

Department of Agriculture, Bombay.

BULLETIN No. 57 OF 1913.

IMPROVEMENT OF THE INDIGENOUS PLOUGH OF WESTERN INDIA.

BY

S. S. GODBOLE, L.C.E.,

Assistant Professor of Physics, Agricultural College, Poona.

D6,9(J:1:21).231
E4
048937

BOMBAY
PRINTED AT THE GOVERNMENT CENTRAL PRESS
1914

[Price—12a. or 1s. 2d.]

**OFFICIAL AGENTS FOR THE SALE OF INDIAN OFFICIAL
PUBLICATIONS.**

In England.

- Constable & Co., 10, Orange Street, Leicester Square, W C.,
London.
Grindlay & Co., 54, Parliament Street, S. W., London.
Henry S. King & Co., 65, Cornhill, E. C., London.
P. S. King & Son, 2 & 4, Great Smith Street, Westminster, S. W.,
London.
Kegan Paul, Trench, Trübner & Co., 68-74, Carter Lane, E. C.,
London.
B. Quaritch, 11, Grafton Street, New Bond Street, W., London
W. Thacker & Co., 2, Creed Lane, London, E. C.
Luzac & Co., 46, Great Russel Street, London, W. C.
B. H. Blackwell, 50 & 51, Broad Street, Oxford.
Deighton Bell & Co., Cambridge.
T. Fisher Unwin, 1, Adelphi Terrace, London, W. C.

On the Continent.

- Friedlander & Sohn, 11, Carlstrasse, Berlin.
Otto Harrassowitz, Leipzig.
Karl W. Hiersemann, Leipzig.
Ernest Leroux, 28, Rue Bonaparte, Paris.
Martinus Nijhoff, The Hague.

In India.

- Higginbotham & Co., Madras.
V. Kalyanarama Iyer & Co., Madras.
P. R. Rama Iyar & Co., Madras.
Thacker, Spink & Co., Calcutta.
W. Newman & Co., Calcutta.
S. K. Lahiri & Co., Calcutta.
E. Cambray & Co., Calcutta.
Thacker & Co. (Ld.), Bombay.
A. J. Combridge & Co., Bombay.
Superintendent, Government Central Press, Bombay
D. B. Taraporevala, Sons & Co., Bombay.
Sunder Pandurang, Bookseller, etc., Bombay.
Gopal Narayan & Co., Booksellers, etc., Bombay.
N. M. Tripathi & Co., Booksellers, etc., Bombay.
Mrs. Radhabai Atmaram Sagoon, Bookseller, etc., Bombay.
Ramohandra Govind & Son, Booksellers, etc., Bombay.
Bombay Tract and Book Society, Bombay.
N. B. Mathur, M. K. H. Press, Allahabad.

Department of Agriculture, Bombay.

BULLETIN No. 57 OF 1913.



IMPROVEMENT OF THE INDIGENOUS PLOUGH OF WESTERN INDIA.

BY

S. S. GODBOLE, L.C.E.,

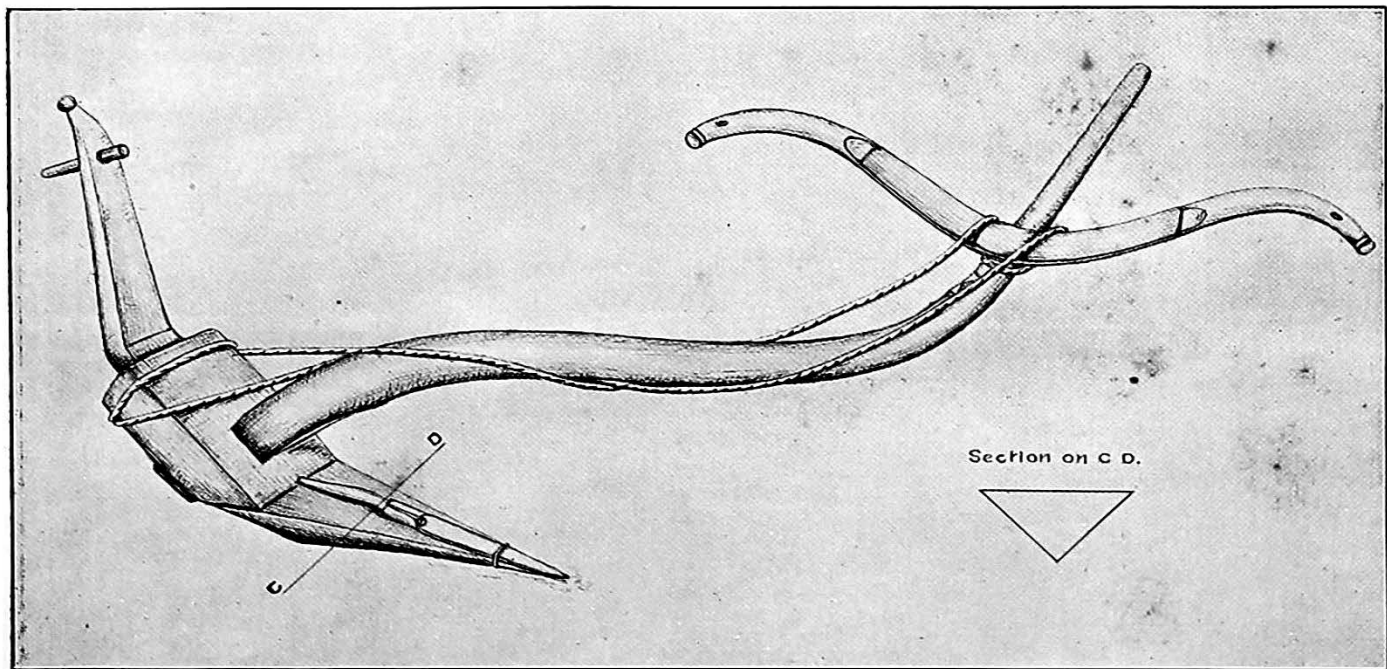
Assistant Professor of Physics, Agricultural College, Poona.



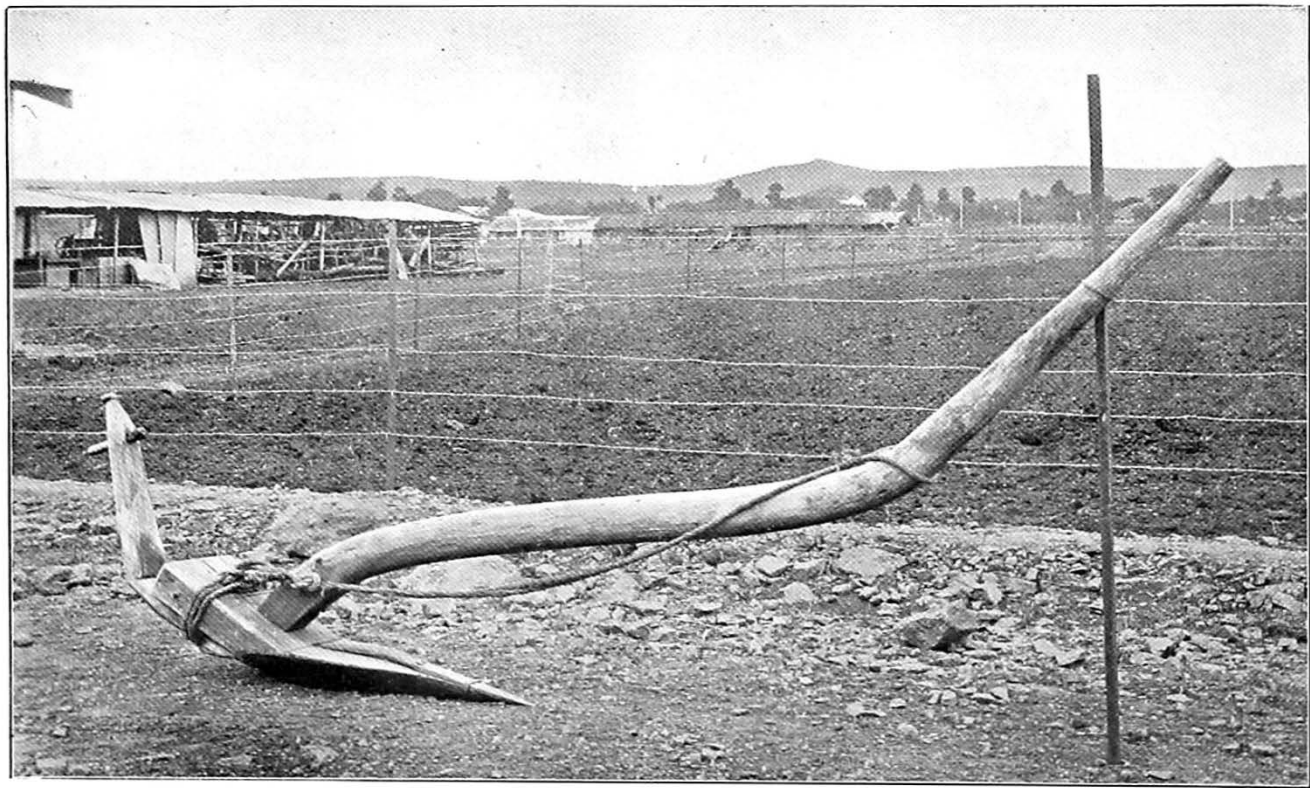
BOMBAY

PRINTED AT THE GOVERNMENT CENTRAL PRESS

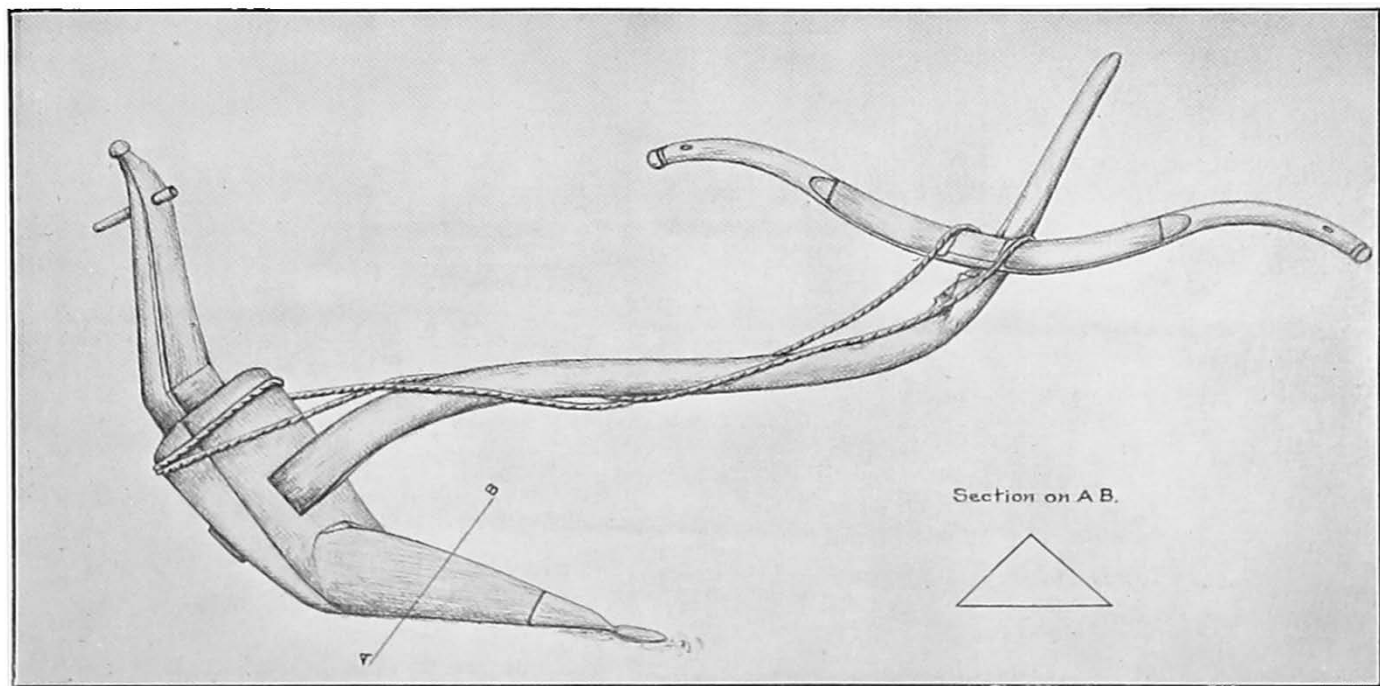
1914



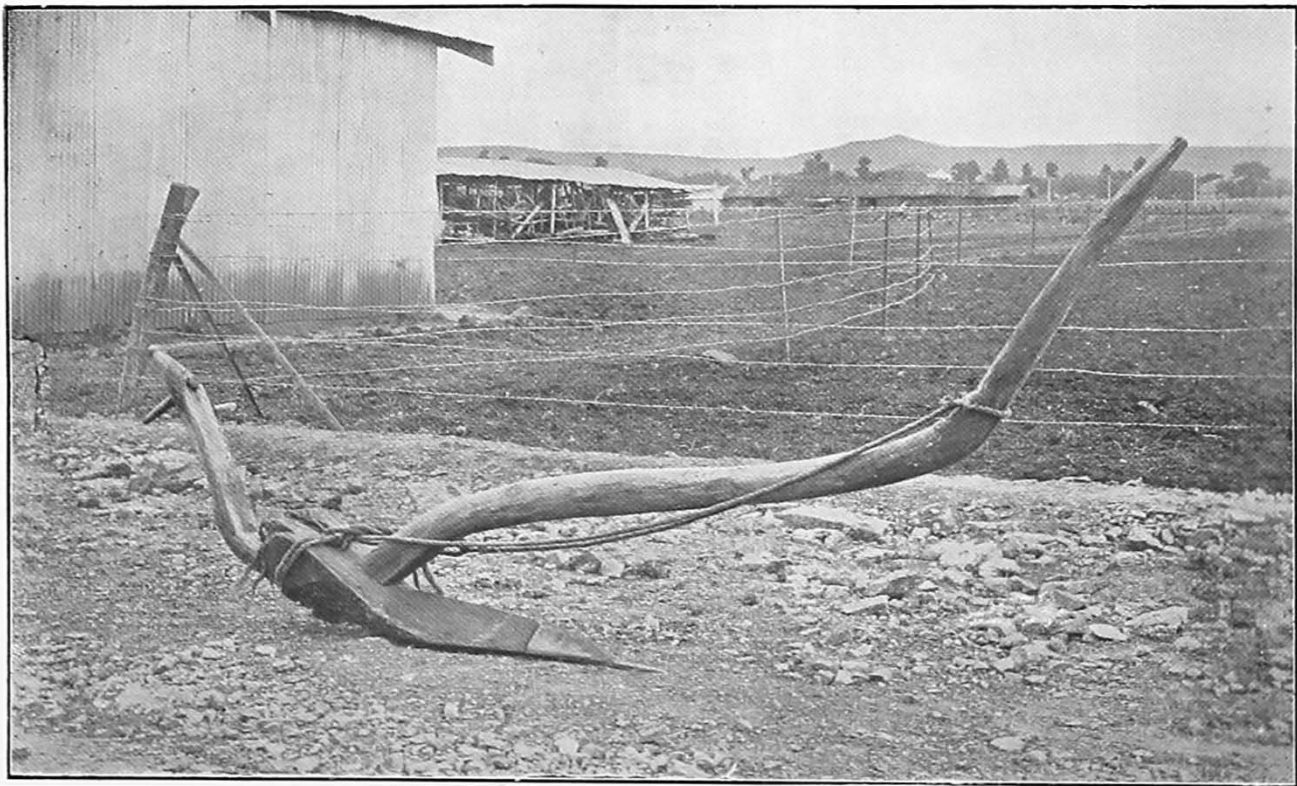
Deccan Plough (A).



Deccan Plough (B).



Experimental Plough (A).



Experimental Plough (B).

THE IMPROVEMENT OF THE INDIGENOUS PLOUGH OF WESTERN INDIA.

THE plough as used by the cultivators of Western India is an extraordinarily inefficient implement. It demands great power to work it considering the work it does,—and, as usually used, it leaves quite a considerable proportion of the land unworked and unploughed. But it has two saving virtues—it is very cheap and it is very easily repaired by the crudest workman in the most remote village. And these facts are very important matters in a country where agriculture is carried on with the minimum of capital, and where expert workmen are rarely found outside large centres. They are so important, in fact, that it is probable the old fashioned wooden plough, with at most an iron tip, will maintain itself for a long to come in many large tracts of Western India, and it would seem a matter of importance to see if improvement cannot be effected without increasing the cost materially, and without making it more difficult to repair.

The main drawbacks in the ordinary plough are :—

(1) It cuts a triangular furrow, that is to say, a furrow wide at the top and narrow at the bottom.

(2) It is not a turnover plough, not even a small quantity of the earth moved being turned over.

(3) As it is constructed of ordinary *Babul* (*Acacia arabica*) wood, its cutting edges soon wear out and become rounded. So that these edges do not long serve the purpose for which they are intended.

To remove the first drawback the form ought to be such that the furrow cut should be rectangular one. For this purpose the bottom of the share, instead of being tapering, might well be made flat, as a result of which the plough moving through the soil would cut a furrow which at its bottom is as wide as the maximum width of the share.

The next thing is the turning over effect. To get this the simplest method would be to make the top of the share a sharp ridge. I think the ridge on the share might well, even, be continued in the head of the plough. The slopes of this ridge would not allow the soil to rest on them as much as the flat surface of the present plough does. Besides this ridge, which would also

slope upwards from the point of the share to the head, would serve the purpose of breaking the clods into smaller pieces. Thus the ridge-like form would tend to break the soil and throw it on both sides of the furrow. This arrangement would also prevent the soil from standing on the plough and thus exerting its own weight and so increasing the friction between the surfaces of the furrow and the plough. Besides, it would do away with the inconvenience which is caused in the case of the ordinary plough by the clods of the earth being held between the beam and the share.

The third drawback about the cutting edges might also be done away by this form; because it would be much more easy, if the suggestions already made are carried out, to have the cutting edges protected by iron. If these are so protected they wear much better and the plough remains an efficient instrument for a much longer period.

If this reasoning is correct, then a plough, made otherwise in the same manner as the present plough, but having a share with a flat base, with a ridged top sloping upward towards the beam, and shod with iron, will be a much more satisfactory implement than that generally in use at present. On purely theoretical grounds it should be nearly twice as efficient,—and the present paper is an attempt to see how far this is realised in practice, and how far the increased work which it does is obtained by an increase in draught. If increased draught is great, the advantages may be too dearly bought: if, on the other hand, this is not the case, it may be a very considerable improvement.

Mechanics of the Indigenous Plough.

Let us see whether the suggested plough is such a one as is required.

The forces that are to be overcome by the plough when it moves through the soil are:—

- (1) Friction between the surface of the plough and the surface of the furrow caused by pressure exerted by the weight of the plough.
- (2) Friction between the same surfaces caused by pressure exerted by the weight of the soil.
- (3) Resistance offered by the soil to cutting.

In the case of the suggested plough the first force acts between the bottom of the plough and the bottom of the furrow. These surfaces are horizontal; the weight of the plough is a vertical

force and therefore acts at right angles to these surfaces. If n represents the coefficient of friction the total force of friction to be overcome is nw (where w represents the weight of the plough).

With the ordinary Deccan plough, if its weight is the same as the experimental plough, the normal pressure on each of the inclined sides of the plough—sides which are in contact with the sides of the furrow—is a component of half of the weight of the plough. The sum of the pressures exerted on the two surfaces will be the sum of these components. In the following figure

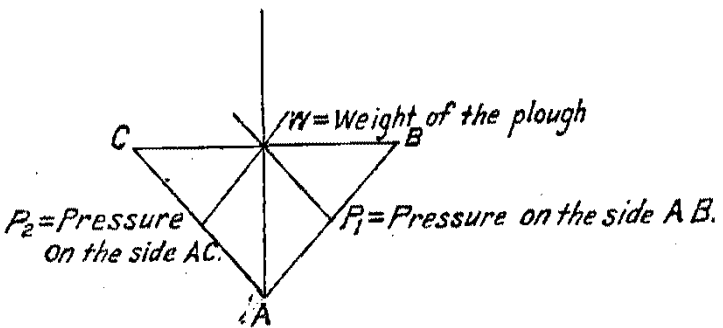


Fig. 1

P_1 and P_2 are these normal pressures. Each of these normal pressures will be greater than $\frac{1}{2}$ of half the weight of the plough as long as the angle at A is greater than 60° . This angle represented by A in the figure is generally more than 90° . The sum of these normal pressures therefore will be $\cdot 7w$ or greater according as the angle A is a right angle or greater than a right angle and the total force of friction will, under the same circumstance, be $\cdot 7nw$ or greater. We thus see that this force of friction between the surface of the plough and the surface of the furrow caused by the weight of the plough is, in the suggested plough, less than twice the same in the usual plough though the suggested plough does twice the work done by the usual plough. This force of friction is a large factor in the total force required to be exerted (*cf.* calculations given in Appendix I).

As regards the second point, that is to say the friction due to the pressure of the soil lying over the plough, the weight of this soil is very small as compared with the weight of the plough. Besides, the difference in the weight of the soil in the two cases under consideration is very small, but here also, if anything, the advantage is to the suggested plough on account of its tendency to throw away the soil along the slopes of its top as soon as the soil comes over it.

The third point raised, namely that of the force required for cutting, may be considered by examining the way in which the two ploughs do their work. In the ordinary Deccan plough the cutting is done by the edge at the bottom and the two edges at the top. All the three edges have to do actual cutting work when the plough is moving. The bottom one cuts in more compact soil than the top ones. In the suggested plough there are two cutting edges which separate the soil from the adjoining ground while the third edge only breaks the clods opened by the two cutting edges at the bottom. If we assume that both the ploughs work to the same depth the compactness of the soil met at that depth would be the same and therefore the suggested plough will have to do twice as much work with the two cutting edges at the bottom as the ordinary plough will have to do with only one cutting edge. But the ordinary plough will be doing more work with its top edges than the suggested one will do with one top edge. Supposing that all the edges at the top of the ploughs (two at the top of the ordinary and one at the top of the suggested plough) do the same amount of work each, then the ordinary plough will be doing twice the work of the suggested plough with its top edges.

If X be the amount of work done by one top edge, and Y the amount of work done by one bottom edge, the total work done by the two ploughs under discussion will be as follows :—

Ordinary Deccan plough — $2X + Y$

Suggested plough — $2Y + X$

The work done by a bottom edge is much more than that done by a top edge so far as cutting the soil is concerned (*i. e.*, Y is greater than X). Hence the work done by the suggested plough is much greater than that done by the ordinary plough, and at the same time it becomes clear that the total cutting work done by all the edges of the suggested plough is *less than twice* the total cutting work done by all the edges of the ordinary plough.

And yet, inasmuch as the furrow opened by the suggested plough is rectangular while that opened by the ordinary plough is triangular, it is evident that the furrow opened has twice the cross sectional area in the former case. It becomes evident, therefore, that *though the suggested plough opens twice the amount of soil opened by the ordinary plough of the same dimensions and excavating to the same depth, yet the force required by the suggested plough is proportionately much less.*

Experimental Verification with small models.

To verify the results arrived at by this reasoning two models were constructed, one resembling the usual plough and the other resembling the suggested plough. Experiments were made with these ploughs in the laboratory in the following way.

Ordinary black earth was put on the surface of an experimental table. The models under experiment were put in this soil and were pulled by a string which was kept horizontal and which passed over a pulley and carried at its other end a pan for carrying weights. Weights were put in this pan until the plough began to move and moved through the soil. This weight represents the force required to move the plough through the soil. Each of the model ploughs was made to move in this way twenty-five times and the following figures were obtained as a result of these experiments :—

Ordinary Deccan plough.

| | |
|--|----------------------|
| Weight of plough | = 822 grammes. |
| Depth of furrow | = 1·6 inches. |
| Breadth of furrow | = 3 inches. |
| Pull in grammes | = 1,216 grammes. |
| Area of section $\frac{3 \times 1·6}{2}$ | = 2·4 square inches. |

Pull in grammes for every square inch of the section of the furrow opened = $\frac{1216}{2·40} = 507$ grammes nearly.

Deccan plough with flat bottom (suggested model).

| | |
|----------------------|------------------|
| Weight of the plough | = 778 grammes. |
| Depth of furrow | = 1·5 inches. |
| Breadth of furrow | = 2·75 inches. |
| Pull in grammes | = 1,416 grammes. |

Area of section = $2·75 \times 1·5 = 4·125$ square inches.

Pull in grammes for every square inch of the section of the furrow opened = $\frac{1416}{4·125} = 343$ grammes nearly.

This shows that the ordinary plough requires nearly 1.6 times the pull that the flat bottomed plough requires per square inch of soil moved.

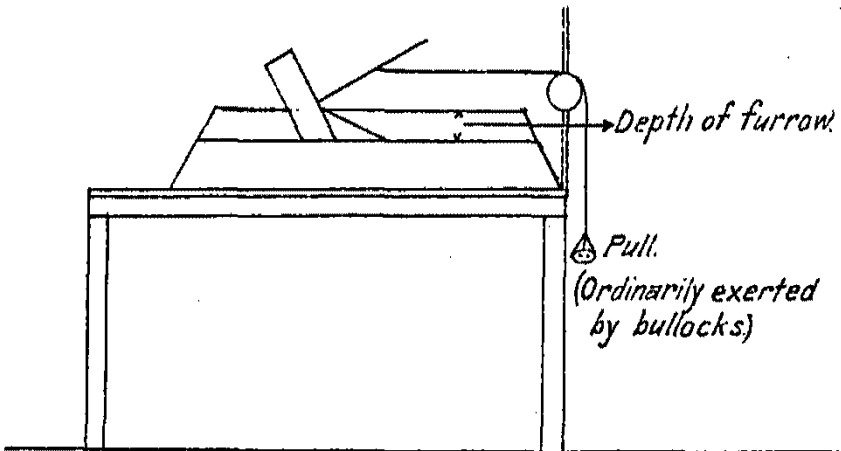


Fig. 2.
Method of experiment with small model.

These experiments therefore in a very large measure corroborate the result of the reasoning given above.

Points to be considered in the construction of Full Size Model of the Suggested Plough.

In consequence of these favourable results a plough of the same dimensions as that ordinarily in use but of the form of the suggested plough referred to before, was constructed for actual use in the fields.

At the time of constructing this experimental plough the following points were paid attention to:—

- (1) To make the centre of gravity of the plough as far back from the point of the share as possible.
- (2) To make the direction of the force as horizontal and as low as possible.
- (3) To give the plough sufficient pitch to make the plough enter the soil.
- (4) To make it as smooth as possible.

The first two of these considerations were insisted on, on account of the reasoning which follows

Ordinary Deccan Plough.

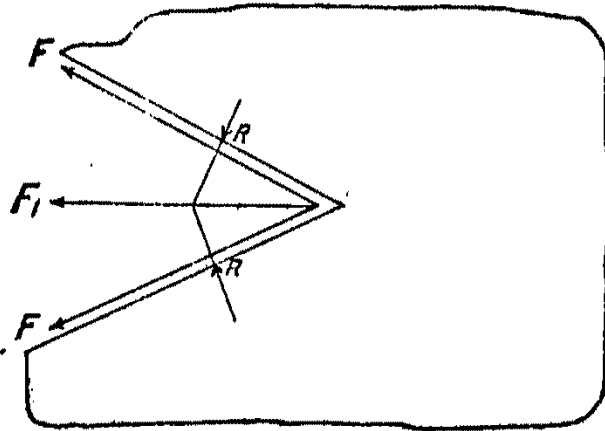


Fig. 3.

In the attached diagram, which is a horizontal plan of the share as it enters the soil—

R and R represent the reaction of the material of the earth tending to force the wedge out.

F and F represent the friction against the sides of the plough.

The resultant of R , R , F and F must all pass through the same point which lies in the plane of the centres of the triangular faces.

F_1 = friction along the top surface. This acts along the top surface and through the centre of that surface.

All the forces to be overcome are horizontal forces.

The weight of the plough tends to keep it balanced and in contact with the ground.

(1) If the line of draught is horizontal and passes through the point of application of the resultant of the forces to be overcome, all the applied force would be useful in working the plough.

(2) If the line of draught is inclined to the horizontal, only the horizontal component of this would be useful, the

vertical component having the effect of raising the plough from the ground. As long as the moment of this vertical component about the point of the share is not greater than the moment of the weight of the plough about the same point, the plough will not be lifted but as soon as it is greater it will be raised from the ground.

(3) If the force is horizontal but is applied above the point of application of the forces to be overcome, there will be two equal unlike parallel forces acting at a distance from one another. The result of this would be to cause the plough to revolve, *i. e.*, the manifest effect will be to overturn the plough. Whether it would be overturned or not, would depend both on the weight and the position of the centre of gravity of the plough. It is therefore necessary that the moment of the couple should not be so much as to be in excess of what can be counterbalanced by the weight of the plough.

(4) If the line of draught is inclined to the horizontal, and if the force acts at a point higher than the plane through which the resultant passes, then both (2) and (3) must be considered.

In all these cases it is assumed that the surface along which the plough moves is perfectly horizontal.

The conclusions to be drawn from these results are that in designing a Deccan plough the following points should be noted :—

- (1) The beam should, as far as possible, be horizontal.
- (2) The beam should be joined to the head at a point which should be as low as possible.
- (3) The head of the plough should be made heavy.

Construction and Testing of Suggested Plough.

The plough was then constructed in accordance with the principles laid down on pages 1 and 2, and also in accordance with the considerations just dealt with, and the result was a plough illustrated diagrammatically in figures on the frontispiece marked Experimental plough a and Experimental plough b and its difference from the ordinary plough can be seen from the figures marked Deccan plough a and Deccan plough b on the frontispiece. With this instrument experiments were then carried on in the field.

For this purpose lines were marked with lime at equal distances. The dynamometers were placed on the chains connecting the

Fig. 4.
Plan of Plough.

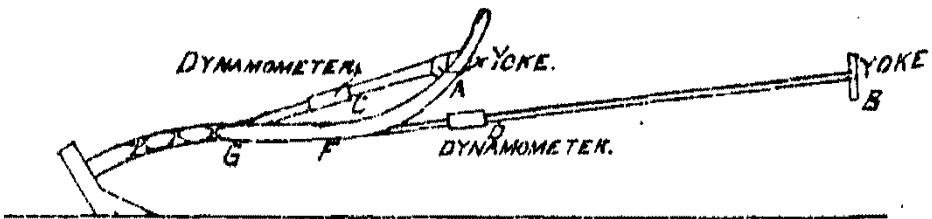
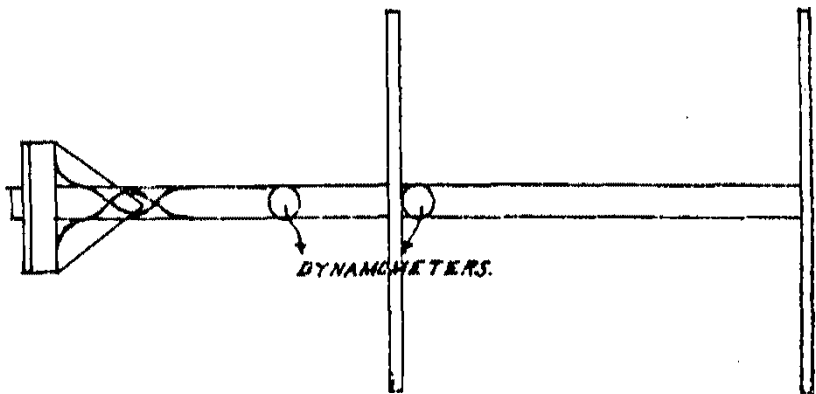


Fig. 5
Side view.

plough with the yokes of the bullocks. In Figs. 4 and 5, A and B are the yokes, C and D are the dynamometers placed along the ropes G A and F B. The ploughs in both cases were balanced and were worked with the same speed. The readings on the dynamometers were recorded when one of the dynamometers was on a lime-marked line and the work done by this pull was measured by opening the furrow at a point which was as many feet behind the lime-marked line as the dynamometer was in front of the point of the share. A sufficient number of readings were recorded and the dimensions of the furrow were measured. The actual pull required to be executed by bullocks was calculated as shown in Appendix III, and from these Tables 1 and 2 as well as Plates 1 to 5 and the other calculations were arrived at. By adopting the same method of calculation for the pull on the chain pulled by the nearer rope a certain amount of the horizontal force borne by the beam is neglected. But, in order that this should not affect the calculations, all the conditions (lengths and heights), as far as comparison is considered, were kept exactly the same in every case.

Methods of Comparing Ploughs.

From the results of the experiments recorded on the accompanying Tables 1 and 2 these ploughs can be compared with one another. This comparison can be done in two different ways :

(1) By comparing their efficiency, *i. e.*, by finding the ratio of the work done in opening the furrow, per square inch opened, to the force exerted by the bullocks which can be measured in pounds.

(2) By comparing their adjustability, *i. e.*, seeing whether pulls differing widely from one another are required for excavating the same depth of the soil and consequently the same area of the furrow in square inches, and also by seeing whether depths varying widely from one another are excavated with the same pull.

Field Tests by the First Method.

For both of these we cannot take into consideration all the pulls recorded ; for some of the pulls which occur rarely are due to accidental causes, such as the stiffness of the soil and others. These cannot be included in comparing the two ploughs with one another. We cannot also go by the *mode** alone, as in doing so we

* The ' Mode ' is the pull which occurs most frequently.

shall have to neglect several pulls very close to the *mode* and which are too numerous to be neglected. For the sake of comparison we shall therefore take into consideration the pulls included in the rectangles on Tables Nos. 1 and 2, *i. e.*, those pulls and those depths which are sufficiently numerous.

For the comparison by the first method, *i. e.*, for comparing the efficiency of the one with the other, we find out the area excavated by the plough with different pulls.

In the suggested plough the pull of 6.5 cwts. occurs for 21 times. The average depth excavated by this pull out of the depths that we are taking for comparison is 7.45 inches. The width of the plough is 9.25 inches, therefore the pull of 6.5 cwts. or 728 lbs. excavates a furrow 69.94 square inches. The pull per square inch is 10.40 pounds.

The pull of 7 cwts. occurs for 35 times; the average depth excavated by this pull is 7.68. The area of the furrow is therefore 71.04 square inches and the pull is 784 lbs.; therefore the pull per square inch is 11.03 lbs. Similarly for a pull of 7.5, 8, 8.5 and 9 cwts. the pull per square inch of furrow opened is 11.98, 11.85, 12.64, 13.62 lbs., the pull in these cases occurring 92, 31, 38 and 21 times, respectively. The average pull per square inch of furrow opened in the case of the experimental plough is therefore

$$= 11.93 \text{ lbs. per square inch.}$$

This differs from the pull per square inch judged by the *mode* only by .05 lb. Treating the case of the ordinary plough in the same way we get the following results:—

The pulls of 6, 6.5, 7, 7.5 and 8 cwts. occur 17, 55, 113, 38, 19 times, respectively, and the average depth excavated by each is 7.59, 8.08, 8.17, 8.47 and 8.31 in the several cases. The area of furrow opened respectively in the case of the above pulls is 35.11, 37.37, 37.79, 39.18 and 38.44 square inches. The average pull required for opening one square inch of furrow is in each case 19.14, 19.48, 20.74, 21.43 and 23.34 respectively.

The average of these averages gives the pull required on the part of the bullocks to open one square inch of the furrow and it is = 20.65 lbs. per square inch.

This differs from the pull per square inch judged by the *mode* only by .09 lbs.

These results are extremely satisfactory. By actual tests made with a full sized plough constructed to my design after the

suggested pattern, the pull required to open one square inch of soil area was reduced by nearly half—from 20·6 pounds to 11·9 pounds. Judged by the first standard laid down, the suggested plough is thus a very great improvement indeed.

Field Tests by the Second Method.

On the second basis of comparison it will, however, be found that the experimental plough is not as easily adjustable as the ordinary plough. The calculations showing the standard deviation from the mean are as under,—in other words, the extent to which the plough was affected by casual differences in soil, method of driving, etc. :—

| | | | | | | |
|--------------|-----|-----|--------|-----|------|-----|
| Depth | ... | 7" | 7·5" | 8" | 8·5" | 9" |
| Experimental | ... | ·60 | (·93)? | ·60 | ·65 | ·57 |
| Ordinary | ... | ·49 | ·53 | ·50 | ·38 | ·50 |

This shows that with additional accidental resistance the force required to pull the experimental plough varies in larger proportions than the Deccan plough.

Conclusion.

On the whole it seems that the experimental plough requires much less force per square inch of furrow opened than the ordinary plough. It is found that it can be run straight, can be balanced and worked as easily as the other plough. The method of yoking, working and all other things, though not as perfect as in the case of foreign ploughs, are exactly like those things for the Deccan plough and hence the cultivators require no training at all. Thus this plough is the ordinary plough, simply in an improved form which can be adapted without the least difficulty in any village.

TABLE I.

ORDINARY DECCAN PLOUGH.

NUMBER OF TIMES VARIOUS PULLS OCCUR AT VARIOUS DEPTHS.

Total Number of Tests—299.

| Depth in inches. | Pulls in cwts | | | | | | | | | | Total. |
|------------------|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 10 | |
| 5 | ... | ... | 1 | ... | 1 | ... | ... | ... | ... | ... | 2 |
| 5.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 6 | ... | 1 | 1 | 2 | 1 | 2 | ... | ... | ... | ... | 7 |
| 6.5 | ... | ... | 1 | 2 | ... | 1 | ... | ... | ... | ... | 4 |
| 7 | ... | 3 | 6 | 7 | 13 | 1 | 1 | ... | ... | .. | 31 |
| 7.5 | 2 | 2 | 5 | 11 | 17 | 2 | 3 | ... | ... | ... | 42 |
| 8 | 1 | 8 | 4 | 18 | 35 | 13 | 7 | 2 | ... | ... | 88 |
| 8.5 | 2 | 1 | 1 | 6 | 22 | 9 | 1 | 2 | 2 | ... | 45 |
| 9 | 1 | 1 | 1 | 11 | 18 | 8 | 5 | 2 | ... | 1 | 48 |
| 9.5 | ... | 1 | ... | 2 | 8 | 5 | 2 | 1 | ... | ... | 19 |
| 10 | ... | ... | ... | ... | 6 | 2 | 1 | 1 | ... | 1 | 11 |
| 10.5 | ... | ... | ... | ... | ... | ... | 1 | 1 | ... | ... | 2 |
| Total .. | 5 | 17 | 20 | 59 | 121 | 43 | 21 | 9 | 2 | 2 | 299 |

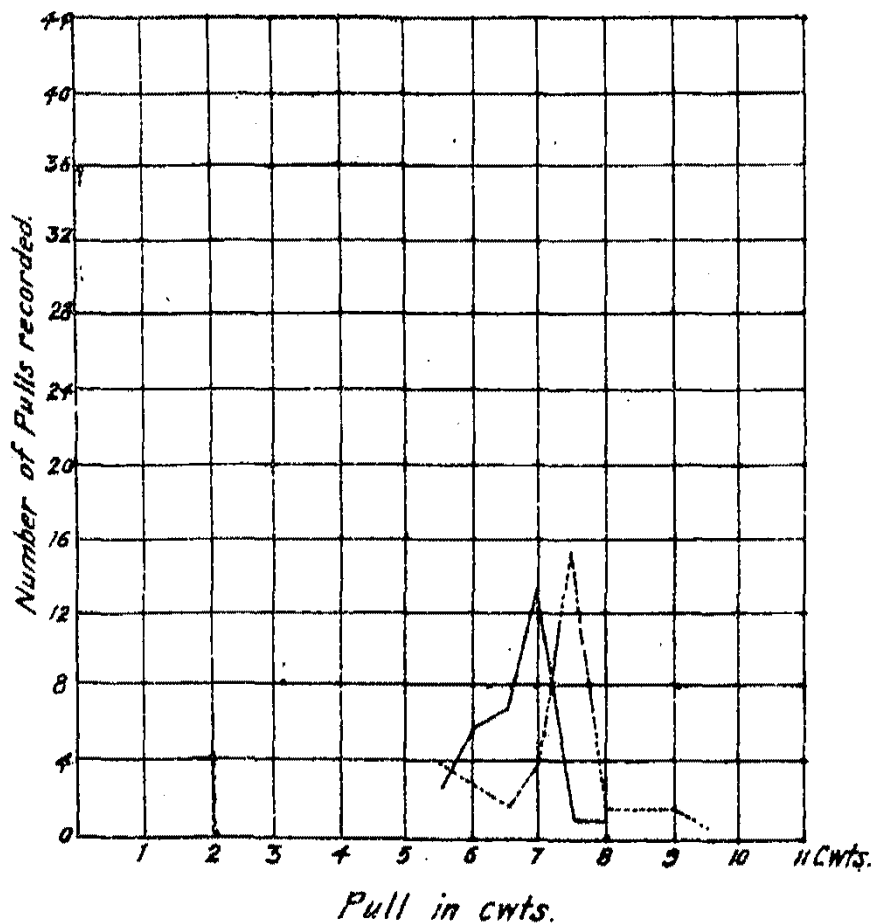
TABLE II.
EXPERIMENTAL PLOUGH.

NUMBER OF TIMES VARIOUS PULLS OCCUR AT VARIOUS DEPTHS

Total Number of Tests—303.

| Depths in inches. | Pulls in cwt. | | | | | | | | | | | Total. | | |
|-------------------|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|------|-----|
| | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | | 10.5 | 11 |
| 5.5 | ... | ... | 1 | 4 | 1 | ... | ... | ... | ... | ... | ... | ... | ... | 6 |
| 6 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | ... | 1 | ... | ... | ... | ... | 9 |
| 6.5 | 3 | 2 | 1 | 6 | 4 | 6 | ... | 2 | 2 | ... | 1 | ... | ... | 27 |
| | ... | 4 | 3 | 2 | 4 | 15 | 2 | 2 | 2 | 1 | ... | ... | ... | 35 |
| 7.5 | 1 | 1 | ... | 6 | 8 | 8 | 5 | 6 | 3 | 1 | ... | ... | ... | 39 |
| | ... | 1 | 1 | 3 | 14 | 38 | 10 | 10 | 6 | 1 | 3 | 3 | 1 | 91 |
| 8.5 | ... | ... | ... | 3 | 4 | 16 | 8 | 9 | 3 | 3 | 4 | 1 | ... | 51 |
| 9 | ... | ... | ... | 1 | 1 | 9 | 6 | 9 | 5 | 2 | ... | 1 | ... | 34 |
| 9.5 | ... | ... | ... | ... | ... | 1 | 1 | 3 | ... | ... | ... | ... | ... | 5 |
| 10 | ... | ... | ... | ... | 1 | ... | 1 | ... | ... | ... | ... | ... | 2 | 4 |
| 10.5 | ... | ... | ... | ... | ... | ... | 1 | ... | ... | ... | ... | 1 | ... | 2 |
| Total | 5 | 9 | 7 | 27 | 38 | 94 | 35 | 41 | 22 | 8 | 8 | 6 | 3 | 303 |

PLATE I.



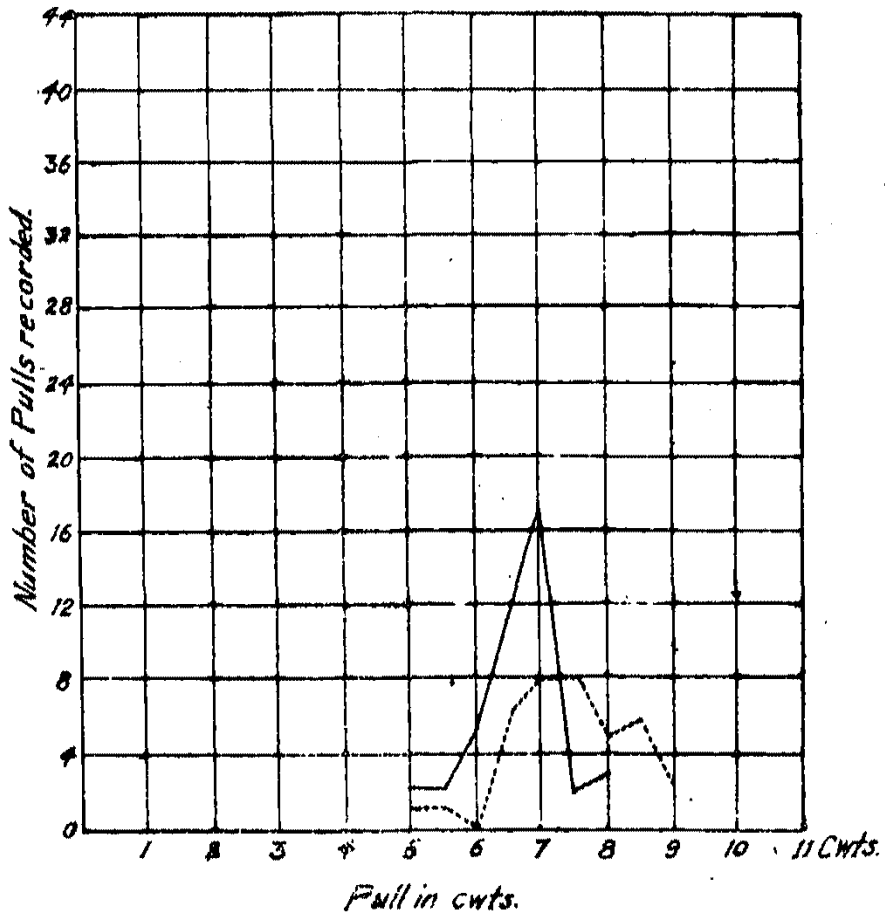
Frequency of various pulls with the two Ploughs.
at 7 inches depth.

Depth 7 inches.

Black lines:- Ordinary Plough.

Dotted lines:- Experimental Plough.

PLATE II



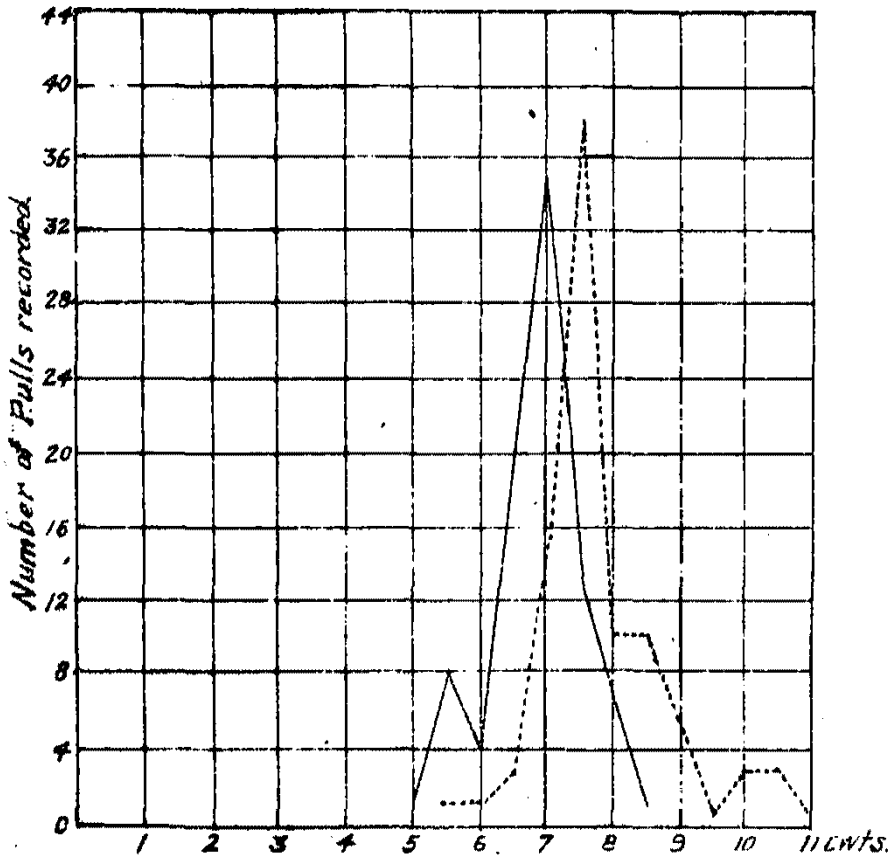
Frequency of various pulls with the two ploughs.
at $7\frac{1}{2}$ inches depth.

Depth $7\frac{1}{2}$ inches.

Black lines :- Ordinary Plough.

Dotted lines :- Experimental Plough.

PLATE III



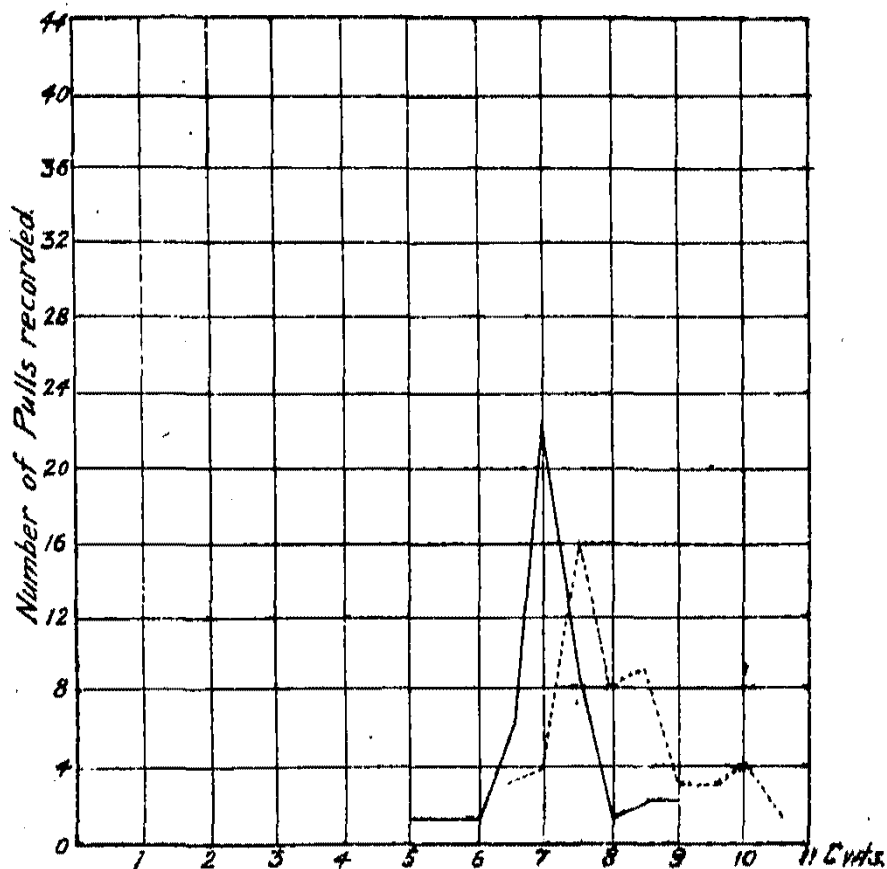
Pull in cwt.
Frequency of various pulls with the two ploughs.
at 8 inches depth.

Depth 8 inches.

Black lines:— Ordinary Plough.

Dotted lines:— Experimental Plough.

PLATE IV.



Pull in cwts.

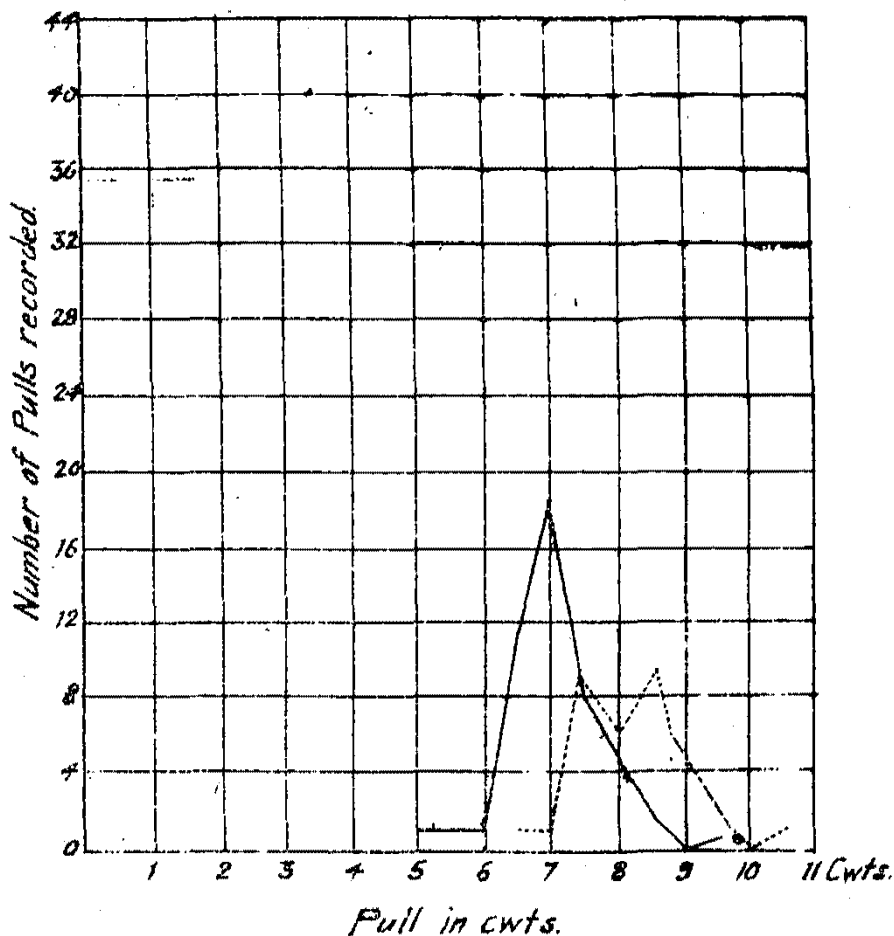
Frequency of various pulls with the two ploughs.
at $8\frac{1}{2}$ inches depth.

Depth $8\frac{1}{2}$ inches.

Black lines :- Ordinary Plough.

Dotted lines :- Experimental Plough.

PLATE V.



Frequency of various pulls with the two ploughs at 9 inches depth.

Depth 9 inches.

Black lines :- Ordinary plough.

Dotted lines :- Experimental plough.

APPENDIX I.

It has been stated on page 6 that the plough should be as smooth as possible. The reason for stating this is that a very large proportion of the total force exerted by bullocks is spent in overcoming the friction between the sides of the plough and the sides of the furrow. The proportion of this friction to the total force exerted was arrived at by a laboratory experiment with a small model.

The following are the details of the experiment :—

| | | |
|---|--------|------------------|
| The weight of the plough | | = 536 grammes. |
| The distance of the centre of gravity of the plough from the end of the share | | = 2.37 inches. |
| The weight of the soil standing over the plough | | = 176.6 grammes. |
| Distance of the centre of gravity of the plough from the end of the share | | = 3.25 inches. |

The sum of the moments tending to balance the plough

$$536 \times 2.37 + 176.6 \times 3.25 = 1844.27.$$

I.—Determining the position of the plane along which the resistance acts.

The pull is exerted along a horizontal string attached to the beam which is also kept horizontal. In this case it was found that the plough, instead of being moved through the soil, was raised up from behind when a force of 726 grammes was applied at the end of the string.

At this moment the overturning moment due to the force must be equal to the balancing moment. If in the following figure P represents the pull, R the resistance (R being equal to P) and X the arm of the couple tending to overturn the plough, $P \times X$ will be the overturning moment.

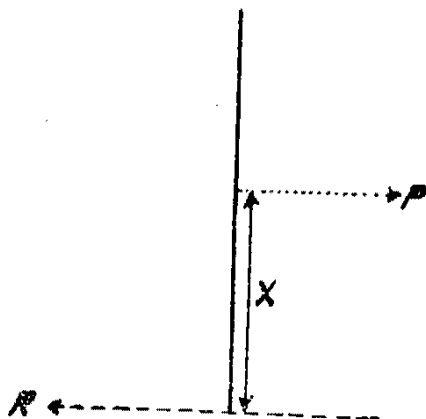


Fig. 6.

As $P = 726$ the overturning moment is $726 \times X$. This is equal to 1844.27 the balancing moment. The arm of the couple therefore is equal to 2.54 inches, *i. e.*, the plane along which the resistance acts is 2.54 inches below the point at which the beam is fixed to the head of the plough.

II.—Determining the total resistance.

The pull is exerted along a horizontal string attached to a nail driven in the plough so that the string should lie in the plane along which the resistance acts. In this case it was found that the plough was perfectly balanced and moved in the soil when the tension on the string was 1,616 grammes. The depth of the furrow in this case is 1.60 inches. The tension on the string represents the total resistance offered to the movement of the plough. The total resistance for every inch of depth excavated is therefore 1,010 grammes.

III.—Determining the resistance due to friction.

The pull is exerted as in I, along a horizontal string attached to a horizontal beam which is 2.54 inches above the plane along which the resistance acts. In this case it was found as in I that the plough was overturned before it began to move. This was clearly due to the fact that the overturning moment was greater than the balancing moment. It was therefore necessary to increase the balancing moment and make it equal to or a little greater than the overturning moment in order that the plough may be perfectly balanced and move in the soil. This was effected by putting a weight on the head of the plough. The distance of the head of the plough from the end of the share was 8 inches. The balancing moment was increased by eight times the weight put on the head of the plough.

A number of experiments was made to determine the exact weight which, when placed on the head of the plough, would balance it while moving in the soil. As a result of these experiments it was found that when a weight of 500 grammes was placed over the head of the plough, it was moved through the soil and was perfectly balanced. The tension on the string was 2,411 grammes and the depth of the furrow was 2 inches. It has been found in II that the total resistance for every inch of depth excavated is 1,010 grammes. The pull in the above instance where the depth of the furrow is 2 inches should have been 2,020 instead of 2,416. This shows an increase of 396 grammes in the total resistance. This represents the frictional resistance caused by the extra pressure of 500 grammes. This shows that for every 100 grammes of the weight of the plough the frictional resistance is 79.2 grammes.

In this case the total weight of the plough is 1,036 grammes and the weight of the soil which increases with the depth of the furrow is 220 grammes. The total pressure is 1,256 grammes. The frictional resistance due to this pressure is 994.75 grammes.

* The total frictional resistance is therefore 41.17 per cent. of the total resistance to be overcome. It is therefore absolutely necessary to diminish this as far as possible by making the surfaces of the plough very smooth.

* It should be noted that the soil taken for this experiment was loose soil and therefore less force had to be exerted to overcome the cohesion of the soil. The percentage of the force of friction is therefore a little greater.

APPENDIX II.

On pages 7 and 8 four different methods of exerting the pull for drawing the plough are given with their respective advantages and disadvantages. Of these the fourth is the one which always occurs in practice, and therefore is important enough to demand an experimental verification with a small model. An experiment was therefore made, of which the following are the details:—

| | | |
|---|-----|-----------------------|
| Weight of the plough | ... | ... = 686 grammes. |
| Distance of the centre of gravity of the plough from the end of the share | ... | ... = 4.25 inches. |
| Weight of the soil over the plough | ... | ... = 277.86 grammes. |
| Distance of the centre of gravity of the soil from the point of the share | ... | ... = 4.83 inches. |

The sum of the moments tending to balance the plough
 $= 686 \times 4.25 + 277.86 \times 4.83 = 4258.56.$

I.—Determining the position of the plane along which the resistance acts.

This was arrived at as explained in Appendix I, step I. In the case of this plough this plane is situated at a distance of $\frac{1}{4}$ th inch above the bottom of the plough and 1.5 inches below the point at which the beam is fixed to the head of the plough.

II.—Determining the total resistance.

This was obtained as explained in Appendix I, step II. In the case under consideration the total resistance was 1,488 grammes when the depth of the furrow was 2 inches and its breadth at top is 3.5 inches. The sectional area of the furrow opened is 3.5 square inches and therefore the resistance per square inch of furrow opened is 425.14 grammes. In this case the resistance being equal to the pull, the pull is also 425.14 grammes per square inch of furrow opened.

III.—Effect of applying the force as explained in method (4), page 8.

The pull was exerted along a string fixed to a beam which slopes upwards. The inclination of the beam to the horizontal was gradually increased until the maximum inclination, at which the plough could be balanced and worked, was obtained. This inclination or slope was 2 inches in 12.5 inches. The vertical component of the pull is $\frac{2}{12.5}$ or .16 of the total pull. Under these circumstances the plough could be worked with a pull of 1,639 grammes along the string. The depth of the furrow was $1\frac{3}{4}$ inches and its breadth at top was 3.5 inches. The sectional area of the furrow was 3.28 square inches. The horizontal component of the pull which only is useful in working the plough is 1,367 grammes or 416.77 grammes per square inch of furrow opened. This is almost the same as the pull required for doing the same work when the pull was exerted along the plane along which the resistance acts.

In this case the overturning moment is

$$272 \times 7.25 + 1367 \times 1.5 = 4022.5$$

and the balancing moment is 4082.52. Both these are almost equal to one another.

It was further found that when the inclination of the beam was made steeper than this the plough could not be balanced and worked.

The statement made in method (4), page 8, is thus clearly proved by this laboratory experiment.

APPENDIX III.

This is intended to illustrate the way in which the actual pull exerted by the bullocks is determined from the recorded readings of the dynamometer.

In Fig. 5, page 8, A and B represent the yokes. GA and FB represent the chains along which the dynamometers are placed. The positions of the dynamometers are also shown in the figure.

The heights of F, B, G and A were measured from the ground and the lengths of GA and FB were also measured.

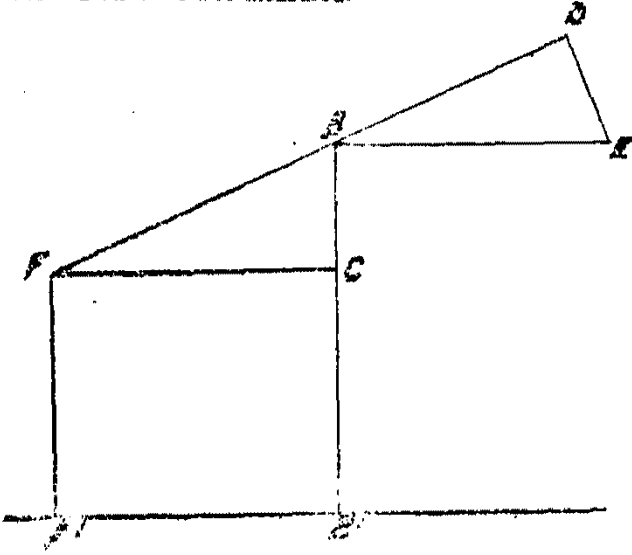


Fig. 7

In the above figure FF' and BB' represent the heights of F and B above ground.

$BC = BB' - FF'$ and FB was actually measured.

Therefore the angle BFC of the right angled triangle BCF could be determined. The angle $BFC =$ the angle DBE . BE represents the direction in which the pull is exerted by the bullocks. We want to find the relation between BD and BE , *i.e.*, between the tension on the chain which was given by the reading on the dynamometer and the actual pull exerted by the bullocks.

$$\cos DBE = \frac{BD}{BE} \quad \text{Therefore } BE = \frac{BD}{\cos DBE}$$

The actual pull exerted by the bullocks is equal to the reading on the dynamometer divided by the cosine of the angle made by the chain with the horizontal.

The same method is adopted in calculating the pull due to the tension on the chain GA .

LIST OF AGRICULTURAL BULLETINS PUBLISHED BY THE DEPARTMENT OF AGRICULTURE FROM 1908 TO 1913.

| No. | Year. | Subject. | Price. | |
|-----|-------|---|--------|------|
| | | | Rs. | P. |
| 80 | 1908 | Field, Garden and Orchard Crops of the Bombay Presidency, by G. A. Gammie, Economic Botanist, Bombay | 0 | 1 5 |
| 81 | 1908 | Establishment and Management of the Dairy Farm, by G. K. Kelkar, Assistant Professor of Agriculture | 0 | 8 0 |
| 82 | 1908 | Locusts in India, by H. M. Lafroy, Imperial Entomologist, Pusa | 0 | 8 0 |
| 83 | 1909 | Cultivation of Broach Cotton in Dhárwár, by M. L. Kulkarni, Divisional Inspector of Agriculture, B. D. | 0 | 4 0 |
| 84 | 1909 | Night-soil—A Valuable Manure, by G. K. Kelkar, Assistant Professor of Agriculture, Agricultural College, Poona | 0 | 4 0 |
| 85 | 1909 | Kalar in Sind, by G. S. Henderson, Deputy Director of Agriculture, Sind | 0 | 4 0 |
| 86 | 1910 | First Experiments in the Treatment of Grape-vine Mildew in the Bombay Presidency, by W. Burns, Economic Botanist | 0 | 14 0 |
| 87 | 1910 | An Examination of the Seed-supply of the Broach District, by G. D. Mehta. | 0 | 4 0 |
| 88 | 1910 | Experiments with the Water-Finder, by H. K. Mehta, Assistant Professor of Physics, etc., Poona Agricultural College | 0 | 5 0 |
| 89 | 1910 | The Salt Land of the Nira Valley, by Harold H. Mann, Principal, Agricultural College, Poona, and V. A. Tambane, Laboratory Assistant, Agricultural College, Poona | 0 | 5 0 |
| 40 | 1911 | Cultivation of Guavas near Poona, Dhárwár and Limbgaon, by L. B. Kulkarni, L.Ag., Agricultural Department, Bombay | 0 | 12 0 |
| 41 | 1911 | Groundnuts in the Bombay Deccan, by G. K. Kelkar, Assistant Professor of Agriculture, Poona | 0 | 4 0 |
| 42 | 1911 | Note on Long-stapled Cotton in Sind, by G. S. Henderson, N.D.A., N.D.D., Deputy Director of Agriculture, Sind | 0 | 8 0 |
| 43 | 1911 | An Examination of the Seed-supply of the Broach District, Part II, by G. D. Mehta, L.Ag. (Bombay), B.A. (Cantab.), N.D.A., N.D.D. | 0 | 5 0 |
| 44 | 1911 | Preliminary Study of the Red Rot of Sugarcane in the Bombay Presidency, by G. S. Kulkarni, L.Ag., Assistant Mycologist | 0 | 8 0 |
| 45 | 1911 | Second Year's Experiments in the Treatment of Grape-vine Mildew in the Bombay Presidency, by William Burns, B.Sc. (Edin.), Economic Botanist to the Government of Bombay | 0 | 14 0 |
| 46 | 1911 | Seed Selection Series, I, Broach Cotton, by T. Forster Main, B.Sc., Deputy Director of Agriculture, Bombay Presidency, Poona | 0 | 8 0 |
| 47 | 1911 | San Hemp (Crotolaria Juncea), Tág (Maráthi), by P. C. Patil, L.Ag., Divisional Inspector of Agriculture, C. D. | 0 | 4 0 |
| 48 | 1911 | Poona Furnace (in the Sátára District), by P. C. Patil, L.Ag., Divisional Inspector of Agriculture, C. D. | 0 | 7 0 |
| 49 | 1911 | An Examination of the Seed-supply of the Ahmednagar District, Part I, by G. D. Mehta, L.Ag. (Bombay), B.A. (Camb.) | 0 | 5 0 |
| 50 | 1912 | An Examination of the Seed-supply of the Ahmednagar District, Part II, by G. D. Mehta, L.Ag. (Bombay), B.A. (Camb.) | 0 | 8 0 |
| 51 | 1912 | Third Year's Experiments in the Treatment of Grape-vine Mildew in the Bombay Presidency, by W. Burns, B.Sc. (Edin.), Economic Botanist to the Government of Bombay, and G. B. Patwardhan, B.Sc. (Bombay), Assistant Economic Botanist | 0 | 8 0 |
| 52 | 1912 | Muscovado Sugar Machinery and its scope for <i>Gul</i> manufacture in India, by G. N. Sahasrabudhe, L.Ag. | 0 | 8 0 |
| 53 | 1912 | A Method of improving the Quality of Cotton Seed, by G. D. Mehta, B.A.; L.Ag., N.D.A., N.D.D., and V. G. Gokhale, L.Ag. | 0 | 7 0 |
| 54 | 1912 | A Note on Steam Ploughing, by A. A. Musto, P. W. D., Agricultural Engineer, Bombay Presidency | 0 | 10 0 |
| 55 | 1913 | An Examination of the Seed-supply of the Poona District, Parts I and II, from the Seed Testing Department, Agricultural College, Poona. | 0 | 8 0 |
| 57 | 1913 | Improvement of the Indigenous Plough of Western India by S. S. Godbole, L.O.E., Assistant Professor of Physics, Agricultural College, Poona | 0 | 12 0 |