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# SOIL DRAINAGE

BY

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# SOIL DRAINAGE

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## Introduction.

THIS paper covers a subject the principles and practice of which will be fairly common knowledge to any one who has had any practical experience in estate and field drainage in England. The work in progress on the Agricultural College Farm at Nagpur has so often proved of interest to visitors and so frequently been the cause of subsequent letters on their part, or on the part of others enquiring for details, that the necessity of a paper on the subject seems well-founded.

The advent of the monsoon and the enormous interest taken in the arrival and plentitude of the rains—undoubtedly a factor of absolutely essential importance in Indian farming—have led to a popular feeling that rain is all that really matters.

In the writer's experience, however, this is very far indeed from being the case, at any rate over large areas of the Central Provinces and probably so elsewhere in India. Both the plants growing in the soil and many of the lower biological forms of life inhabiting the soil, on which the plants' growth depends, demand both water and air—not only water and air but fresh water and fresh air—for their existence and growth.

In many soils, in particular during the earlier part of the monsoon downpour, the former is in excess and the latter chiefly remarkable by its absence or great deficiency. As the soil pores are chocked with water, the passage of this water downwards is normally very slow, and there is thus a considerable stagnation of water in the soil which prevents the necessary entry of air. This takes place at a period of the plant's growth when it is young, delicate, and particularly susceptible to unfavourable conditions. Not only is the plant root-system practically suffocated by drowning but certain processes, such as nitrification, almost cease. In short, the crop shows all the evidence of being waterlogged. Plants checked in their growth when young rarely, if ever, recover, while the effort on the part of such as survive this bad condition to avoid the excess of water below the immediate surface layer, tends to the development of a number of shallow surface-feeding roots with the result that later the plant is not in a position to strike down when the excess water has eventually percolated.

In addition, the various processes of tillage are either restricted or suspended. For example, deep ploughing as preparatory for cotton or *kharif* (monsoon) crops in general, unless given for the purpose of the extermination of *kans* (*Saccharum spontaneum*) or *hariali* (*Cynodon dactylon*), is a process of very doubtful value in many areas and fields in the cotton tract. The objection to the practice lies partly in the delay which arises in getting the cotton sown and partly in the increased water-holding capacity and subsequently intensified tendency to water-logging which ensues. Yet, if conditions exist which permit of the removal of this water from the immediate root-zone, early sowing, really done to allow of the establishment of the plant before the heavy July-August rains, is not essential and the waterlogging effect does not exist. Ploughing before cotton, in the majority of cases, cannot be advised as being better than the country surface *bakhar* work, except in areas of low rainfall or on fields in which either position or subsoil permits of a satisfactory soil drainage. Again, intercultivation, of which the primary objects in the monsoon are weed destruction and the breaking of hard surfaces to allow of aeration and the adequate production of a soil mulch later in the year, is prevented or reduced to a minimum. Weeds, hard surfaces, and inferior mulches become more and more common features of cotton cultivation as one travels from the areas of comparatively light rainfalls to those in which the rain of July and August is more persistent and as one passes from the higher and better drained fields under cotton to those in lower positions where the water received for disposal by the soil is greater and where the soil is deeper and heavier.

Observations in many parts of the cotton and principal *kharif* growing areas and on the College Farm (which is situated in one of the wettest sections of the cotton tract) have led the writer to the belief that lack of adequate drainage is one of the primary factors affecting the output of cotton over thousands of acres now under this crop. The great increase in the value of cotton has tended to its expansion to fields which are apt to dry out too early for the highest yields at one extreme, and, at the other, on to fields which are definitely too wet in July and August. Even in fields which have grown cotton for a very long period of their history in many places in the eastern section of the cotton belt, the soil climate is usually too wet for the best returns. Respectable yields, when compared with those commoner in

Berar, are only got after distinctly heavy manuring and an exceptionally favourable distribution of the July-August rainfall. Again, there are hundreds of fields which might, on the whole, be classed as suitable for fair production without direct assistance, which contain lower-lying hollows or corners in which the only choices to the grower are a very poor outturn or the relegation of the patch to the growth of a second-rate wheat or gram crop—second rate as, on account of its isolation, smallness, and wetness in the rains, the cultivation given is inferior and not on the level of that given to true *rabi* (winter crop) fields.

Poor outturns, lack of effect of the manure applied, and inferior tillage appeared to be the direct outcome not of want of water but of excess of water and resulted in the production, in the classes of soil usually carrying cotton, *i.e.*, loams and clay loams, of a soil climate which was detrimental to the growth of semi-arid tropical crops like cotton and *juar* (*Andropogon Sorghum*) and to the development of the lower biological forms of life on which much depends. Experimental work in underdrainage and surface drains was thus started on various fields over the College Farm, till at present there are about 10 or 11 underground systems, draining areas ranging from a fraction of an acre to 3—4 acres in extent. All these have not been completely successful, but in such as have partly failed in their object the reason of failure has been identified. The majority have however fulfilled every expectation. In one or two cases crops of cotton are now growing on areas which were practically useless till action was taken, and on others the cotton crops growing are earlier, bigger, and considerably more prolific than the same crops on the best placed true cotton fields of the farm after similar manurial treatment. These results are the outcome of a better environment and better opportunities of cultivation in the monsoon.

The recent opening up of cotton cultivation in Chhattisgarh has but emphasized the general observations on the growth of cotton on the College Farm—that a free drainage in the monsoon and aeration are essential factors of success. The *bhata* soil of Chhattisgarh has little to recommend it from the general standpoint of a good soil; it is poor, stony, and infertile. Given, however, small dressings of manure, it responds immediately and the growth of cotton and other crops in the monsoon is steady, rapid, and unchecked. This arises purely from a natural free drainage, as the actual rainfall is some 20″ in excess of the wettest part of the cotton tract proper. Some recent partial trials of cotton cultivation on some of the heavier soil of the same area, with the assistance of moderately deep surface-drains, have again indicated that cotton can grow in even these soils in wet districts, if attention is paid to getting rid, sufficiently rapidly, of the gravitationed water from the soil.

The removal of water on the College Farm has been attempted by the direct use of under-drains, by the shaping of the field surface into gentle undulations like that noticeable on old pasture land on heavy soil in many counties in England, by a system of contour ditches which imply a partial surface-drainage flow succeeded by a suction action on the water in the neighbourhood of the ditches and by the protection of fields from water received by surface flow from higher fields. The writer has, however, principally developed the first named, in the belief that the initial cost though greater is more than compensated for by the increased cultivable area, the greater efficiency of the drainage, the absence of weeds (the usual accompaniment of any open drainage system), and the removal of the heavy annual cost of ditch upkeep invariable with open drains in the wetter areas on the black cotton soil.

## Field Protection.

Before dealing with under-drainage, it may be as well briefly to outline the work and results of the other three methods adopted to control the monsoon water in the soil. Field protection is not drainage in the sense that there is no removal of water received from the neighbourhood of the plant and there is no effort to reduce the water received by natural rainfall. Many fields, however, in the undulating conditions of the black cotton country are called on to deal with and dispose of by percolation a good deal more water than actually falls on the surface in the form of rain. Considerable relief can thus be given a field by controlling the surface flow from upper areas. This control often allows such fields to be sown in *kharif* crops, whereas before treatment it was impossible to cultivate them. Field protection is arrived at by the construction of *bunds* (embankments) and suitable water carriers. Any form of field protection demands both. *Bunds* which check erosion and possibly protect the field below them are not infrequently to be seen unaccompanied by any means of controlled water-removal. Such systems are definitely faulty, as the prevention of erosion and damage to the lower fields is gained at the expense of waterlogging in fields higher up. Any system of field protection must be designed so as to allow of the removal of the water held up by the protective checks.

The map attached illustrates the condition before and after protective measures were started on one of the College Farm fields. (Fig. 1.)

Originally F received the flow water of all fields, while C got all the water of A and part of that of B and E. An examination of the map will show that these two fields are now entirely protected. The area C was at first practically a water-cut valley between the higher parts

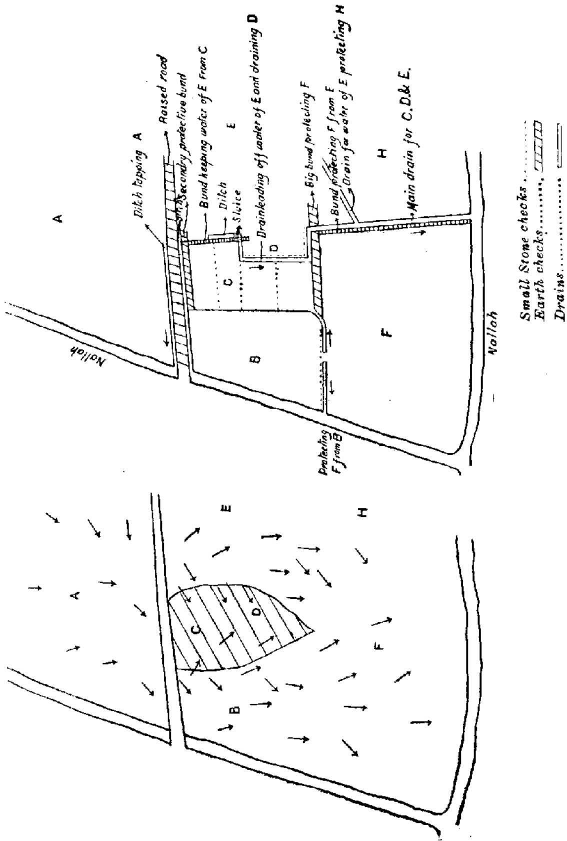

A
Ditch topping A
Raised road
Secondary protective bund
Bund keeping water of E from C
Ditch
Sluice
Drain leading off water of E and draining D
Big bund protecting F
Bund protecting F from E
Drain for water of E protecting H
Main drain for C, D & E.
E
H
C
D
B
F
Nalloh
Nalloh
Protecting F from B
Small Stone checks
Earth checks
Drains

FIG. 1.

of E and B. Large parts of F are now capable of growing good fodder in the monsoon and C is fully under cultivation. The upper checks are now nearly flat and carry *kharif* crops.

## Ridge and Furrow.

This adaptation of an old system, common on heavy soils before the introduction of under-drainage in England, has proved quite effective. The field under treatment is ploughed into lands with alternating gathered ridges and open furrows. In practice, the final condition of the field is not reached for 2-3 years, but a very considerable difference may be produced by completing two ploughings of like character over the same area. In case any one may not understand what is intended the plan and section of a field so treated are given below.

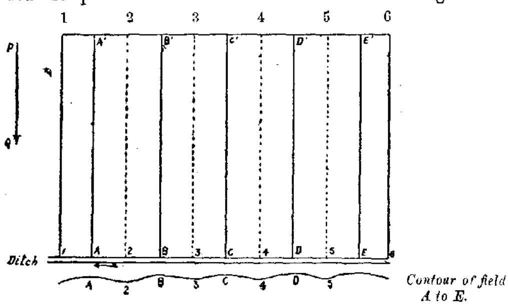



FIG. 2.

Assuming the mould board is on the right, the plough is sent up the line A—A′, is turned to the right at A′ and returns to A, thus throwing the soil together along A—A′. Ploughing is continued round A—A′ till 1—1 and 2—2 are reached when the plough is transferred to B—B′, and the same process continued till the plough works out to 2—2 and 3—3, and so on. At the lines A—A′, B—B′, etc., we have raised soil, while along 2—2, 3—3, etc., we have wide open furrows. Water received on the area A—A′ and B—B′ drains down two short slopes without effecting erosion to the line 2—2 which acts as controlled water channel and removes the water to a drain along the line ABCD.

The best distance between 2 and 3 will vary with the texture of the soil. On the clay loam character of the black soil we have found 30 feet satisfactory. Some attention must be given to the slope of the field in deciding the direction in which the lands are to be ploughed. If the slope in direction PQ above is at all steep, the lands should be put at an angle to the main slope. The ultimate gradient of 2—2, 3—3, whether down the direct slope of the field or at an angle to this, should probably not exceed 1 in 300. It is advisable to place a few short pegs, roughly interwoven with cotton or *san* (*Crotalaria juncea*) stalks or grass, at the point where 2-3-4, etc., reach the main drain. If the two above are attended to, little or no loss of soil occurs, while the general growth over the field is considerably improved and a reduction is made in the area usually covered by the meandering streams so commonly seen.

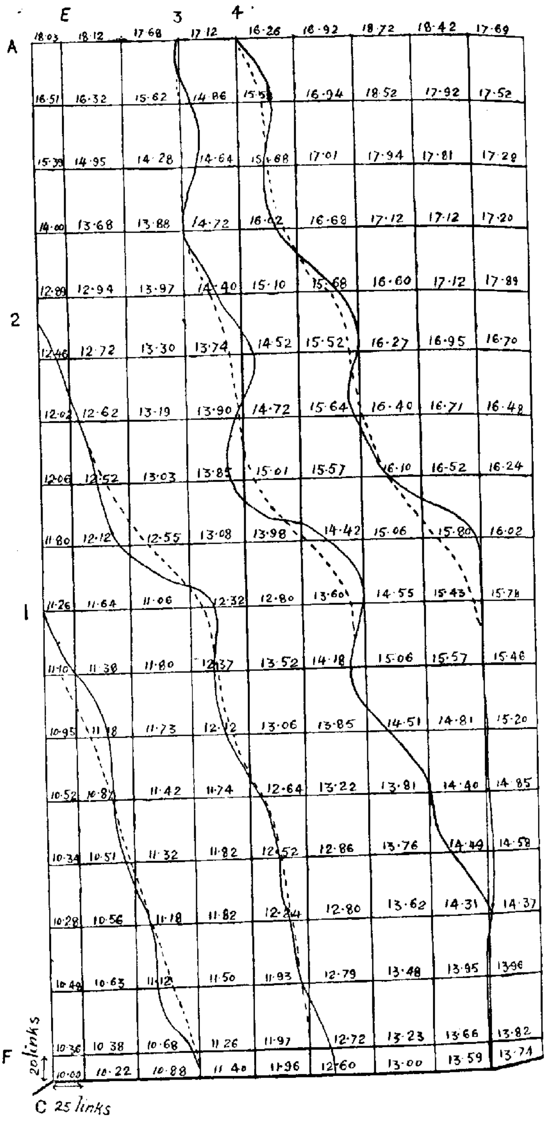
## Contour Open Drains.

When working with under-drains on the farm, it was noted that certain fields responded badly to under-drainage or required so close a placing of these drains as to become too expensive for common practice. This was the case, in particular, on fields in which the subsoil consisted of *chopan*, a stiff yellow clay. As the areas covered with this class of soil are of a gentle undulating character, it was decided to use open ditches. These ditches were aligned approximately along contour lines, small hollows, which might cause the true contour channel to be too winding, being filled in with earth removed from the ditches. A contour survey was first made and the lines of the proposed ditches marked out on the map. The field was then visited and staked out and subsequently examined with a view to straightening out the ditch lines. The ditches were then dug 20″-22″ deep, about 1′ 3″ wide at the bottom, and with sides at about 60° slope. Along the upper margin of each ditch about 1′ from the edge was placed a small check of boulders about 6″-8″ high, surfaced with a little earth from the ditch.

The plan of one of the areas drained in this fashion is given on p. 8 (Fig. 3).

The action during rain is a surface flow over the area bunded by two contour channels towards the lower channel and its boulder check. At this point the water is close enough to the drain for its suction-action to have effect and the water is drawn through the soil below the check into the drain, and subsequently flows away down the drain, which is given a slight fall of about 1 in 400 to the main ditch on the field boundary. The writer has termed this system "contour open drains" as they appear to be more likely to be of value when laid on fields which possess a fall. On level or nearly level lands, the surface flow would be very slow, and in consequence the drainage-ditches to be effective would have to be sufficiently close to provide a suction effect. This would entail either very deep drains or too many, with consequent loss of area, as well as difficulty of tillage and excessive cost of up-keep. When first set out, contour surface drains require a good deal of attention on account of fall of soil and the like, till the angle of settlement is finally

CONTOUR DRAIN PLAN ON FIELD 47.



Whole lines = Original contour position of ditches.
Dotted lines = Final position of ditch after filling hollows with earth.

reached. They require cleaning annually in order to keep them in a state of efficiency. In draining stiff soils, they appear to be cheaper and as effective as under-drains. The cost of the system given in the plan was :—

| | Rs. |
|---|---|
| Digging and construction of channels and bunds . | 29 |
| Boulders 900 cubic ft. . . . . . . | 45 |
| | 74 |

or about Rs. 30 per acre

## Under-Drainage.

A study of this method of correcting the water-content of soils growing crops in the monsoon has now been in practice for 7 or 8 years on the College Farm and some ten systems are in working order. Of these only one is a partial failure. Though it was not till recently that land was available on which a close experimental study was possible, results obtained on the areas selected for improvement have been so marked, that the advantages gained by the treatment have been obvious. It is hoped however that it will be possible in the near future to make a closer study of the root-development, loss of salts, and the like. In this paper it is only intended that a brief description of the results obtained and the methods employed should be given.

With reference to the former the following are among the larger systems which have been in work for 3 years or longer.

*Field 8.* Part of sewage farm. Soil, a loam developing to a stiffish clay loam at about 1½′ below surface; area, fairly high-lying. This area was under-drained to study the effect on *juar,* which had given indications of being an unsuitable crop for a sewage farm in the rains on this class of soil. It was under comparison with a similarly sown and cultivated, but undrained, area on the farm.

The returns of *juar* fodder are recorded below :—

| Year | Drained lb. | Undrained lb. |
|---|---|---|
| 1914-15 . . | 11,609 . . | 7,833 |
| 1915-16 . . | 20,506 . . | 15,290 |
| 1916-17 . . | 22,100 . . | 20,450 |

In spite of being naturally well placed as regards its drainage, the effects of under-drainage, particularly in the early years before the soil had got enriched, is evident.

*Field 44.* This field is one generally allotted to a *kharif* crop. It has, however, at one corner a portion which was totally unsuited to this class of cropping, as it is low-lying and thus receives the surface flow of the best part of 15 acres. The soil varied from a free clay loam to a clay loam. The following history yields an indication of the effect of under-drainage on this block of about 2 acres.

1909-10. *Tur* (*Cajanus indicus*) was almost a failure over the area owing to excess water.

1910-11. *Juar*; a year of light rainfall; the crop was about the same as in the higher areas of the same field.

1911-12. Gram. Net returns about Rs. 5 per acre.

1912-13. Wheat. Net returns about Rs. 8-6 per acre.

*Under-drainage.*

1913-14. Not a very good cotton year. Return of cotton over under-drained area 355 lb. per acre as against 230 lb. on the balance of the field.

1914-15. Fodder. Yield nearly twice that of the rest of the field per acre. Crop almost 18,000 lb. dry fodder per acre.

1915-16. *Juar* for grain. Yield of grain per acre of drained land, 910 lb.; and from the best acre of the balance of the field 747 lb.; fodder not weighed.

1916-17. A poor cotton crop due to an excessive and protracted monsoon. Average, over farm, only about 6 annas of normal. Outturn of drained area was not much above rest of field due to the fact that, as ripening is about 3 weeks earlier on this area, the bad effects of the late rain were more marked.

1917-18. In this year the rain was excessive in July. The only part of the field which could be got under cultivation and sown was the drained area. The rest of the field was fallow. The cotton crop grew well in spite of rain, but the yield was seriously reduced by the continuation of the rains to mid-October. The outturn 163 lb. compared favourably with the poor average over the farm. The estimated average net profit per acre over the first period was between 9 and 10 rupees. The average net profit over the balance of the period when under-drained was Rs. 46 in spite of two years in which causes, entirely apart from the soil-moisture, markedly lowered the yield.

*Field 23.* A most unsatisfactory field. It was usually badly waterlogged over two-thirds of its area in the monsoon and dried too rapidly in the cold weather to allow of wheat or gram. Under-drainage showed a layer of typical black soil to a depth of 18″ to 2′. Below this lay a bed of coarse sand about 3″-4″ thick at the lower end and deepening as one passed up the field. This in its turn was underlain by a stiff clay which possessed a natural dip from the lower end of the field, thus allowing the increased depth of sand as one moved up the field. The *chopan* (clay) produced a semi-lake-like condition during the monsoon. The introduction of under-drains at once corrected the defect and the field now grows among the best cotton and fodder crops of the farm area.

*Field 47.* A soil of very variable character consisting of loam near the surface, passing at the upper end to a sandy murrum, and in the lower parts to a stiff *chopan* subsoil. In this field the under-drainage was only successful in parts. Examination showed that failure was due to a faulty laying of the pipes as regards depth (due to much surface irregularity) and distance between lines. The more recently laid systems are all working excellently and further extensions have been continued this year which have enabled blocks of more accurately experimental character to be taken in, thus allowing of a closer comparison of results with those on undrained blocks.

## Methods employed.

*Materials.* The pipes used are home made. They are, practically speaking, the ordinary wheel tile before cutting for roofing purposes, *i.e.*, baked whole instead of halved. The shape of the tile is thus usually slightly conical, though more recently the potter has got into the habit of making them more cylindrical, so that the end of smaller diameter just fits into the end of wider diameter, thus reducing waste by unnecessary over-lap. The tiles passed for use are those free of cracks and possessed of a clear ringing note when tapped, and, on laying, three are estimated to each two feet of drain. The cost, all charges included, works out at about Rs. 19 per 1,000 minor drains and about Rs. 30 per 1,000 main. The minor drains are about $2\frac{3}{4}''$ diameter at one end and about $3\frac{3}{4}''$ diameter at the other, while the mains are $3\frac{3}{4}''$ and $4\frac{1}{2}''$ respectively. The main size is only used if the system of minors feeding it is extensive. Allowing for the large quantity of water which has to be drained out during certain periods of the monsoon, a main would probably be necessary in any area over two acres; but the minimum size of main for various areas has not been worked out, though there is evidence to indicate that a main of a certain size will not deal with the same area of under-drained land as is usually estimated in England. In all systems the minors are arranged to deliver on the top of the main. Minors intended for a junction are closed at the smaller end and have a hole cut in the side, which fits over a special main pipe made with a hole of similar diameter on its side in addition to two at each end. (Fig. 4.)

TYPES OF UNDER-DRAIN TILES

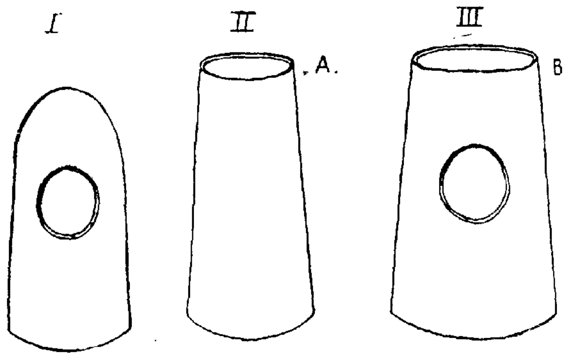



FIG. 4.

I. Minor junction tile.
II. Ordinary minor tile, 9″ long and 3″ diameter at A.
III. Main tile at junction of a minor, 9″ long and about $3\frac{3}{4}$″ at B.

*The process.* It may be mentioned here that nothing very difficult has hitherto been undertaken and, further, the majority of the areas which best respond to treatment are those which are low-lying. In the black cotton area such spots are generally reasonably near a *nullah* and so there is not much difficulty in finding a suitable outlet. The area to be under-drained is examined. Frequently the eye can tell which way the minors and mains should run. If however the area is flat or almost so, a check contour is taken. After a chain survey of the area, a suitable position for the outlet of the system is selected. If the general fall is obvious the position of the main and minors is pegged out on the field and the elevations along the future lines taken. If not directly obvious, the position of the drains is worked out on the check contour plan, and then pegged out on the field. The elevations along these lines may be deducted from the contour check or, when accurate work is essential or the ground irregular, a fresh set of elevations may be made along the field lines.

*Distance and depth of minors.* These two are closely associated and depend principally on the soil to be drained. In stiff soils and in draining grass areas the drains approach each other and the depth is reduced. As the soil becomes lighter a wider spacing and a greater depth may be allowed. Generally speaking 2′ 6″ represents about the minimum depth and 3′ 3″ the maximum on any classes of soil drained on the College Farm—the lightest of which is free clay loam with some *kankar.* The closest placing yet adopted was 18″. This was in a stiff clay soil. Though the drains appear to work freely, even at this distance, on the stiff soil mentioned, the central area is only just influenced by the drain. On very stiff soils it is thus probable that a surface system like No. 3 is more economical, especially if the area has any fall from one drain line to another. On the black soil proper, a stiff clay loam, the drains are effective at 21′—23′ apart with a depth of 2′ 8″ (average). A number of areas on the farm are slightly less heavy than typical black soil and in these 24′—27′ have been found satisfactory with a depth of 2′ 10″ (average). It should be noted that one has often, due to surface undulation, to exceed the average and pass above 3′, but, given that the distance is correct, care should be taken not to let the depth be less than 2′ 6″, if it is possible to avoid it.

*Fall of minors.* In several areas the fall of these has been about 1—100 though falls of 1—150 have been used satisfactorily. It is probable that lower falls can be utilized; but, allowing for the amount of water which at times has to be disposed of, the writer is of the opinion that 1 in 200 is about the least fall which should be aimed at and a sharper gradient, if possible, is advisable.

*Ditch gradient and digging.* When the ground elevations along the line of the main from its outlet and that of the future minors have been recorded, the gradient of the main ditch line is arrived at by deducting the ground elevation at the outlet, less the depth at the outlet, from the ground elevation at the top of the main less the proposed depth at this point. This figure divided by the length of the main gives the fall per foot. If unsatisfactory, an alteration in the depth at the outlet or upper end or both may be necessary. The gradient of mains on the College Farm has varied between 1 in 150 to 1 in 260 but, provided that the main used is of sufficient size, probably falls as low as 1 in 300 would be effective.

The ditch gradient of each minor is arrived at in the same way. No gradient should, if preventable, change from a low to higher one, as one passes up from the outlet of the main or from the outlet of minor into the main. The reverse is not objectionable; but in the event of the necessity of changing from a low to a higher gradient on passing up a drain a silt catchment box should be introduced as a precaution, though the amount of silting in such drains as have been opened up for examination after 2-3 seasons is remarkably small.

The digging out of the ditches of a system is generally done in the fair season. On account of the hardness of the soil and the necessity for pick, *phora* and *gamala*, 18″ has been the usual width dug. As the necessity for digging, grading, and laying the tiles as a continuous job is not essential, the usual process adopted has been to dig out the mains and minors to some standard depth given by the minimum depth along the line of drain—say 2′ 6″ all over the system—paying for this at the usual digging rate of 8 annas per 100 cubic feet. This work does not require skilled supervision and can be left to a contractor of normal intelligence. The only point is to see that the pegs which mark the points of known ditch-depth are replaced at the edge of the ditch. The soil to a depth of 1′ is thrown out on the right and the rest to the left of the ditch.

This being completed, the balance of the digging, the grading, and the tile-laying are proceeded with under a trained overseer's supervision. Usually, the extra depth of soil removed is of the width of about 9″—10″, giving a cross section of ditch as in Fig. 5. The depth of this portion

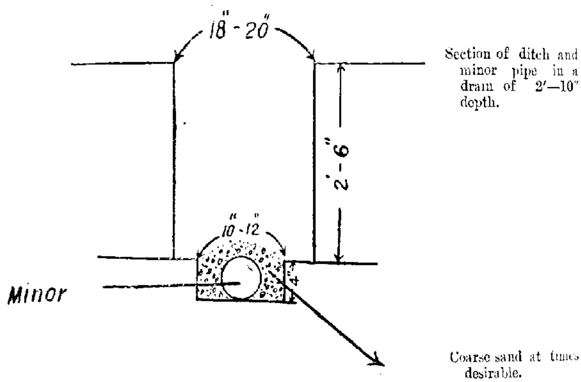



FIG. 5.

is decided by the ditch-depth marked on the pegs placed up the line of the ditch. The gradient of the ditch between these fixed points is arrived at by the use of plumb line and triangle on a ten foot plank laid on edge (as in Fig. 6), or better, by the device shown in Fig. 7. The digging

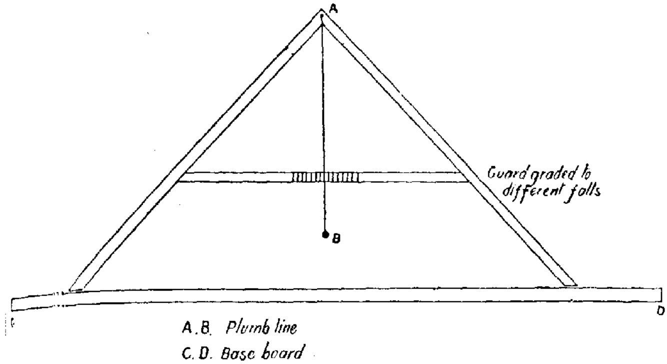



FIG. 6.

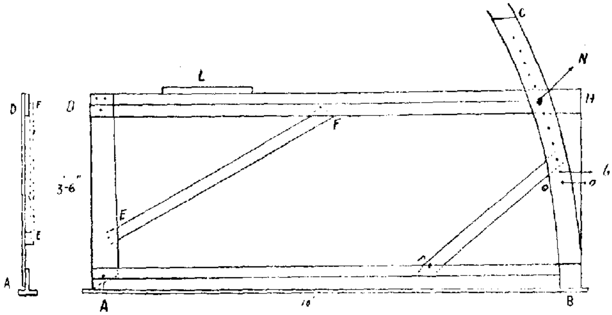



FIG. 7.

D H is 3" × $\frac{3}{4}$" deal plank 10′ long fixed at right angle to A D, a similar plank 3′ 6" long and held rigid by the strut E F.

A B is a similar plank to D H, but with a base plank of same length (3" × $\frac{1}{2}$") below it. It is fixed to C B and held in position by P Q, but is capable of turning at A.

B C is a plank fixed at B and held in position by the peg N according to angle desired. It carries a number of holes a, b, etc., which mark various falls.

L is a spirit level.

If a fall of 1 in 100 is desired, C B D is moved about the centre A, till the hole on C B, corresponding to 1 in 100 is over the fixed hole in D H, when N is inserted.

The instrument is then placed in the ditch bottom. The soil is scraped till the spirit level reads that it is horizontal when the correct gradient is arrived at.

and grading and pipe-laying proceeds from the outlet of the system up the main. The minors in turn are graded and laid from their outlets, the pipes being laid with their narrow end towards the outlet and kept in line. The writer has usually covered the tiles with a layer of coarse sand or fine gravel, after laying them and before the return of the earth to the ditch. This has been done to protect the pipe from clogging with fine soil. Whether this precaution is absolutely necessary is uncertain, but, if these coarse materials are easily procurable, it is probable that the slight extra cost of doing so is worth incurring, as giving the system a better chance of extended efficiency.

*Junction of main and minors.* The minor should invariably enter the main in the direction of the fall of the minor. The minors, to secure this, may be set at a slight angle to the main or if laid at right angles should be made to curve slightly on approaching the main. On the system on the College Farm, the minor pipe has been made to deliver on to the main pipe as shown in the section below. Fig. 8.

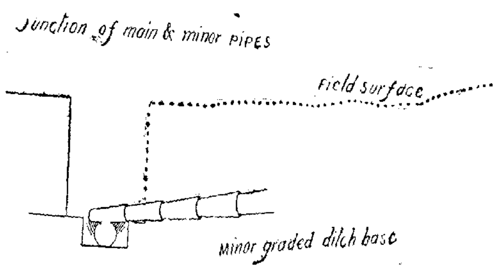
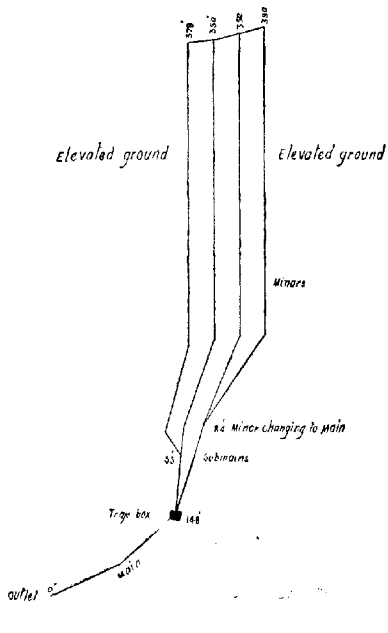



FIG. 8.

*The outlet.* This is a common point of possible weakness. It is advisable to protect the end with stones to prevent earth falling and blocking the mouth, and the end of the pipe must be covered with some wire net to prevent its use by vermin. In selecting the point of outlet into a ditch or *nullah* care should be taken to see that the water on leaving the pipe has a free fall and that the outlet is sufficiently high above the usual position of the water in the *nullah* in the monsoon to run no chance of being temporarily blocked by water except possibly in cases of abnormal flood.

The plans of these systems are attached—the first of the drainage of a field and the others of long hollows lying between two fairly naturally drained areas but themselves incapable, till drainage, of producing satisfactory *kharif* crops. An example is also given showing how the depth of a drain is arrived at after survey of the drain line. (Figs. 9, 10 and 11.)




Drainage system on field 41
Draining hollow.
Distance between minors 25 ft.
Fall of minors submain 1–100
Fall of main . . 1–200.
Average depth minors 2'-9"

FIG. 9.

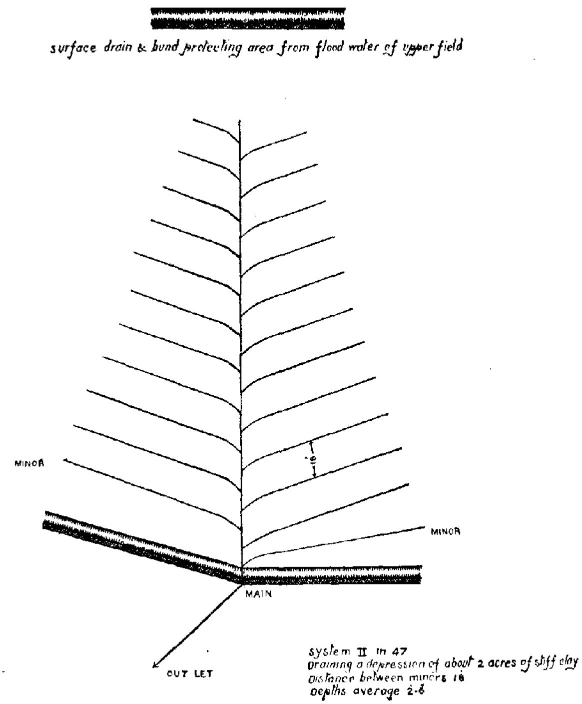



Fig. 10.

*General effects.* The effects of under-drainage have shown themselves in a steady growth of the plant throughout the monsoon, a dark green foliage and marked difference in maturity. The first picking of an under-drained cotton area is from 16 to 18 days in front of the first on the rest of the field, while *juar* and fodder become ready for harvest 2-3 weeks sooner. The staple of cotton is improved. The action of the drain has tended to reduce erosion, and the areas so treated, in spite of their unfavourable position, have been usually fit for cultivation from 24—36 hours after the heaviest rain and considerably before the higher

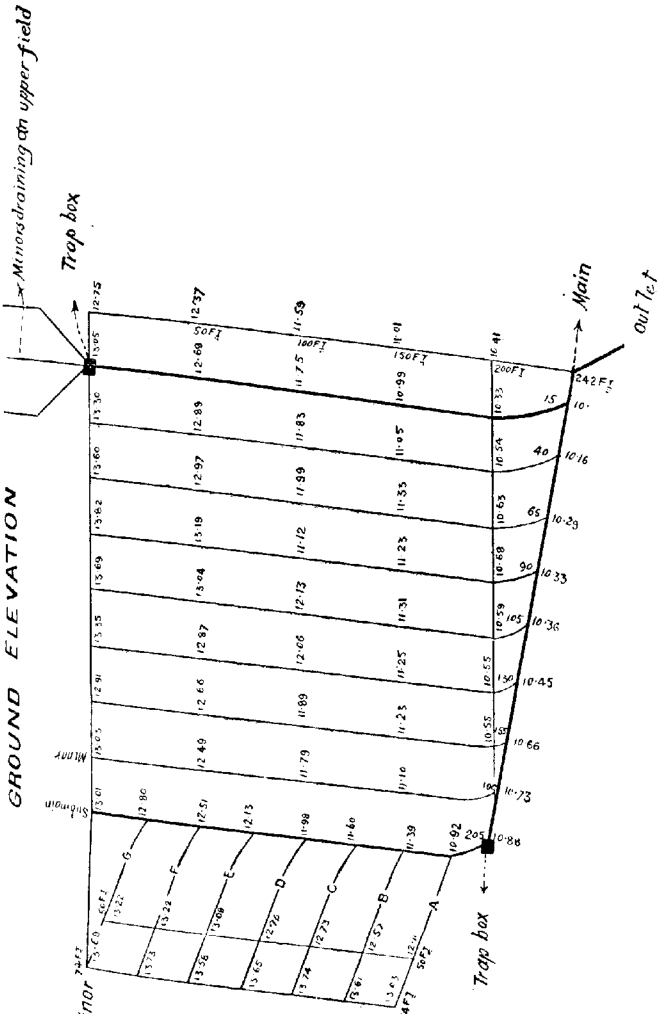

GROUND ELEVATION
Minors draining an upper field
Trap box
Main
Outlet
Submain
Minor
Trap box
Minor

FIG. 11.

but undrained areas. This has allowed of greater cleanness and a very much improved mulch at the end of the rains. Casual observations of the roots show a tendency to deeper growth. As a result of this and of a better mulch, the plants appear to thrive better than those on undrained soil even after the monsoon has ceased and dependence has to be placed on subsoil water.

There has been but little trial of *rabi* crops on such areas. In a case of oats, grown under sewage in the cold weather as a fodder on the drained area, the crop does better than the same crop on undrained land when irrigated once a week, but slightly worse when only irrigated with sewage once a fortnight. This appears to indicate that crops of this season may be affected by the lower water table of drained land and their inability to get their roots down fast enough. Garden crops like cane, tomato, etc., are certainly benefited by drainage and are able to take fuller advantage of the somewhat frequent application of water necessary in sewage farming.

An approximate table of distance, depths and cost per acre has been worked out below.

*Relation of ground elevation to drain depths.*

| Station | Distances | Ground elevation | Drain elevation | Depths |
|---|---|---|---|---|
| 0 . . . . . | 0 | 10·00 | 6·70 | 3·30 outlet. |
| 1 . . . . . | 15 | 10·00 | 6·79 | 3·21 |
| 2 . . . . . | 40 | 10·16 | 6·92 | 3·14 |
| 3 . . . . . | 65 | 10·29 | 7·05 | 3·24 |
| 4 . . . . . | 90 | 10·33 | 7·18 | 3·15 |
| 5 . . . . . | 115 | 10·36 | 7·31 | 3·05 |
| 6 . . . . . | 140 | 10·45 | 7·44 | 3·01 |
| 7 . . . . . | 165 | 10·66 | 7·57 | 3·09 |
| 8 . . . . . | 190 | 10·73 | 7·70 | 3·03 |
| 9 . . . . . | 215 | 10·88 | 7·83 | 3·05 |

(10·88—3)—(10—3·3)—1·18

$$\text{Gradient of drain} = \frac{1\cdot18}{215} = 0\cdot054 \text{ per ft.}$$

bout 1 in 185.

*Table showing approximate statement of materials and cost per acre.*

| Soil | Distances | Depths | Approximate number of minor pipes per acre | Approximate number of main pipes | Cost of pipes | Cost of excavation and grading | Cost of laying and filling | Total cost | If sand is used | Total cost including sand |
|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Ft. in. | | | Rs. A. P. | Rs. A. P. | Rs. A. P. | Rs. A. P. | Rs. A. P. | Rs. A. P. |
| Free clay loam with some *kankar* . | 26 | 3 0 | 2,520 | 350 | 59 6 0 | 36 12 0 | 15 12 0 | 111 8 0 | 12 0 0 | 123 8 0 |
| Free clay loam . | 24 | 2 10 | 2,830 | 350 | 65 8 0 | 41 0 0 | 17 8 0 | 123 0 0 | 13 8 0 | 136 8 0 |
| Stiff clay loam . | 21 | 2 8 | 3,150 | 350 | 71 8 0 | 45 0 0 | 20 8 0 | 136 0 0 | 15 0 0 | 151 0 0 |
| Clay . . . | 18 | 2 6 | 3,780 | 350 | 83 8 0 | 50 0 0 | 21 0 0 | 154 8 0 | 17 0 0 | 171 8 0 |

Prices based on—

| | |
|---|---|
| Minor pipes . . . . . . . . | Rs. 19-0 per 1,000. |
| Main pipes . . . . . . . . | „ 30-0 „ „ |
| Primary digging . . . . . . . . | „ 5-0 „ 1,000 c. ft. |
| Digging and grading . . . . . . . . | „ 6-8 „ „ |
| Cost of laying and filling . . . . . . . . | „ 2-8 „ „ |
| Cost of laying sand . . . . . . . . | „ 2-8 „ 100 c. ft. |

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