Design of Farm Machinery

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Lecture 18 : Combination tillage implements

Hi everyone, this is Professor H. Rahman from IIT Kharagpur. I welcome you all to this NPTEL course on Design of Farm Machinery. Today is Lecture 18, where I will try to cover combination tillage implements. The concepts which will be covered are: the need for combination tillage, why do you require combination tillage, then combination tillage implements, different combination tillage implements developed for carrying out combination tillage, and the performance of combination tillage implements.

To start with, the challenge for the agricultural sector is to meet the growing demand for food. So, how do you meet that demand because the population is increasing? So, the food requirement is increasing. So, you have to meet the demand. So, the demand has to be met from the same cultivable area. The cultivable area in India is nearly constant, you can say 142 million hectares. So, if you can increase the productivity of land, then only you can meet the growing demand for food. So, this is possible through mechanization. And with the help of mechanization, you can increase the cropping intensity and reduce the turnaround time. So, by using mechanization, we have to meet the growing demand for food. Now, the question arises: how do you achieve that mechanization?

Should we continue with the traditional methods or conventional implements? There are certain drawbacks or disadvantages associated with conventional tillage implements. When you go to the field for preparing the seed bed, which is the basic operation required, then we have to go thrice or maybe a minimum of twice to prepare the seed bed. First ploughing, then harrowing, then third levelling or twice harrowing, maybe you can go up to 4 times. So, these are time-consuming, and we are moving to the field with heavy machinery. So, that will create compaction of the soil. So, let us see now what are the disadvantages associated with conventional tillage implements. The first one is soil compaction, which occurs due to several passes of these implements. As I said, you have to go to the field 3 to 4 times. So, there will be weight transferred to the soil that may create compaction. Higher fuel consumption. Obviously, if you are going through the field three times, then we require a good amount of fuel. So, fuel consumption is more. Then, losses of tractor power due to improper matching of the implements. Because most of the time, the tractors are not properly matched with the size of the implement. Whatever the manufacturer says, they just—the farmers, they just purchase it and use it. Whether this is matching with the tractor power or not, they do not know. So, that creates a loss of power. The tractor is able to develop power, but we are not utilizing that power. Then, more time-consuming. Obviously, 3 times or 4 times you are going to the field, there will be more time requirement, more labour requirement. So, labor cost will increase; then, how to overcome these drawbacks or disadvantages? The solution is either to increase the speed or width of the implement or to reduce the number of passes of tillage implements. So, looking at the size of the land that Indian farmers have, it is not possible to increase the speed or width of the implement. So, the only solution is to reduce the number of passes of tillage implements. As the land sizes are small, as I said, increasing both the speed and width of conventional implements is less feasible, and the feasible solution, as I said, is by combining different tillage operations. That means we can combine two or three operations to be done simultaneously. So that you do not have to go to the field twice or thrice, and we will save labor and fuel consumption. So, thereby, the cost of operation. So, we have to combine some operations. So, since we are talking about tillage, we have to combine different tillage operations.

Then, how do you combine this? The question is: whether the tractor which is selected, does it have the power to pull the implement when you combine different tillage operations? To do or to find out that thing, we have carried out a simulation study, where we have taken tractor power starting from 26 HP PTO power, sorry, 20 kilowatt PTO power to 31 kilowatt PTO power. And then, there we try to operate - operate means simulate the operation of a moldboard plough, a two-bottom moldboard plough at a depth of 30 centimeters, sorry, at a depth of 15 centimeters, and the cutting width is 60 centimeters; two bottoms, 30 centimeters each, that way we are getting 60 centimeters.

Now, what we observed here is the draft requirement of that moldboard plough at different forward speeds, starting from 3 kilometers per hour to 5 kilometers per hour. And then, we try to find out this draft requirement utilizing two equations: one equation is the well-known ASABE equation, which is given here: Dr is equal to Fi into A plus B S plus C S square into Td, and the other equation is what we have developed at IIT Kharagpur. So, based on these two equations, we have found out what the draft requirement is and at what slip value the tractor is going to deliver that draft to pull the implement. Then, during the operation, whether this tractor is stable or not is measured, assuming that 20 per cent of the total weight of the tractor should always be on the front axle. If it is less than 20 per cent, then there is instability. So, that is called the front weight utilization factor that we have mentioned here, and then what is the power utilization?

So, if you look at power utilization, yes, the front axle weight is always more than 20 per cent of the total weight. So, that is why we are getting 0.26, 0.26. Now, if you look at the tractor power utilization, whether you use our own developed equation at IIT Kharagpur or whether you use the ASABE equation, you can say that only 48 per cent is utilized at 3 kilometers per hour, and a maximum of 90 per cent, say 88 to 90 per cent, at 5 kilometers per hour. That means there is power available in the tractor, and a similar exercise has been carried out with a 27-kilowatt PTO power tractor. So, what you observed is that when you are operating at 3 kilometers per hour, the power utilized is only 34.8 per cent. That means only 35 per cent is utilized, where 65 per cent is still available. If you increase the speed and if the land sizes are bigger, then you can go to the extent of 6 kilometers per hour and then utilize only 82 per cent, with 18 per cent power still available. Similarly, for a 31-kilowatt PTO power tractor, we can see the power utilization is 30.4 per cent. Power utilization means drawbar power used by power available at the drawbar into 100, that becomes the percentage of tractor power utilization. So, 30 per cent at 3 kilometers per hour and 71.5 per cent, that means 72 per cent, at 6 kilometers per hour. This is for a two-bottom moldboard plough.

Now, for a 9-tyne cultivator, which is very common in the Indian scenario, when it is operated at a depth of 15 centimeters, I have given the maximum depth. Usually, you do not go up to that depth with the cultivator, but to know whether the tractor is in a position to pull it or not, we tried a similar simulation exercise for a 20 HP - 20 kilowatt PTO power tractor to a 31 kilowatt PTO power tractor. And what we observed is: again, there is a surplus - there is power available which is not utilized, starting from say 30 to 42, that means, 60 per cent - 58 to 60 percent at 3 kilometers per hour to 23 per cent at 5 kilometers per hour. Now, similarly, when the tractor PTO power is increased to say 36 HP, that means, 27 kilowatt PTO power, then we can see that 70 per cent power is available when we are operating at 3 kilometers per hour. And if you increase the speed somehow to 6 kilometers per hour, then the power utilization is increased, but still, 30 per cent is left.

Now, for a 31 kilowatt PTO tractor, the same exercise shows - you can look at the figure here, 27 per cent. Only we are utilizing 27 per cent, which is a huge loss. Now, if you increase the speed to say 6 kilometers per hour, again 60 to 62 per cent we are utilizing, the rest is unutilized. So, this shows that there is a possibility to utilize this power. How to utilize? That means, we can combine different tillage operations. So that power - tractor power utilization can be improved from say 30 per cent to 90 per cent, ok.

So, with this concept, we try to develop a combination tillage implement. So, what is basically a combination tillage implement? When 2 or more implements are attached to carry out tillage operations simultaneously, that is important, simultaneously you have to carry out the tillage operation. This will reduce the number of passes required to prepare the seedbed or the soil, then it is called a combination tillage implement. We can use 2 or 3 depending on power availability. This will improve the power utilization efficiency of the tractor. This will combine multiple tillage operations to be done simultaneously; you do not have to go to the field again and again. Then it will reduce since the number of passes is reduced, hence the labor requirement, fuel, and time requirement for preparing the sheet bed will reduce. Then, looking at the advantages, what are the different types of combination tillage implements available? The availability includes passive-active combination tillage implements or passive-passive combination tillage implements. So, these are some of the schematic diagrams - we can see the moldboard plough in the front and the rotavator on the back side. So, this is called passive-active because the moldboard plough is a passive implement and the rotavator is an active implement. So, the combination is called a passive-active tillage implement. You can have a cultivator in the front and a rotavator at the back, which is called a rota cultivator. So, this is also a passive-active tillage implement. So, at IIT Kharagpur, we developed some implements; we will come to that a little later.

The possible benefits of using active-passive or passive-active combination tillage implements are: power to the tilling implements can be transmitted through a mechanical powertrain, which is more efficient than through the tire-soil interface. That means, if you are utilizing an active tillage implement, we are taking power from the PTO. So, that is a PTO outlet - it is the more efficient power outlet. So, that is what is written here. The overall average power transmission efficiency for PTO-powered active tillage implements is 82 per cent as compared to 49 per cent for drawbar power because it depends on the interaction between the soil and the tire. So, that is why, there is a reduction. If you look at the PTO outlet and then at the drawbar, you can see the difference. Here, the difference is around 30 per cent to 31 per cent, like that. So, the negative draft of the active elements can be used to provide some or all of the draft of the passive implements. That means, when an active tillage implement is biting the soil, it will provide a pushing force, provided it is in concurrent mode. Concurrent mode means it is in the direction of travel. So, that will reduce the total draft requirement, which means it will try to push the implement forward. So, the draft requirement will reduce. Then it will reduce the draft of tillage implements. Reduced draft of tillage implements will help in reducing wheel slip. So, when the draft is reduced, obviously, wheel slip, that means tractor wheel slip, will reduce. Hence, your production time will reduce. Production time means the tilling time will reduce, and you can cover more area. So, your productivity will increase.

So, reduced draft of tillage implements allows the use of lighter tractors, which means we may not require higher HP tractors but lower HP tractors. So, when you go for a lower HP tractor, obviously, the weight of the tractor is low, hence, what will happen is it will reduce soil compaction. Reduced draft of tillage implements allows operations to be performed in more difficult traction conditions, where basically the draft has to come from the interaction between the soil and the wheel, that pull force which is developed. So, that will take care of the draft. So, if the tractive conditions are not good, then pull may not be developed. So, when the draft is reduced - even if the traction conditions are poor, it will be in a position to develop the draft required by the implements. So, these are some of the benefits, and now I will show you a few combination tillage implements which we developed at IIT Kharagpur. The first one, in the year 2006, we developed, is a gang of cultivator followed by the single-acting disk harrow. The cultivator is in the front. Similarly, there is another passive-passive tillage implement we developed: a moldboard plough in the front and a gang of disk harrow in the back. You can see the operation here. So, the moldboard plough is throwing the soil to one side, and the disk harrow is just rolling over that. So, that will improve pulverization and give lesser soil clods.

Now, if you look at the soil condition here after the operation of the tillage implement: the first one, if you look at, this is barren land. The land has not been plowed for several years, and some weeds have grown. Then, after the operation of the MB plow, this is the soil condition. And when you operate a moldboard plow and disk harrow combination tillage implement, you can see the soil condition. And if you run twice this moldboard plow disk gang and cultivator and disk gang, one after the other, then you can see the seedbed is completely prepared. We have to evaluate the performance and then compare the performance of these traditional or conventional tillage implements with combination tillage implements.

So, there are certain parameters like what is the volume of soil handled, what is the soil inversion, what is the actual field capacity, and then the mean weight diameter. These are some of the parameters. In addition to that, there will be fuel energy. Because when you try to express the performance of any tillage implement, we measure in terms of what is the volume of soil it is handling per unit time, which is equal to your actual field capacity multiplied by depth multiplied by 100. So, that will give you the volume of soil handled. Depending on the unit of field capacity, we have multiplied by 100. So, FC is hectare per hour, and the volume of soil is in meter cube per hour, and depth is in centimeters. That is why I multiplied by 100 to find out the volume of soil handled in meter cube per hour. Then, soil inversion is how much weeds have been removed. So, we measure in terms of the weight of weeds. So, the weight of weeds before the tillage operation minus the weight of weeds after the tillage operation, divided by the weight of weeds before the operation, multiplied by 100, will give you soil inversion.

Then, field capacity - total area - actual field capacity is the total area covered per total time taken. So, this includes your turning losses, any breakage, or unproductive time. Then, field efficiency, $\text{FE}\,(\%) = \frac{\text{actual field capacity} \times 100}{\text{theoretical field capacity}}$, and we measure theoretical field capacity by only multiplying the width with forward speed without taking into consideration the turning losses or the unproductive time. Then, the other important parameter is your soil pulverization, which is expressed in terms of mean weight diameter of the clods. After the operation and before the operation, if you know or after the operation, you take a sample of soil, sieve it through a set of sieves, then we try to find out how much is retained in each sieve and what is the representative diameter of the sieve where the soil clods are retained. So, you take the weighted mean average that is represented as mean weight diameter. Then, fuel energy - how much fuel is consumed per unit time, then we know the calorific value, and when you multiply that, it will give you this much of energy which is consumed per unit time. So, these are some of the parameters which are used for evaluating the performance of any tillage implement. I will discuss in detail after some classes, but for the time being, let us know these are the parameters. And then, finally, we develop a composite parameter, which is called tillage performance index, $\boldsymbol{TPI_{PP} = \mathbf{K}\,\frac{V_s \times \mathbf{S}_i}{\mathbf{MWD} \times F_e}}$. So, V_s is the volume of soil handled. So, TPI is directly proportional to V_s. It is directly proportional to S_i, that means inversion, and inversely proportional to mean weight diameter and inversely proportional to the fuel energy. Now, if you summarize these values for this moldboard plough, cultivator, offset disk harrow, and the combination tillage implements - moldboard plough disk gang and cultivator disk harrow, you can see the performance parameters, and they are again combined to find out TPI. So, MBPDG is nothing but moldboard plough disk gang, and CDH is nothing but cultivator disk harrow. Now, we compare moldboard plough with MBPDG. So, you can see the mean weight diameter - is drastically reduced.

Now, soil inversion - in the case of moldboard plough, it is 91.2 per cent, whereas, in the case of MBPDG, it is 85.4 per cent. The inversion is reduced because first the soil is thrown to one side, when the disk harrow gang is operating over that, some weeds are coming to the top surface, which is why the soil inversion is reduced. The volume of soil handled is a little bit increased, and the actual fuel capacity is also a little bit increased. Then, if you look at the fuel consumption, yes, there is an increase in fuel consumption. So, if you look at the final composite parameter, tillage performance index, you can see with a normal moldboard plough, you are getting 0.70, whereas, in the case of an MBPDG, you are getting 1.84. So, that means there is an improvement, and this improvement is mainly because of the decrease in soil clod diameter. Similarly, if you compare a cultivator with a cultivator disk harrow combination tillage implement, you can see 24.1, 20.3, and if you look at the other parameters, again, there is a gain, and finally, what you get - TPI is 10.06 with a simple cultivator, whereas, in the case of a CDH, the TPI value is 12.05. And if you compare the MBPDG with CDH or a moldboard plough with a cultivator, you can see there is a drastic increase between this value and this value, between this value and this value. So, that increase is because of the higher volume of soil handled, because a cultivator has a higher width compared to your moldboard plough. So, that is why the volume of soil handled is increased. So, you are getting a higher value. So, 0.70, 10.06, 1.84, 12.05. So, there is a drastic increase. So, overall, we can say that the performance of a combination tillage implement is higher than the performance of individual tillage implement.

One more tillage implement - a combination tillage implement which we have developed is your rota-cultivator. If you look at the right side of the figure, you can see the cultivator - a gang of tines are mounted in the front of a rotavator; this is called a rota-cultivator. Now, this has to be operated by a tractor. So, you can see the operation. So, the cultivator is opening the soil, and then the soil which has been opened will be tilled by the rotavator. So, you will get better pulverization, inversion, everything. So, now, if you look at the field condition, this was the case that means, just after harvesting, stalks are present. You can see - look at the field, the paddy stalks are available. And when you operate the rota-cultivator, you can see the field condition. When you operate only the rotavator, you can see the field condition. That means, visually you can say better is the performance. That means, soil is tilled to a finer clod size with the help of a rota-cultivator as compared to the rotavator. But only visual observation will not help. We have to supplement with some data, and if you look at the data, the rotavator and rota-cultivator, the first group has been given for rota-cultivator at different gears starting from L1, L2, and L3 and at two different depths, 8 and 12 centimeters. And the rotavator is used at the same depth, 8 and 12 centimeters, and at the same gears. So, that becomes easier for us to compare. Now, if you only look at the rota-cultivator, you can see the TPI value, where it is calculated as a constant K into Vs into CI percentage. Percentage reduction in CI, I have taken here instead of taking the mean weight diameter. What I have taken is the percentage of cone index reduction. So, the percentage of cone index reduction means if soil is pulverized, soil particles or the diameter of the soil particles are reduced. Obviously, the cone index, that is the force required to push a cone-shaped probe into the soil, that is called the cone index value. That will offer lesser resistance - the soil will offer lesser resistance, and the cone index value will reduce when the soil is pulverized. So, what was the cone index value before the operation of the implement, and what is the cone index value after the operation? If you measure, then the difference, if it is expressed in percentage, that becomes the cone index percentage reduction. So, that way you can see, we are getting a TPI value. The maximum is at a depth of 8 centimeters at a u by V ratio of 5.26, we are getting a value of 1.174, and the minimum is we are getting 0.841.

Now, when you increase the depth to 12 centimeters again, the value is decreased. If you compare it with 8 centimeters, at 12 centimeters the values are decreased. And when you further increase the u by V ratio, how do you increase the u by V ratio? That means the rotor RPM remains the same only by reducing the forward speed, which is possible by changing the gears. So, you can see here, the TPI value has increased and again it decreased with a further increase in forward speed. With an increase in forward speed, it decreased. So, that means there is an optimum u/V ratio which will give you the maximum TPI. And if you compare the TPI of all the arrangements - all the possible combinations which we tried, we found that TPI is maximum at gear L2 and at a depth of 8 centimeters. This is mainly because of lesser fuel consumption and higher volume of soil or higher percentage of reduction 0.53 and more volume of soil handled.

Now, if you compare rota-cultivator with rotavator, you can see the TPI values are higher than what we observed in the case of rotavator. So, the maximum TPI value you are getting in the case of a rotavator is 0.982, and that is at a depth of 12 centimeters and at a forward speed of 3.04 kilometers per hour and at a u by V ratio of 5.4. So, if you compare these two, rota-cultivator is giving better performance than the rotavator.

From this discussion, what we can conclude is, yes, the combination tillage implements are better than the respective individual tillage implements - conventional tillage implements. So, the only thing is: the tractor should be in a position to pull it. So, let us call it - let us conclude that there is a need for combination tillage implement if you want to reduce the turnaround time, that means, the time required to prepare the seed bed and the fuel consumption, all these factors are reduced. So, we have to go for combination tillage implement, That is all.

Thank you.