Design of Farm Machinery

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Week – 05

Lecture 25 : Tillage performance index

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 25, where I will try to discuss the tillage performance index. We have been discussing performance parameters, then the question is how to express all these performance parameters into a common parameter called the tillage performance index. Now, the concept which will be covered is the performance index, then a few numericals related to performance evaluation of tillage implements.

When I said the tillage performance index, obviously, it is a function of so many parameters like we discussed in the last class, and the class before that. The first one is fuel capacity, depth, inversion, pulverization, power requirement, or fuel consumption. You cannot take both; either you take power requirement or you can take fuel consumption. So that means, if you want to evaluate the tillage performance, then these are the parameters to be measured, and then these are to be combined together to express one parameter called the tillage performance index or performance index. So, before doing that, let us see how these parameters are related to TPI tillage performance. We know that tillage performance is directly proportional to the quantity of work done, because more the work, more will be the output.

So, tillage performance will be better. Similarly, it is directly related to the quality of work done. Higher the quality, better is the performance. So, we can say tillage performance is directly related to the quality of work done. The third one is the energy requirement. When you carry out tillage operations, our target is to consume less fuel or consume less energy. So, if you can carry out a tillage operation with lesser energy, that is better; that means, the performance of the implement is better. So, that's why the tillage performance index is related to energy requirement inversely.

So, these are the three parameters I have considered. Now, under quantity of work, which are the parameters to be taken? Field capacity, obviously, field capacity, and the depth.

So, together you can take that, which is nothing but the volume of soil handled per unit time, that will be your quantity of work done. When I said field capacity, so there we take the cutting width, then the actual field capacity, not the theoretical one.

Now, under quality, the parameters to be considered will be pulverization and inversion. These are the two parameters related to tillage under quality. Or, you can take crop burial efficiency. If stalks are present in the field, for example, we are carrying out a tillage operation in a freshly harvested paddy field, so stalks are left after harvesting paddy - stalks are left. So, we can take that parameter also, crop burial efficiency, which is nothing but indirectly you can say this is soil inversion.

When the soil is inverted or soil inversion is there, these stalks will be incorporated into the soil. Ok. So, these are the two parameters we consider under quality of work, and under energy requirement, either you can take draft value or you can take fuel consumption. When I said draft value, it means draft into forward speed, that will give you power requirement, but again that is limited to the drawbar power because when you use PTO power. So, again you measure the PTO power, convert it into drawbar power, and then take the sum of the drawbar power required and the converted PTO power to drawbar power, and then finally, put it in this equation, or directly you can take the fuel consumption. If you know the calorific value and the amount of fuel which is consumed to carry out different tillage operations, and then you just simply multiply.

So, that will give you kilojoule per minute or second, whatever. So, that will give you the energy requirement per unit time. Now, $\mathrm{TPI} = \frac{\mathrm{K} \times \mathrm{Q_n} \times \mathrm{Q_l}}{\mathrm{E}}$. The constant K, I have written because when you try to compare two implements under the same field condition, then K can be taken as 1. So, that means, $\mathrm{TPI} = \frac{\mathrm{Q_n} \times \mathrm{Q_l}}{\mathrm{E}}$ So, in that way, you can get a number with different units because the units of Qn, Ql, and E are different.

So, I am not putting the units here. So, whatever units you take for Qn, the same unit you have to take for the other tractor for the other implement, and then it becomes easier for you to compare by knowing the number. Instead of comparing individual parameters like inversion is this much value for implement 1, for implement 2 this much value, then pulverization is this much value. So, pulverization of the second implement is having this much value. So, that will create confusion kind of thing.

To avoid this, we express an overall performance index parameter which is called Tillage Performance Index, $\mathrm{TPI} = \frac{\mathrm{K} \times \mathrm{Q_n} \times \mathrm{Q_l}}{\mathrm{E}}$-. Now, let us see a rotavator, for example, we try to calculate for a rotavator. So, the tillage performance index for a rotavator $TPI_{ar} \propto \frac{K \times V_s \times \frac{\Delta CI}{CI_b}}{F_e} = \frac{\mathbf{K \times V_s \times \frac{\Delta CI}{CI_b}}}{\mathbf{F_e}}$. You can remove this K value here. This K value can be deleted. So, that means, V_s is the volume of soil which is handled, and ΔCI is the change in cone index value. Indirectly, it will give you inversion. And sorry, indirectly, it will give you pulverization and a rotavator does not do inversion. So, we have not considered inversion, and F_e is the fuel energy consumed. So, this can be V_s, the volume of soil which is handled. ΔCI is the average cone index before operation, which is denoted as CI_b, minus the average cone index after operation, which is denoted as CI_a. The difference of that is ΔCI, and CI_b is your cone index before operation. So, this will give you the percentage decrease in clod size. V_s is the volume, which is nothing but actual field capacity into depth. So, quantity, quality divided by energy requirement. So, I can write this as $TPI_{ar} = \frac{K \times V_s \times \frac{\Delta CI}{CI_b}}{F_e}$.

So, this is the final expression. Now, if you want to compare rotavator 1 with rotavator 2 or rotavator 3, then K can be taken as 1. So, you will get a number that will be easier for us to compare and say that this implement is better than that implement. For a combined offset disk harrow, the expression is like this: $TPI_{ap} \propto \frac{K \times V_s \times \frac{\Delta CI}{CI_b} \times S_i}{F_e}$ in a combined offset disk harrow, the front gang is powered, and the rear gang is not powered. So, there will be inversion. So, we cannot neglect inversion. So, you have to take inversion - soil inversion. So, actual field capacity into depth becomes your quantity, and this value will give you the soil pulverization, and this value will give you soil inversion. That means these two parameters will give you the quality of work done, and the denominator is again fuel, which is consumed - that is, energy which is consumed.

Now, BIS has given an expression for a mouldboard plough, specifically for a mouldboard plough, and not for other tillage implements. It has only given it for a mouldboard plough. Performer index, $PI = \frac{d \times A \times I \times P}{D}$. So, here small d is the depth of operation, capital A is the field capacity in hectare per day, and small d is in centimeter. Then I is the soil inversion given as percentage, and P is the pulverization in terms of penetrometer reading. That means, BIS says how much depth this cone index, the cone penetrometer, has ~~given.~~ entered into the soil after putting 2 consecutive drops of hammer. So, directly they have given in centimeter how much depth it has gone into the soil. So, when the soil is pulverized, obviously, it will go more depth; more soil pulverization means more depth of penetration, and D is the draft. It is written as draft, but actually, if you look at the unit, it is not the draft; it is the unit draft kg force per centimeter square. So, if I put in this equation, then what I will get is d and A, which is nothing but your volume of soil handled per unit time, and I and P are nothing but quality of work done. I is inversion, P is pulverization; inversion you can calculate in terms of weight of weeds before operation and weight of weeds after operation divided by weight of weeds before operation, that is inversion; pulverization in terms of cone penetrometer reading, and D is the draft value, which is nothing but indirectly it will give you how much power or how much force is consumed for handling unit area of soil. The only limitation here is this is not a dimensionless number. So, d has some unit, that means, centimeter into hectare per day. So, I is in percentage, P is in centimeter again, and D is in kg force per centimeter square. So, this is a very complicated unit.

Then, to evaluate the performance, there are different tests to be conducted as given by BIS. The first test will be a short run test; at least 3 series of field tests for short run should be carried out under different soil conditions. As far as possible, the test should be conducted in the field having optimum soil moisture content for carrying out tillage operation, that is short run test. So, the parameters to be measured in a short-run test are width and depth of cut, soil polarization, power requirement, field efficiency, ease of operation and adjustment, soundness of construction, and you can also measure inversion if it is a mouldboard plough.

Then we can have a long-run test where the harrow, or the implement, should be operated for at least 50 hours, excluding the period for which the short-run tests are conducted. Okay. In addition to that, you have to conduct it for 50 hours, and if possible, it may run for 200 hours. So, indirectly, that will give you an indication if there is some major breakdown or if some defects are there or have developed. So, that can be noticed when you operate for a longer-run test, but for carrying out performance, it is best to conduct only the short-run test.

Testing of tillage implements, the area should be important. How much area should we cover? As per BIS standard, it says the area should not be less than 0.2 hectares for a disk harrow and for any implement for mounted or trailed by a tractor, and 0.1 hectares for others. If it is not a mounted implement, then you can reduce the field size, the field to be covered. Now, the thing is, this area which you select, or the plot which you select, should be rectangular. The length should be at least 2 times more than the width, so that the length-to-width ratio should be 2:1, so that we have minimum turning losses. The items to be measured again are the width of the harrow. I am giving an example for a harrow. So, that is why I am reading it as I have written it as harrowing. So, the actual width of harrowing, then the actual traveling speed, the number of passes, the actual operating hours, the time spent for adjusting the implement, the time spent for trouble and others, then fuel consumption, the degree of pulverization, the degree of mixing vegetative matter with the topsoil, then the evenness of the harrowed surface, the percentage of wheel slip, and draft.

So, all those parameters directly lead to quantitative and qualitative and power requirements. Now, width and depth of cut are two important parameters because width will help you in finding out the area covered, width into, sorry, the cross-sectional area you can find out, and if you know the draft, draft divided by cross-sectional area that will give you the unit draft value, which is required in the case of a mouldboard plough as per BIS standard. For a disk harrow, again, you can setting the gangs at the minimum angle and then follow whatever has been recommended by the manufacturer to follow that angle at the lowest hydraulic position and without the extra mass, then it has to be operated in the field for 2 to 3, 2 or 3 lengths, and then width and depth of cut for a maximum of 10 places are to be measured and then they have to be averaged out. Soil pulverization, either you can use mean weighted diameter or you can use the cone index value.

So, this is how the width of cut has to be measured. Initially, you put a mark in the field, and then from one end, you start carrying out the tillage operation. So, in the first pass, you do it again; you do the second pass close to the first pass, then the third. And then measure the total width initially, and whatever width is cut, you can measure it, or you can measure the uncut width. So, the total width minus the uncut width will give you the cutting width; in this case, it is for 3 passes. So, that means this is the cutting width for 3 passes. So, whatever cutting width you have received, we have measured that will be divided by 3 to find out the actual average cutting width. Initially, we have to take the total width, then after running for a number of passes, whatever width of the field which is not tilled, you have to measure, and the difference will give the cutting width for this number of passes. So, while taking this uncut width and total width, we have to take them at different places, not only once; you have to take them along the length, say 4 to 5 times, so that you can get a better result. Similarly, for the measurement of the depth of cut, what you have to do is you have to clean the furrow, and then you have to take the help of two scales by which one scale will be lying on the untilled land, the other scale, which is the depth scale, has to be put into the furrow, and then you can find out the level from the furrow's sole; that will give you the depth of cut.

Then, if you are interested in a rota-tiller or rotavator, testing a rota-tiller should be carried out at 5 selected fields. So, these are all given by the BIS standard. So, I have just followed that one. The area of each plot should not be less than 0.2 hectares for rotary tillage, tiller mounted or trailed by the tractor and 0.1 hectares for others, just like the MB plough or disk harrow. And the area, as I said, the length to width ratio should be 2:1, and then whatever field conditions before operations - before carrying out any testing have to be mentioned. Average moisture content, the infestation of weeds, are there or not, all those things have to be mentioned.

And the items to be measured will be just like your mouldboard plough or disk harrow - width and, then time spent during turning at the headland. Time spent for adjustment of the machine, time spent for troubles and others, fuel consumption, degree of burying of weeds and crop residue in the soil, then pulverization of soil, entanglement of weed and crop residue to the machine, and then adhesion of soil to the machine, evenness of tilled sole, percentage of wheel speed, power consumption. These are some of the parameters which are to be taken. So, working width same way same procedure whatever I discussed - same procedure has to be followed and then degree of burying the weeds and crop residue in the soil.

Then in addition to this you can take the wear of blades. For carrying out wear of blades both wetland and dry land tillage operations are to be measured that means, the wear of blades they are to be measured for both dry land and wet land based on the mass of the blade. The weight of individual blades is to be taken before and after tillage operation and for 25 to 26 hours and 16 to 18 hours for dry land and wet land, respectively. So, for dry land it is little higher for wet land it is little lesser 16 to 18 hours. And, then average of the hours of the total number of blades will be computed to find out what is the wear of the blade, but this is again for carrying out performance this is not that important only thing whether some blades are broken or not that we can report. Then I will take up some numericals which will help you in whatever we have discussed in the class, how to compute those values?

The first one is how to find out the mean weighted diameter, mean soil clod diameter. So, a field was tilled by using a tractor drawn mouldboard plough followed by a disk harrow and the soil samples are collected randomly from an area of 50 by 50 centimeter and the soil samples collected were sieve analyzed using a set of sieves and the amount of soil retained in each sieve is given in the following table. So, we have to find out the mean soil clod diameter of the tilled soil sample. So, what we have done is we have taken set of sieves and the top we have put the 60 millimeter and the bottom is 2.8 millimeter and below that there is a pan.

So, the amount of soil - the weight of soil which is greater than 60 mm is 1050 grams. So, the representative diameter is 65 mm. Similarly, the amount of soil which is passing through the next sieve, that is 40 to 60, is 350 grams. So, the representative diameter is 50 mm. So, likewise, you have calculated this weight and the representative diameter.

So, as usual, what you have to do is take the multiplication of the last two columns divided by the summation of the last column. So, that will give you directly the mean weight diameter. Ok. So, the mean soil clod diameter becomes 22.73 millimeters. $\mathrm{MWD} = \frac{1}{\mathrm{W}}(\mathrm{A} \times \mathrm{RD1} + \mathrm{B} \times \mathrm{RD2} + \mathrm{C} \times \mathrm{RD3} + \mathrm{D} \times \mathrm{RD4} + \mathrm{E} \times \mathrm{RD5} + \mathrm{F} \times \mathrm{RD6} + \mathrm{N} \times \mathrm{F})$, F is the weight in the pan that is retained and the representative diameter. Then, the summation of all the weights gives you 6825 grams, and then putting the values in the bracket will get the mean soil clod diameter as 22.73 millimeters.

Another problem, let us see: while operating a tractor-drawn two-bottom 30-centimeter mouldboard plough in clay loam soil at an actual forward speed of 3.5 kilometers per hour, the forces and angles made by the three links of the tractor are measured using an instrumented three-point linkage system of the tractor and are as given below. Find out the drawbar power requirement for operating the mouldboard plough, that means, What are the forces acting, and what are the angles the links are making? Those are recorded. So, those are given here like left lower link, right lower link, upper link.

How much tensile or compressive force - because the lower links are experiencing the tensile force, and the top link or the upper link is experiencing the compressive force. So, that is why I put it in one column, and the bending force will be exerted both on the left link as well as the right link. And what are the angles the links are making with the horizontal as well as with the vertical, since the upper link does not make any angle with the horizontal. So, it has only one angle, which is with the vertical plane. So, knowing this and utilizing this equation, $D_f = \sum_{i=1}^{2}(L_i \cos\theta\cos\emptyset + B_i \cos\theta\sin\emptyset) - C_t\cos\gamma$. draft of the implement can be computed. Where, D_f is the draft force; L_i is the tensile force in lower link; B_i is the bending force in lower link; C_t is the compressive force in top link; i = 1 lower left link; i = 2 lower right link; θ is the angle of lower link in the horizontal plane; φ is the angle of lower link in the vertical plane; and γ is the angle of top link in the vertical plane.

Now, the values have to be put for the left link and the right link. So, this is for the left link, the force for the right link, this one is the bending force for the left link, and then the bending force for the right link. So, values are given, and I have just put it, and then this is the compressive force which is experienced by the top link. Now, putting in this equation, directly you can get the value of this much of draft.

Now, if you want to find out the power requirement, we need to know the actual forward speed, which is given as 3.5 kilometers per hour. So, I have converted it into meters per second by multiplying 5 by 18, and the draft into actual speed will give you what is the power consumed. So, that way, you are getting a power requirement of 4.25 kilo Watts.

Now, another numerical where a two-bottom 30-centimeter mouldboard plough, which when operated in an untilled plot of size 45 × 20 meters at an actual forward speed of 2.5 kilometers per hour. The following observations are recorded to evaluate its performance and find out the performance index of the mouldboard plough. So, what values are given? Depth is given, actual width of cut is given, draft is given, mass of weeds before ploughing, mass of weeds after ploughing are given, and cone penetrometer reading directly in terms of depth is given. So, the total time taken to plough the plot is also given, and the shape of the furrow made by the plough is given as rectangular. So, this will help you to find out the unit draft. Draft is given, and you have to find out the cross-sectional area of the furrow, which is nothing but width × depth. Width is given, and depth is given. So, you can easily calculate what is the unit draft.

So, the first thing for calculating the performance index is to know the effective field capacity, which is nothing but the actual area covered divided by the total time taken. So, the actual area covered is 45 meters by 22 meters, and the time taken is given. So, you can calculate how much area it is covering per unit time, which is per minute, as I have calculated. Then, assuming the effective operating hours as 7 hours in a day, the actual field capacity will be calculated by multiplying 7 by 60. So, that way, you are getting this much hectare per day.

Now, the soil inversion part: the weight of weeds before ploughing and after ploughing are given. So, by putting these values into this formula, we are getting an inversion of around 85 per cent. Then, soil pulverization in terms of cone penetrometer readings is directly given, so you do not have to calculate anything. Then, specific draft, as I said, the draft value is given, and then divided by the cross-sectional area. So, that will give you the unit draft value. This is divided by 65, where 65 is the width, and 12 centimeters is the depth. So, that way you are getting the unit draft.

Now, utilizing the BIS standard performance index of plough, $PI = d \times A \times I \times P/D_u$. So, you just simply put the values. So, P I is the performance index, d is depth, A is effective field capacity per hectare per day, we have calculated hectare per day. And then soil inversion in percentage we have calculated in percentage, pulverization in terms of cone penetrometer reading. So, that is directly given and unit draft value we have calculated in terms of kg force per centimeter square.

So, that way we got a value performance index of the plough is 15022.45 I have not put the unit because units are so many units you can say centimeter into hectare per day into percentage into centimeter again divided by kg force per centimeter square. So, that is why I have not put the unit. So, it is a number I have mentioned.

So, these are the references and standards, then the books, then our research paper and in brief we can say we have discussed different performance parameters for different tillage implements and how to express these performance parameters in terms of overall performance that is tillage performance index. And then we try to solve some numericals. So, that will help you in calculating these performance parameters or the overall performance of any tillage implement.

Thank you.