2020) etc. A review of research in these aspects reveals that the concept of combining consecutive field operations started in the eighties. As tillage operations were the most energy and time-consuming one, the first focus was on combining the different tillage operations, further expanded to combine tillage and planting operations. In the recent years, researches are concentrated on MFI as an improved approach to reduce the investment in mechanisation. Implements can be designed with the facility to perform different operations. The benefits of combined and MFI implements are described in Fig. 1. Fig. 2 depicts the outcome of combining different types of tools (active & passive) and MFI.

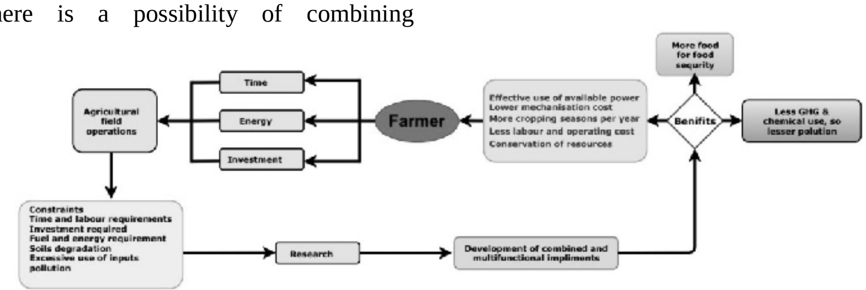

Fig. 1. Benefits of combined MFI.

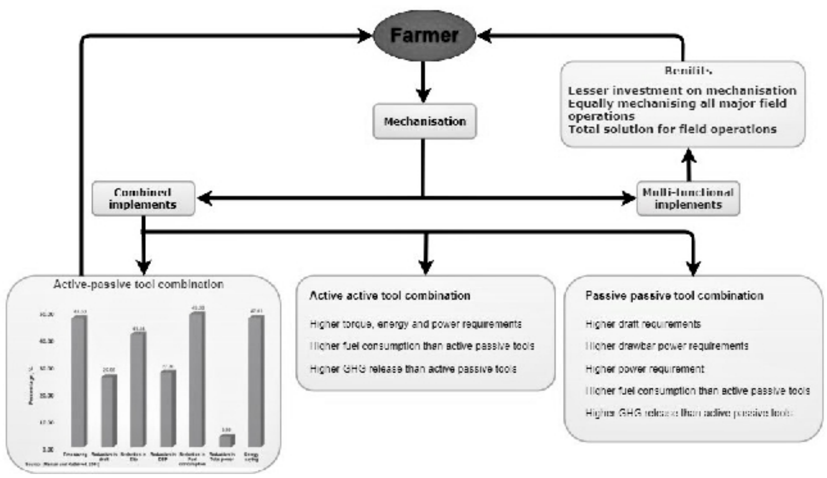

Fig. 2. Outcome of using different types of tools with MFI.

COMBINED TILLAGE IMPLEMENTS WITH A COMBINATION OF PASSIVE TOOLS

Combined tillage implement (CTI) can be developed by using either passive-passive or active-passive tool combinations (Babu *et al*., 2020). This section briefs the various technical aspects of passive-passive tool combination.

A. Draft, Power and Energy requirements for operating CTI using passive tools

Mouldboard plough (MP) and disc plough (DP) are popular passive primary tillage implements, while cultivator (CL), disc harrow (DH) and spring tined harrow (STH) are widely used secondary tillage implements. Soil pulverizing rollers (PR) such as Cambridge roller (CR) and plough packers (PP) are used to break clods. The CTI (MP+PP) required a specific draft between 0.41 – 0.57 kg/cm^2 and CTI (MP+STH) required 0.46 – 0.59 kg/cm^2, which were respectively 12.2 – 28.1% and 21.7 – 30.5% higher than the requirement for MP (Bukhari *et al*., 1981). It was found that the major portion of the draft required in CTI is contributed by the implement/tools set in the front. Thus, in CTI (MP+DH) 65 – 80% of the total draft required is contributed by the MP set in the front and similarly 75–85% of the draft required by CTI(CL+DH) is contributed by the CL set in the front (Sahu and Raheman, 2006). Among the DH's, Off-set disc harrow (ODH) is popular secondary tillage implement. CTI (CL+DH) having 2.1 m width when tested in sandy clay loam soil, was found that it required a draft between 7.4–11.1 kN, which was 1.1 to 9.3% higher than the individual implements (Raheman & Roul, 2013). Similarly a 2.1 m width CTI (ODH+CR) had same draft requirements (Prem *et al*., 2017) as CTI(CL+DH) .

B. Field Performance of parameters of passive tool combination

The field capacity of CTI(MP+PP) ranged between 0.369 – 0.743 ha/h and 0.364 – 0.772 ha/h for CTI(MP + STH), which was though 7.1 – 8.7% and 8.3 – 5.2% respectively lower than MP, but both primary and secondary tillage was completed in the same pass (Bukhari *et al*., 1981). Operating the CTI (CL+DH) using a 31 kW tractor produced wheel slippage 10.5 – 22.4%, consumed 4.3 L/h of fuel at an effective field capacity (EFC) of 0.59 ha/h with 74.2% field efficiency (FE) (Raheman & Roul 2013). While operating CTI (ODH+CR), had a maximum slippage was 22.4% with EFC between 0.51 to 0.63 ha/h and FE between 74.2 to 80.2%. The tractor consumed 3.6 to 4.3 L/h fuel while handing 637.5 to 945.0 m^3/h soil (Prem *et al*., 2017). It was found that combining MP and CL with the share point of the CL tine pointed in the direction opposite to the direction of ploughing gave better performance in braking of clods, levelness, surface smoothness, wheel slippage, field capacity and saved 7.67 L/ha fuel than each unit operated alone (Al-khafaji *et al*., 2018).

Generally, the quantity of soil worked per hour and percentage of soil loosened by CTI (MP + STH) was higher than CTI(MP + PP), while CTI (MP + PP) showed superior performance in soil crumpling. Single pass of CTI(ODH + CR) was able to produce a bulk density almost similar to two passes of ODH and had 7.25% higher distribution of small clod size. Operating CTI(ODH + CR) produced a mean mass diameter of soil aggregates between 17.0 to 25.7 mm (Prem *et al*., 2017). It was thus found that, combining passive tools result in lesser time requirements but results in higher draft requirements, which means higher tractor power.

INFLUENCE OF ACTIVE SOIL ENGAGING TOOL IN COMBINED IMPLEMENT

The forward rotation of the active tillage tools produces negative draft (ND) (Shinners *et al*., 1990). Thus, when active tillage tools are used in CTI, the ND produced play a great role in reducing the overall draft required by the implement. In addition to draft, active-passive tool combination (APC) also helps reducing wheel slip, improve field productivity and enable the use of lighter tractors, thereby reduce soil compaction (Machindra & Raheman 2017). With respect to soil compaction, along with the use of lighter tractors, CTI using APC further helps in reducing the number of passes needed (Upadhyay and Raheman 2020a).

Rotavators are being widely accepted by farmers as it is considered to be an energy and cost efficient implement for seedbed preparation (Singh, 2016). It is an implement which can be used both for primary and secondary tillage, both on dry and wet conditions (Behera *et al*., 2020), produces very fine tilth with good clod size distribution (Nam *et al*., 2012; Makange and Tiwari 2015), incorporates crop residue and mixes the soil very well (Prakash *et al*., 2013) and reduces the number of passes (Makange and Tiwari 2015). Two types of rotavators are common, crank-type (CR) and rotary-type (RR). Among implements with the same rated power, CR is heavier and can achieve 65.7% more nominal rotavating depth than the RR. While the soil inversion, mixing and pulverisation was better in RR than CR (Kim *et al*., 2013; Nam *et al*., 2012).

The RR when combined with passive tillage implements such as chisel plough, disc harrow, disc plough, mouldboard plough and subsoiler, was found to respectively reduce their drawbar pull (DP) requirements by 4.68%, 16.95%, 12.57%, 8.27% and 2.16% and draft force requirements by 4.68%, 16.95%, 12.58%, 8.28% and 2.17% (Ahmadi, 2021). As an additional benefit, the ND developed will help the combined implement to operate at higher speed than when operated with the passive implement.

Power harrow (PH) is another active implement commonly used (Prasertkan and Usaborisut, 2018; Usaborisut and Prasertkan, 2020). The PH when tested in clayey loam soil showed a ND of 1.98 kN, positive slip of 2.40 % and 0.37 kN vertical force. Though the RR demonstrated better performance in the same experiment, the power harrow was able to have deeper operation than RR (Usaborisut *et al*., 2020). Thus, combining active tool with passive tool can benefit the CTI, selection of the active tool has to be done based on the nature and extend of tillage needed.

A. Combined tillage implements with active-passive tool combination

(i) Draft, Power and energy. In a study to find the effect of negative draft produced by active tools on the total draft and DP of active-passive tool combination, Shinners *et al*. (1990) found that two 6-tyne rotors having 1.5 m diameter each was able to develop a ND of 1.27 kN and negative DP of 2.21 kN. These rotors (2 numbers) when combined with passive cultivator tines was able to reduce the total draft and DP respectively by 26.63% and 21.63%. The combination had an increase in specific energy by 2.67% and 10.9% and PTO power by 22.9% and 39.42% respectively with 2 and 4 cultivator tine combinations. Combining RR with bed furrow former consumed 652.1 MJ/ha, which was 60.95% lesser than MP + Power tiller and 63.6% less than MP + CL sequential operations (Manian *et al*., 1999). A CTI (RR + digging blade) similar to the one developed by Kumar and Manian (1986) was designed and developed by Kailappan *et al*. (2001a) and was found to require 31 hp power for its operation. The energy required to operate CTI (RR + chisel share) was 64.7% to 71.3% less than what was required by the conventional system to get the same tilth. It was found that the draft requirement increased with the number of chisel shares mounted, but was less than the requirement of chisel shares when operated alone due to the ND developed by RR. As forward speed was changed from 0.53 to 1.25 m/s the torque required by CTI (RR + chisel share) increased by 15%, but DP required by RR decreased from 0.7 m/s and reached zero at 1.03 m/s. The PTO power required by RR was greater than CTI (RR + chisel share), but the rate of increase of PTO power required by CTI (RR + chisel share) was found to decrease beyond the forward speed of 0.8 m/s (Manian & Kathirvel 2001).

Cultivator (CT) is another possible combination with RR, CTI (RR+CT) having an operating width of 72 cm was found to require a draft force of 10 kN/m operating width, with an active-passive velocity ratio of 14.9 and depth ratio of 0.4. In the combination, the RR was developing a ND of 10 kN, required 45.6 kW rotational power and the cultivator required a DP of 16.7 kW. It was found that increasing the forward speed of the CTI(RR+CT) from 0.5 to 1.5 m/s demanded additional power requirement of 45.6 kW (Ahmadi, 2017). Powering the front gang of ODH (PDH) is another example of active-passive tillage tool combination. The PDH in comparison with the ODH at 3.46-6.82 kmph forward speed, working depth of 80 -120 mm and 95 - 150 rpm of the active gang was able to save on average 47.8% draft, 27.7-34.8% DBP and showed an increased specific energy requirement between 0.06-25.53% (Upadhyay and Raheman 2020a). Increasing the velocity ratio from 1.48 to 3.49 reduced 42.8% draft and 53.3% of front gang axle torque required, but further increasing the velocity ratio to 4.59 produced only a reduction of 2.6% in draft and 2.8% in front gang axle torque requirement (Upadhyay and Raheman 2020b).

Continued tillage activities can lead to the development of plough-pan affecting the growth, development and yield of the crop cultivated (Yang *et al*., 2021). This makes sub-soiling an essential operation to enhance water infiltration, root growth, crop development and yield (Yin *et al*., 2021). Long-term sub-soiling has proved to be an effective measure in improving soil properties (Yang *et al*., 2021), this highlights the importance of having a sub-soiling tool (ST) in CTI. The draft required for a 2.95 m width CTI(ST+RR+CR) was 10 kN (Weise, 1993). Using PH instead of RR, it5 was found that CTI(ST+PH+ CR) on sandy loam soil required a draft between 5.89–7.33 kN and power 5.56-26.61 kW. When operated at a forward speed of 1.8 kmph and PH rotation of 598 rpm, the combination was able to save 24.39% of total power required and 36.9 – 47.1% of drawbar pull required by the subsoiler than when operated separately (Prasertkan and Usaborisut 2017). When tested on loam soil the CTI(ST+PH+ CR) required 21.55-35.74 kW power at 1.89-2.78 kmph forward speed (Prasertkan and Usaborisut, 2018a). Testing on fields with clay ratio 26.1% (F-1) and 39.27% (F-2), the respective power requirements were 34.38 kW and 36.81 kW. Increasing the forward speed from 1.89 to 5.09 kmph the increase in PTO power was 32.35% and 22.25% and torque required increased by 67.1% and 32.56% respectively in F-1 and F-2 (Prasertkan and Usaborisut, 2018b). Providing a free shank pivot of 30 in the CTI(ST+PH+CR) reduced the specific energy requirements by 10.7% and 6.3% respectively on F-1 and F-2 (Usaborisut and Prasertkan, 2019). The draft reduction in the CTI(ST+PH+CR) was comparatively lesser than that obtained by CTI(ST+RR+CR). The higher draft saving by CTI(ST+RR+CR) is due to the impact force generated by the RR which pushed the ST forward in CTI(ST+RR+CR) (Usaborisut and Prasertkan, 2018)

(ii) Performance of tractor and implement combination. In the CTI developed by Shinners *et al*. (1990), produced a wheel slippage of 5.61 and 3.35% while using 2 and 4 cultivator tine combination respectively. This was 35.2% and 27.6% lesser than while using 2 and 4 cultivator tine respectively alone. Shinners *et al*. (1993) reported that tractor implement operating combination influenced on the quantity of ND developed. It was found that the rotor was producing more ND than what is required by the CTI at 4.8 kmph forward speed and active-passive velocity ratio between 1.9 and 2.5. At the same forward speed and active-passive velocity ratio of 1.5 the CTI consumed 28% less fuel than while using passive tools alone. Fuel consumption per hour using CTI (RR + chisel share) was 5.5% less than RR and 45.1% less than while operating RR and chisel share separately. The CTI(RR + chisel share) had 8.11% lesser wheel slippage than while operating chisel share alone (Manian & Kathirvel 2001). The operating speed greatly affects the power required by the CTI(ST+RR+CR), 1 m/s can result in an increase of drawbar power requirement by 6.3 kW and PTO power by 21.2 kW (Weise, 1993). The CTI(ST+PH+CR) was effective in reducing the fuel consumption, engine flywheel power requirements and wheel slippage by at least 50% compared to the passive tools when operated separately (Usaborisut and Prasertkan 2018a).

(iii) Effectiveness of operation. Test results on bulk density, fineness modulus and hydraulic conductivity using CTI (RR + digging blade) both on black cotton soil and red soil showed better results that consecutive MP +CL and MP+CL+DH operations. It was also found that the CTI have better results on red soil than black cotton soil (Kumar and Manian 1986). CTI(RR + bed furrow) also showed a similar pattern as CTI(RR + digging blade) and was effective in saving at least 5.64 h/ha (Manian *et al*., 1999). The CTI (RR + digging blade) developed by Kailappan *et al*. (2001a) was tested by (Kailappan *et al*., 2001b) on both black cotton soil and red soil. The CTI (RR + digging blade) was effective in completing primary and secondary tillage in one pass, maintaining a good tilth with smaller clod sizes and saving 50-55% of time required for seed bed preparation. The clod size of CTI (ST+RR+CR) mainly varied between 10-20 mm with no clod size greater than 40 mm. It was also found that increasing the rotor speed did not produce significant change in the clod size distribution but increased the power required (Weise, 1993). Combining cultivator with PTO driven pulveriser was able to reduce the bulk density of the soil after tillage by 24.4% with a cone index of 455.99 kPa. The field operated with RR had a bulk density of 1.6% and cone index of 58.6 kPa higher than the CTI(CL+PTO driven PR), but the clod sizes were lesser. Higher bulk density obtained while using RR was due to the finer soil particles and the variation of cone index was a result of lover depth of penetration by RR (Parmar and Gupta 2018).

(iv) Cost effectiveness. The operating cost per hectare of the CTI (RR + digging blade) developed by Kumar and Manian (1986) was lesser by 67.9% and 55.8% than MP+CL and MP+CL+DH operations respectively. If operated at a rate of 300 h/year, the implement pays back in a period of 4.15 years. CTI (RR + bed furrow) was able to save on average 47.22% operation cost compared to sequential field operations providing the same effect (Manian *et al*., 1999). The CTI (RR + digging blade) developed by Kailappan *et al*. (2001a), when compared to the conventional tillage practice, could save 44-55% of operating cost. The operating cost of CTI (RR + chisel share) was 61.9% to 70.33% less than the conventional systems (Manian & Kathirvel, 2001). Using CTI (CL + PTO driven pulverising attachment), an operational cost saving of 10.6% and 46% was obtained when compared to RR and cultivator with planker respectively (Parmar and Gupta 2018).

ONCE-OVER COMBINED IMPLEMENTS WITH MULTI-FUNCTION (OCIMF)

Implements designed to complete multiple operations in a single pass is termed as OCIMF. A single axile tractor operated machine which can do tillage, planting and application of fertiliser and pesticide (OCIMF-1) was designed and developed by Yusuf and Asota (1998). To reduce the energy requirements in tillage and planting, combination of ST, RR and a planter (OCIMF-2) was developed by Abo-Habaga *et al*. (2017b). To economise the field operations of tractor mounted machines combining inter-row tillage and fertiliser application (OCIMF-3) and inter-row tillage, fertiliser application and earthing up (OCIMF-4) were developed by Singh *et al*. (2018).

A. Performance of once-over combined implements with multi-function

The OCIMF-1 could be safely operated at 0.5–4.1 kmph speed and showed better performance in planting uniformity, seed injury and seedling emergence than the rotary injection planter (Yusuf and Asota, 1998). The negative draft produced by the RR resulted in the reduction of overall DP required by OCIMF-2 by 51% and 54.5%, for operating depth 17 and 22 cm respectively. At same operating depths when the forward velocity was increased from 0.44 to 0.94, the specific energy increased from 77.1 to 113.5 MJ/ha and 135.45 to 157.52 MJ/ha (Abo-Habaga *et al*., 2017b). Both OCIMF-3 and OCIMF-4 was able to perform weeding, earthing-up and apply metered quantity of fertilizer in one single pass, but had problems in heavy soils and weed infested fields (Singh *et al*., 2018).

MULTIFUNCTIONAL FRAME AND IMPLEMENTS

A. Multipurpose frame (MPF)

With the aim of carrying different animal drawn tools, Lal, (1985) designed and developed a frame (MPF-1) with provisions of attaching different tools based on the field operation to be carried out. To effectively use the animal draft power and increase the working efficiency, a wheeled multipurpose tool carrier frame (MPF-2) with provisions of holding tillage, seeding, fertiliser application and weeding tools was designed and developed by Tiwar *et al*. (2011). To increase the utility of the power tiller, a multi-tool carrier frame (MPF-3) was designed and developed by Veerangouda *et al*. (2011). An animal drawn multi-tool carrier (MPF-4) having the facility to hold ploughing, harrowing and tillering tools was developed by CIAE, Bhopal (Ramya *et al*., 2015). To increase the productivity of labour, Achutha *et al*. (2016) developed a carrier frame (MPF-5) which had the facilitates of holding and operating, sowing equipment, sprayer, weeding tools and inter-cultivation tools. A tractor mountable multi-soil working tool carrier frame (MPF-6) was designed and developed by Mandloi *et al*. (2017). To suit the small and marginal farmers, a frame (MPF-7) with wheels having the facility to hold tools such as furrow opener, hoe blade, seed covering plate, V-blade and cultivator tine was developed by Ghadge *et al*. (2020).

(i) Performance of multipurpose frame. Comparing with the traditional way of operating the tools, use of MPF-1 helped to increase the command area by 240-325%. The draft required by MPF-1 was 500-550 N and 440-480 N with tillage and sowing tools respectively (Lal, 1985). Using MPF-2 there was a draft reduction of 18-20% and obtained a field capacity of 0.16-0.20 ha/h (Tiwar *et al*., 2011). MPF-3 while using tillage and harrowing tool required 70 and 60 kg draft, 0.2 and 0.23 ha/h EFC, 66.66 and 69.88% field efficiency and required 0.518 and 0.488 hp power (Veerangouda *et al*., 2011). Evaluating MPF-4, the average draft required was 686.70, 490.50 and 539.55 kN, energy required was 98.70, 17.40 and 37.23 MJ/ha and operating cost was found to be 60.12, 59.47 and 59.79 Rs/ hr respectively with ploughing, harrowing and Tillering tools (Ramya *et al*., 2015). Using MPF-5 increased the productivity of labour by four times (Achutha *et al*., 2016). Attaching plough and clod crusher on MPF-6, it was able to prepare the seed bed in one pass saving 20% of operating cost required in sandy loam soil (Mandloi *et al*., 2017). The MPF-7 was evaluated using V-blade, hoe blade and three tyne cultivator, it was found that the EFC was 0.0183, 0.0181 and 0.0173 ha/h and field efficiency was 73.1, 73.6 and 72.21% respectively at forwards speeds 0.9875, 0.95 and 0.97 kmph (Ghadge *et al*., 2020).

B. Multi-functional implements/machines

A scalable model of a multi-functional machine (MFM) which could do tillage, drilling, planting and spraying was evolved by Sakhale *et al*. (2016). As a prior step for developing an autonomous vehicle for agricultural operations, a conceptual scalable working model of a MFM, capable of carrying out tillage, planting, levelling and spraying water was developed by Harsha *et al*. (2017). A working prototype of MFM suitable for small to medium scale farms (MFM-1) was developed by Sadik and Hussain (2017). The MFM-1 was capable of being used for tillage, sowing, water pumping and transporting goods. It was able to save 62.5% and 66% of time respectively for ploughing and seeding operations. To reduce the cost of field operations for small scale farmers, Dhatchanamoorthy *et al*. (2018) and Udaya (2019) developed a small compact sized MFM capable of doing tillage, sowing and harvesting operations. A scalable working model prototype of MFM which can do tillage, levelling, seeding and spraying operations was designed and developed by Bhoopathi *et al*. (2019). The MFM was easy to fabricate and can save both time and labour. A small-scale working model of a MFM which can perform tillage, sowing and spraying operation was put forward by Chandran *et al*. (2020).

CONCLUDING REMARKS

It's true that the demand for agricultural produce never ends, but the price is highly fluctuating and in most of the cases the producer gets lower price. This is due to the fact that crops are seasonal and huge volumes of produce come into the market, resulting in market price reduction. It's a challenging task to increase the production at the same time get better returns to the producer. So as to sustain the agricultural sector, the most effective way is to reduce the cost involved in production. Mechanisation played a very effective role in achieving this target to a great extent. As competition is increasing and land area available for cultivation decreasing and the investing capacity of the farmer is reducing, purchasing, operating and maintaining specialised machinery is becoming uneconomical for small and medium scale farmers. At the same time, they consume a lot of valuable time in carrying out field operations one after another.

Here the importance of combining possible operations together play a great role in saving time, energy and cost. In addition to this, the machines performing combined operations cost lesser than the sum of the individual specialised ones. Combining passive implements together was observed to have problems of increased draft and DP requirements, while combining active implements were associated with increased energy requirements. Utilising the ND of active implements and lesser energy requirements of passive implements, active-passive implement combination is an effective way of reducing both draft and energy along with better results. The RR provides good tilth, effective organic matter incorporation, soil mixing than any other presently available tillage implements and have very high ND. The use of subsoiler eliminates problems related to plough pan. Thus, the combining RR, subsoiler and planting system as one implement was seen to bring better results and savings for the farmer both in time and money.

The other important field operations are plant protection spraying, fertiliser application and incorporation, weeding and harvesting. In the OCIMF if provisions are provided for these activities too, it gives rise to a MFI and will serve as a one total solution for field operations to the farmer. In addition to this it will save considerable investment for mechanising the farm operations and will result to a system which gives equal importance in mechanising all field operations.

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Authors' Contribution. Joe Joe L Bovas developed and presented the main conceptual idea of the study. Joe Joe L Bovas, Dipak S. Khatawkar and Aravind James jointly prepared the outline of the study and collected relevant information's needed for the study. Joe Joe L Bovas wrote the paper. R. Udhayakumar, P. Shaji James, Arjunan Muthiah supervised and corrected the work. All authors discussed every aspect of the paper and contributed to the final shape of the manuscript.

Conflict of Interest. All authors declare that they have no conflicts of interest.

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