Design of Farm Machinery

Prof. Hifjur Raheman

Agricultural and Food Engineering Department

Indian Institute of Technology Kharagpur

Week - 01

Lecture - 03

Hi everyone, this is Professor H. Raheman.

I welcome you all to this NPTEL course on Design of Farm Machinery.

Today I will cover how you are going to measure draft and what are the different parameters which are affecting draft.

So, basically it is related to draft of a moldboard plough.

Now, the concept which I will cover is factors affecting draft, then what are the models available for prediction of draft, then how to compute draft, then what is the tractive effort required to operate the moldboard plough.

Factors affecting draft, then what are the models available for prediction of draft, then how to compute draft, then what is the tractive effort required to operate the mode board

So, draft is an important parameter as we know that it will control how much power will be consumed and what is the size of the tractor power required to pull the implement.

So, now, our discussion will be to find out what are the parameters which are going to affect draft.

Not only draft you can see draft that is L, side component S and vertical component. How they are varying with speed and how they are varying with soil conditions.

The figure which I have shown here, this is for a moldboard plough and the bottom size is 36 centimeter and this has been tested in a soil bin - controlled soil conditions with and without landsides.

So, two different soil conditions, two different operating conditions and speed.

So, three parameters have been studied and what has been plotted is draft, side draft and vertical force.

So, if you look at this figure, what we can say is that the two soils which we have reported here are the fine sandy loam which is given as the dotted line and sand which is given as the solid line.

The black dots refer to when there is no landside and the hollow dots - white dots, they refer to when there is a landside.

So, first we compare a landslide in two different soil conditions one is :

So, this is your fine sandy loam, this is your sand.

So, there is a clear difference. The draft which is experienced is more in fine sandy loam as compared to sandy soil.

And in both the soils, what we observed is, with increase in speed draft is increased.

Now, when the landside is taken off, same moldboard plough what we observed here is - this one - the block dotted line and this one.

Again there is a difference. The fine sandy loam soil gives you more draft as compared to sandy soil.

Ok. With increase in speed draft is also increased.

Same is the case for side draft and vertical force V. So, S and V they all are increasing with increase in speed and they are higher for sandy loam soil as compared to sand.

So, some observation I can say – V by L ratio varies from 0.5 to 0.6 for sand and from 0.35 to 0.45 for fine sandy loam soil. And S by L ratio that means side draft to draft ratio that also varies from 0.35 to 0.45, 0.25 to 0.4 and 0.2 to 0.3 in sand, sandy loam and sandy clay loam soil.

That means, for fine soil, we are getting 0.2 to 0.3 and for rough soil like sandy soil, we are getting 0.35 to 0.45.

So, from all these discussions then what you can conclude is draft is a function of - the speed, number two type of soil, number three whether the presence of landside or not.

So, other thing is even if the share is there, if it is blunt, draft will increase and when the moisture content will reduce, draft will also increase.

So, only soil type is not sufficient, we have to mention what will be the soil moisture during operation and what is the condition of share.

Share means, if it is sharpened share, the draft will reduce. If it is a blunt then draft will increase.

Now, effect of plough bottom shape and design on draft - as I told it depends on soil types and condition. Draft is a function of soil type and condition. Draft is a function of speed and shape - shape of the moldboard.

The shape that gives the best coverage or the best degree of pulverization tend to have highest draft, but the converse is not true.

That means, if you are getting highest draft, it may not give you the highest inversion or highest pulverization.

So, as I said share edge shape can significantly affect draft.

That means, worn shares may have substantially greater draft than new shares, because new shares are sharpened. So, they will penetrate into the soil easily.

So, that is why draft is less.

So, share wear occurs rapidly in many types of soil. After use of say 20 to 30 hours the shears are worn out.

So, the observation is : draft is increased by 15 per cent or more after a few hours of field operation.

So, moisture content and condition of share that is important.

Suppose, there is no - what happens exactly after the soil is cut that means, furrow slice is cut it will slide towards the moldboard plough - moldboard.

So, when that flow is not there the surface is rough then that will increase draft.

So, if you want to reduce that we have to reduce the soil metal friction. And how do you do that?

There are different ways by which you can reduce the soil metal friction. One is : you apply some coating on the moldboard.

You can apply Teflon, you can apply some polish steel.

So, where we can reduce, we will try to reduce the soil metal friction, thereby flow will be easier and what is observed is : friction and moldboard plough surface may represent as much as 30 per cent of the total draft.

Friction if you reduce, then this component is going to reduce.

And the other observations which is written here is : covering a plough button with Teflon reduce the draft by 23 per cent.

So, out of 30 per cent 23 per cent is reduced in a soil where steel would not scour and by 12 per cent in a soil where both scour.

So, whether if the soil is scouring or not, if you apply a polish coating then there is a possibility that draft is going to reduce.

So, the other components which affect draft or specific draft are the depth and width.

So, many a literatures, they indicate that specific draft of a plough decreases with the increase in the depth of operation. Is obvious. Specific draft means draft per unit cross sectional area.

So, that means, when we increase depth, so, the denominator becomes higher.

So, specific draft reduces, but this observation is up to a certain point. Beyond that point if you increase depth, then again the specific draft will increase.

The reason is there will be choking. Choking means there will be accumulation of soil in front of the share and the moldboard.

So, that will increase the draft value.

So, there has to be an optimum width and depth beyond that if you increase your specific draft will increase.

So, the minimum specific draft of plough bottom was observed to be at a depth between 13 to 18 centimeter.

That means, normally we say that moldboard plough is to be operated at a maximum depth of 6 inches that means, 15 centimeter.

So, that is sufficient. Sufficient in the sense that will give you specific draft decrease with increase in depth.

The next observation is in sandy soil varying the width of cut, width from 30 to 41 centimeter with landside removed has little effect on specific draft for the bottom alone.

But, if you put landside then because of the friction and if you put a colter, then, because of the rolling resistance of the plough wheel, that will change the draft little bit.

Hence, it will increase the specific draft as the width of cut is reduced. Even if you reduce the width of cut, your specific draft will increase.

Then if you are providing some colters or jointers, the obvious reason is : these are additional components that will increase draft.

So, results from several sources indicate that draft of a rolling colter may be 10 to 17 per cent of the total draft for the plough-colter combination.

And reduction of 5 to 7 per cent in draft by taking most of the side thrust on the rear furrow wheel rather than on the landside.

If you want to remove landside, you put a rear furrow wheel that will reduce the draft by 5 to 7 per cent.

The other observation is : there is a reduction of draft from 30 to 40 per cent in sand and about 20 per cent in fine sandy loam soil, when the land side is removed. and all the side force is absorbed by a test car.

So, these are some of the observations which I have given for draft.

So, in summary you can say draft is a function of speed at which it is operated, is a function of soil condition, is a function of soil moisture, it is a function of condition of share

And it also depends on whether some attachments are there or not.

So, these are the factors which will influence draft as well as unit draft and of course, the depth and width of cut.

So, how to predict draft?

What are the different models available?

So, let us have some discussion.

There are good number of empirical equations available, but I will just give you the important ones.

The first one is given by McKibben and Reed in the year 1952.

They experimented the variation of draft with speed and plotted the percentage increase in draft as a function of speed, taking the draft at 4.83 kilometer per hour.

That means, he has given an expression with respect to the draft at 4.83 kilometer per hour.

The draft data was varied from a speed of 1.6 to 13 kilometer per hour. So, it is quite a high range.

And draft data for moldboard plough can be given by the equation:

$$\frac{D_S}{D_r} = 0.83 + 0.0073S^2$$

S is the speed in km/h and D_s is the draft corresponding to the speed 'S' and D_r is the draft to the reference speed 4.83 km/h.

So, again if you look at, the ratio will give you a function of square of the speed.

So, speed is an important factor.

So, the difficulty with this equation is you need to know what is the draft D_r, then only you can find out D_s otherwise you cannot do. You have to have a reference draft value.

Let us see now what are the other models available.

The most important model you can say which is available is at American Society of Agricultural and Biological Engineers, where they have developed a generalized equation which can be utilized for predicting draft of different tillage implements - moldboard plough, offset disk harrow, tandem disk harrow, field cultivator, subsoiler, many more things.

So, I have just noted down about few tillage implements.

So, the equation is in the form :

$$D = F_i[A + B\,(S) + C\,(S^2)]T$$

Now, this F basically, it is a dimensionless soil texture adjustment parameter and the suffix 'i' could be 1, could be 2, could be 3.

i 1 means it is for fine soil. i 2 means it is for medium soil. i 3 means it is for coarse soil. Coarse soil means sandy soil, fine soil means clay soil and in between if it is a sandy clay loam soil then the value should be 2. So, i refers to 1, 2 or 3.

Now, coming to A, B and C, these are machine specific parameters and 'S' is the speed of ploughing in km/h and T is the depth of tillage in centimeter.

So, if you want to utilize this equation, the ASABE has given the values of A, B and C and F_1, F_2 and F_3.

That means, for three soil conditions, the values are given for different tillage implements.

But the constraint is : the variation they have reported as plus or minus 40 percent.

So, since no standard equation or generalized equations are available then this is the best equation which you can take for our computational purposes.

Let us now see what is the demerit or what is the disadvantage or the demerit associated with this equation.

I said light soil, medium soil, heavy soil when the soil is compacted or heavy then this equation does not take that into consideration.

It only classifies F_1, F_2 and F_3 that means, whether it is a sandy soil or clay soil or clay loam soil or sandy clay loam soil. But in sandy soil also you can have different soil strength.

So, this equation does not address that thing.

So, that is a drawback of this equation. Else you can utilize this equation, since no other equations are available.

So, at IIT Kharagpur, we have tried to develop an equation similar to ASABE equation for finding out draft of important tillage implements like moldboard plough, cultivator and offset disk harrow.

So, this equation which has been developed by IIT Kharagpur - me and my research team have developed.

So, this was developed in the year 2017 and this is limited to only sandy clay loam soil. But if you look at the equation:

$$\mathrm{D} = \{\mathrm{A} \times \mathrm{CI} + \mathrm{B} \times \mathrm{S} + \mathrm{C} \times \mathrm{S}^2\} \times \mathrm{W} \times \mathrm{T}$$

That means, D is the draft in Newton, A, B, C are the machine specific parameters. A is the function of soil strength. I have included soil strength here, which was not there in ASABE equation.

Then, B and C they depend on - they are the function of speed of operation and S is the speed in km/h. W is the implement width and in meter or number of furrow opener - if it is a cultivator, then number of tines, then T is the tillage depth in cm.

So, this is an improvement over the ASABE equation. But the only limitation is, you need to know the values of A, B and C and you need to know - the other limitation is that this equation has been developed for only sandy clay loam soil.

So, if you are going to apply in sandy soil or clay soil, applicability is not known.

So, these are some important models which I discussed.

So, assuming that ASABE equation is the generalized equation available and then we will try to find out how to compute draft utilizing ASABE equation.

So, I am giving you a problem using ASABE equation find out the increase in draft of a three bottom moldboard plough when operating speed is increased from 3 km/h to 4 km/h in sandy clay loam soil at a depth of 15 centimeter.

So, here what is asked - to find out the draft, increase in draft. There are 2 conditions they have given that means, speed is increased from 3 to 4 km/h.

That means, first you have to calculate the draft at a speed 3 km/h, then you calculate draft at a speed of 4 km/h, then you find out what is the increase in draft?

So, to do that we have to utilize the ASABE equation.

So, ASABE equation is : $D_r = F_i[A + B(S) + C(S^2)]T$.

That means, it is a sandy clay loam soil then the first component F i will be i will be 2. Ok.

So, then we find out, what are the values of A, B and C. So, these values are available in the ASABE standard you can say.

So, A, B, C, we are calculating for a moldboard plough.

So, the A value is 652, B is 0 and C is 5.1.

That means, the second component will be 0 and A and C have some values which are 652 and 5.1.

Then T is your depth of operation. Depth of operation is given as 15 centimeter and then Fi, i value is equal to 2.

So, in this case moldboard plough, it is 0.70.

So, knowing the speed and depth, we can calculate.

So, A will be 652, B will be 0, C is 5.1 and for sandy clay loam soil F2 is equal to 0.7.

So, at 3 km/h, draft will be equal to - if you put in that equation, draft will be equal to 896.38 kg. And at 3 km/h sorry this is 4 km/h, this will be equal to 942.24 kg.

So, the difference will be the change in draft.

So, what we conclude from here is, with increase in speed the draft is increased.

And this kind of exercise will give you an idea how to utilize ASABE equation, the generalized equation, which is available for finding out draft.

Now, next comes what is the tractive effort required to operate the plough.

When I said tractive effort required that means, how much force is required to pull the implement.

So, this has been given by Goryachkin in the year 1968.

The formula is : $P = P_1 + P_2 + P_3$

The P is nothing, but the total force required to pull the implement to operate in the field.

And the term P_1 in this expression represents the constant resistance, constant resistance to plough motion in the furrow.

$$P_1 = f\,G$$

It depends on the coefficient of friction and the weight.

What is the weight of the plough? and what is the coefficient of friction between plough and soil?

So, if you know that, then we can find out the component P_1. And the value of 'f' is given as - for stubble field, the value is 0.3 to 0.5, for clover that means, for weeds when field is infested with weeds, the 'f' value will be equal to 1. That means, P_1 is equal to 'G', which is the weight of the plough.

Now the second component P_2, it represents that part of the resistance caused by soil slice deformation. Ok.

So, it is proportional to slice cross-sectional area. That means, P_2 can be expressed as:

$$P_2 = D_u ab$$

If you know the cross-section of the furrow that means, 'a' is the depth 'b' is the width.

So, 'a' into 'b' will give you cross-section of the furrow, cross sectional-area of the furrow and when you multiply with unit draft that will give you what is the force required, which is denoted as P_2 that means, resistance caused by soil slice deformation.

So, this unit draft value has to be known. As I told before that, values are available, standard values are available. You can see that light soil, medium soil, heavy soil, very heavy soil - these are the values which are given.

So, you can say it starts from 1.96 and it can go up to 14.71, that means, 15 Newton per centimeter square.

So, that value multiplied by cross-sectional area of the furrow, we can find out the P_2 value.

Then comes a third term P_3, which shows the fraction of resistance developed during transmission of kinetic energy to the soil - soil mass, when the soil slices are thrown aside.

Because, when you are operating a moldboard plough, the soil slice will be thrown to one side. If it is a right hand plough, it will be thrown to right side. If it is a left hand plough, it will be thrown to left hand side.

So, what is the force required to throw that one, so that you have to calculate.

So, if you know the cross-section of the slice that 'a' into 'b' that means, dimension of the slice, 'V' is the forward speed, then the volume of soil handled by the moldboard plough per unit time can be equal to $a \times b \times V$. So, that much is the volume of soil which will be handled per unit time.

Then, what will be the mass of soil passing on the moldboard per unit time: if you multiply this volume with the density - bulk density ρabV) then you will get mass of the soil which will be handled by the moldboard per unit time or per second ($m = \rho abV$).

Then if ρ is the soil density, $\rho = \frac{\gamma}{g}$, where, γ is the wet density. So, I can write

$$m = \frac{abV\gamma}{g}$$

So, g comes into picture.

Now, once you know the mass, then I said the soil is thrown to one side.

Now, what is the speed at which the soil is thrown to one side?

The speed is not same as the speed at which the moldboard plough is moving forward. Ok, let the speed be V_1.

V_1 means, V_1 is the speed at which the soil is thrown to one side and V is the speed at which the plough is moving forward.

The relationship is $V_1 = \varepsilon V$

So, the resistance expressed by the third term can be given as:

$$P_3 = m \times V_1$$

So, I am now substituting for m and V_1 as εV. So, that way you are getting an expression

$$P_3 = mV_1 = \left(\frac{\gamma}{g}\right) ab\varepsilon V^2 .$$

This $\varepsilon\left(\frac{\gamma}{g}\right)$, I am denoting as ε'.

So, $P_3 = \varepsilon' abV^2$ and the value of ε' is a constant depending on the moldboard working surface and soil properties, which is in the range of 150 to 200 $kgf.s^2/m^4$.

So, we have the expression for P_1, we have the expression for P_2, we have the expression for P_3.

So, now if you sum it then, $P = fG + D_u ab + \varepsilon' abV^2$, this is the final expression given by Goryachkin to calculate what is the tractive effort required to pull the plough.

So, once you know this one, then you multiply with the forward speed to find out what is the drawbar power requirement.

So, these are some of the models and the model given by Goryachkin how to calculate the total tractive effort that means, the tractive force required.

Now, I will give you a problem. A two bottom 30 centimeter moldboard plough. It was operated at a forward speed of 3 km/h in a rectangular plot of length 40 meter and width 25 meter. During operation, the overlap observed between adjacent passes is of 4 centimeter. The turning loss was found to be 5 seconds per turn.

There the time lost in adjustment and repair was 15 minute per hectare. Calculate the field efficiency.

So, there is one terminology like field efficiency.

Field efficiency is nothing but actual field capacity by theoretical field capacity into 100.

When I said actual field capacity, what is the actual time required to cover 1 hectare. Ok. This is different from theoretical time. Because I have mentioned some losses, when you consider those losses into account then that becomes your actual time required to cover certain area.

So, the solution is : first you calculate the width, then length is 40 meter and width is 25 meter. That is the area of the plot. This is the width of the moldboard plough, two bottom 30 centimeter, 60 centimeter, then speed is given as 3 km/h.

Then overlap is 4 centimeter.

So, now, the effective width will be 60 minus 4. So, that becomes 56 centimeter. So, the theoretical time taken without overlap to cover 1 hectare will be $\frac{10}{0.60\times3}$.

So, that way you are getting 5.56 hour.

So, actual time taken to cover 1 hectare will be $\frac{10}{0.56\times3}$.

Because without overlap we have calculated, but we have mentioned that there is a overlap of 4 centimeter.

So, when there is a overlap, then the actual time required will be 5.95 hour.

So, the time has been increased because of the overlap, the width is reduced.

So, you require more time to cover an unit area.

So, then we will find out how many turns required to cover that width of 25 meter, because 25 meter is the width of the plot.

So, 25 by 0.56 taking into consideration the overlap minus 1.

So, these many number of times you have to operate.

So, the turning losses per hectare again we calculate 5. So, for each turn we are getting 5 second.

So, $5\ into\ 44$ divided by area so that way we are getting, this is the time loss due to turning.

Time loss in adjustment is given in the problem.

So, that we calculate. So, total time you know.

So, then we find out actual field capacity and theoretical field capacity

So, 5.56 is the total time required and this is the total time required when there is an overlap, when there is turning losses are taken into account, when the time loss and adjustment are taken into account.

So, that way, this is the ratio, will give you what is the field efficiency.

So, this problem will give you some idea how to calculate the time required to cover 1 hectare.

Because we simply say that this is the width and we calculate this much of time is required. But actually that is not the case. There is some overlap, there is some losses of time during turning.

So, it requires some more time to find out how much time is required to cover unit area whether it is ploughing, harrowing, etcetera.

So, these are the references and in conclusion what I say what I can say is we have discussed factors affecting draft and different models available for predicting draft for moldboard plough.

Then we have solved some numericals to compute draft, then what is the tractive effort required to operate the moldboard plough.

Thank you.