EDUCATION DEPARTMENT,
ANGLO-EGYPTIAN SUDAN.

BULLETIN No. 1.

CENTRAL RESEARCH FARM,

KHARTOUM NORTH.

PUMP IRRIGATION IN THE NORTHERN SUDAN.

WITH SPECIAL REFERENCE TO THE COTTON CROP.

1915.

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Messrs. R. Hewison, Assistant Director of Agriculture, and W. A. Davie, Inspector of Agriculture, have always placed at our disposal their very extensive experience of local agricultural conditions, and have in many ways contributed to the progress of our undertakings. Timely assistance proffered by the Director of Steamers has, on several occasions, relieved a crisis in irrigation arising from engine trouble, while any measure of success obtained from the organisation of native agriculture must be attributed in large part to the invaluable co-operation of Mr. P. Munro, Inspector of the District.

E. R. SAWER.

1*st November*, 1915.

INTRODUCTION.

THE AGRICULTURAL PROBLEM IN THE ANGLO-EGYPTIAN SUDAN.

ERRATUM.

Page 20, two lines from foot:—For 482 millièmes read 482 metres.

suggestions for the improvement of indigenous agricultural systems. The character and capacity of the local cultivator will consequently largely determine future progress and call for careful examination. At the outset it should be recognised that the mark of slavery is on the land. For centuries the negroid tribes of the south have furnished slave labour for the work of cultivation in the north, and the recent manumission of slaves has destroyed the very foundations of an established system, and has brought into being all the problems of a social revolution.

Lack of initiative reflected by the most primitive methods of agriculture, a strong and inherited objection to work for a daily wage, intolerance of control and an intense conservatism are the legacy of slavery to the land-owner, who is now called upon to bear the unaccustomed burden of field labour. "That he does not yet appreciate the Government's attitude towards slave holding is, in the circumstances, a cause for little surprise, and the dictum of Adam Smith that 'the experience of all ages and nations demonstrates the work done by slaves to be in the end the dearest of any,' leaves him unconvinced, dissatisfied

INTRODUCTION.

THE AGRICULTURAL PROBLEM IN THE ANGLO-EGYPTIAN SUDAN.

A PERIOD of fifteen years devoted to the pacification of our vast areas and heterogenous population, to land settlement, administrative organisation and railway construction has brought the Anglo-Egyptian Sudan to the threshold of a new era of economic development, the results of which must both justify a necessarily costly foundation and furnish a political *raison d'être* for our occupation of the country. In the absence, however, both of minerals of industrial value and indigenous fuel supplies, no prospects for the early establishment of manufactures can be entertained, and the Sudan is consequently destined to stand or fall by agriculture.

The completion of a system of land settlement and the granting, or confirmation, of titles embracing the larger part of the area available for cultivation in the Northern Sudan, establish the native land-owner as the typical agriculturist through whose agency effect must be given to any suggestions for the improvement of indigenous agricultural systems. The character and capacity of the local cultivator will consequently largely determine future progress and call for careful examination. At the outset it should be recognised that the mark of slavery is on the land. For centuries the negroid tribes of the south have furnished slave labour for the work of cultivation in the north, and the recent manumission of slaves has destroyed the very foundations of an established system, and has brought into being all the problems of a social revolution.

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As offset to such limitations as have been indicated above, the younger "samad," or sakia-owner, in the northern provinces, displays a high standard of intelligence, an intense curiosity, marked business instincts, a capacity for constructive criticism, and a certain sweet reason when discussing innovations. Once convinced of the monetary value of a new idea, he is anxious to avail himself of any opportunity of giving it effect, while the rising generation, stimulated by the demands of a higher standard of comfort, exhibits an encouraging degree of industry.

The Organisation of Agriculture.

The present occupation has been marked by a measure of success in the development of inland delta areas at Tokar and Kassala as cotton fields. The annual floods from the mountains of Abyssinia, which were previously lost in the sands of the coastal desert, have been partially controlled and directed to the irrigation of their delta deposits, with the result that in 1909-10 the value of

* H. St. G. Peacock : "Land Settlement of the Gezira."

† The total exports from the Sudan in 1914 were valued at £E.1,020,260, and may be analysed as follows :—

Natural Products.	£E.	Livestock and Products.	£E.	Products of Cultivation.	£E.
Gum	314,919	Bullocks and Cows	99,868	Cotton	111,123
Ivory	84,605	Sheep and Goats ...	85,976	Sesame	52,899
Gold	68,146	Untanned Skins ...	38,427	Dates	29,372
Dom Palm-nuts ...	15,282	Horses, Donkeys, &c.	7,266	Dura	4,429
Senna (wild) ...	5,942	Butter and Ghee ...	5,801	Ground Nuts ...	2,773
M.O.P. Shells ...	2,304				
Salt	1,142				
Bees-wax	201				
	492,541		237,337		201,096

Miscellaneous £E.89,286

the Tokar crop had risen to £146,000.* In the northern provinces somewhat costly experiments in the pump irrigation of cotton have been conducted on a number of estates by syndicates and private persons. Various disabilities and, particularly, exceptional transport costs and the absence of preliminary research, are reflected by the recent abandonment of considerable areas of estate cotton and a progressive reduction in the annual crop.† That such factors are prohibitive of profitable cotton cultivation has not, however, been adequately demonstrated, for our pioneer planters have been called upon to deal, unaided, with conditions which are in many respects unique, and it is becoming increasingly evident that in the case not only of cotton, but of all existing and prospective staples, an agricultural industry worthy of the country's destinies, can be based neither upon empirical principles borrowed from other areas, nor upon the mass of conflicting and unsupported opinions which are at present alone available. It cannot be denied that mistakes have been made over extensive areas which would have been equally instructive on the plots of an experiment station, and that evidence is available of misdirected effort and of dearly-bought experience. The following report consequently offers a first and belated contribution to the systematic examination of the agricultural problem with the object of obviating further wastage and the husbanding of our limited financial resources. The scientific direction of the country's agriculture is, to the writer's mind, the *sine qua non* of future success.

The Scope of Agricultural Research.—In this connection the view is adopted that "in human affairs science has little significance except for practical purposes"; appropriations to an institution for agricultural research are investments: it makes direct return by adding to the productive capacity of the country; facts of profit and loss should figure prominently in its reports as scientific data; the organisation of markets and the indication of profitable ventures fall within its province. Agricultural expansion must necessarily

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* In 1914, however, only 11,353 feddans, as compared with 22,126 in the previous season, were under cotton cultivation, while the value of the crop fell to £E.58,393. "This decrease in area was almost entirely due to the lack of sufficient flood control. Much of the flood water broke away and was wasted." (*Annual Report, Central Economic Board,* 1914.)

† During the past four years there has been a marked and steady decline in the export of cotton, and in the gross value of the crop :—

EXPORT OF COTTON (LINT).

	Bales of 400 lb.	Value of Crop (including seed) £E.
1911	22,823	269,158
1912	15,000	155,004
1913	12,830	173,594
1914	9,435	111,123

(*Annual Report, Central Economic Board,* 1914.)

depend largely upon the assistance that can be offered to producers by such an institution, and in this respect the latter differs from all other administrative bodies. A department divorced from experimental work is one which will never survive; a colony which does not place the experiment farm in the forefront of agricultural development is destined to fall, and the Sudan, if she would succeed with her farming industries, must surely follow the illuminating example of Canada, Australia, South Africa and the United States. The Sudan has a single industry, whose growth will be determined by the scientific investigator; they must stand or fall together, and the measure of success attained by the one will furnish a gauge of progress in the other.

Administration and Research.—In broad outline the duties of the State to the agricultural community are those of administration, research and education. It has been found possible and even desirable in several countries, to dissociate the first from the two latter undertakings. Administrative functions, especially in a country like the Sudan, with its vast areas and primitive means of transport and communication, are little compatible with systematic research, involving, as the latter does in most cases, fixed residence and continuity of attention. It has been noted that several earlier field experiments have been vitiated by the conflicting duties of the investigator, entailing absences from headquarters, losses of data and records, and lack of adequate supervision. It has been suggested, however, that all administrative officials might serve, with advantage, a probationary period at a research centre to acquire a knowledge of local conditions, approved methods of agriculture, and an insight into local agricultural problems. Such a system will open the way for a valuable extension of the educational system, and bring officers engaged in administration and research, respectively, into closer personal touch.

Research and Education.—On the other hand, there must be a bridging of the gap existing between research and education, between the investigator and the practical farmer, which cannot be undertaken in its entirety by the administrative officer. As a medium of communication the residential college or school has so many advantages that it has come to be regarded as an almost essential complement to the experiment station. Such an alliance renders possible a scheme of instruction based upon actual experiments; the student can bring to his studies the advantages of personal observation, and the teacher is enabled to speak with the assurance derivable from accumulated data and the repeated confirmation of his facts. To communicate his news in intelligible form to those by whom it is to be put to practical effect, is as much the duty of the investigator as the conduct of the experiments from which it has been derived, and frequently by no means the least difficult part of his task. Without such communication the work of the investigator has an academic value only.

It had consequently been hoped that the completion of a first series of investigations might have coincided with the inauguration of an agricultural school affiliated to the Gordon College. Such an institution should provide a body of trained agriculturists of local extraction to carry forward the work of development, and incidentally free the Sudan from an existing dependence on Egypt, Syria and Asia Minor for this class of skilled labour. It is a cause for regret that while ample facilities exist for professional and technical training in fields of necessarily limited horizon, the potential demands of the agricultural industry have as yet received scant consideration.

The Agricultural Mission.—To teach at first the few and then wait patiently for the seed so scattered to spread from a single centre is, however, a method which will not commend itself to those who appreciate the vital necessity for hastened progress in agricultural development, and other channels of communication must be sought. In addition to officers entrusted with research and residential tuition, we require missionaries with a training at headquarters to develop the agriculture of promising areas through the agency of the land-owning "samad," who, despite his antecedents, has shown himself abundantly capable of benefiting from advice and assistance. An attempt to realise this ambition on a tentative scale is reflected in the present report, and it is hoped that the results obtained may justify a rapid extension of the system. This class of teacher should not be encumbered with administrative functions, but devote his entire attention to the work of field education, receiving and distributing selected seed from the research farms, possibly controlling the water supply, collecting data, combating insect-pests and plant diseases, arranging for the marketing of crops and sale of livestock, and generally accepting responsibility for the agricultural welfare and development of the area under his charge. Such efforts applied even to a block of 5,000 feddans in a selected district, should have far-reaching results of a value out of all proportion to the salary which would be paid for the services rendered. Such functions would appear to appertain fitly to the Government, as no other agency would command a similar degree of confidence.

Decentralisation.—The mission field is broad and its problems far-reaching, for adaptibility to a wide range of climate, topography and soils must characterise successful agricultural development in the Sudan. Systems must be evolved for more or less clearly defined areas within which the choice of staple crops, methods of cultivation and the part played by livestock should have direct reference to the prevailing local conditions. Agricultural experiments will similarly have an application limited by natural boundaries, and in the form of field tests should be duplicated at as many points as may be financially possible.

Mean annual rainfall will determine the latitude of larger agricultural provinces, within which further subdivision should be based on considerations of soil, contour and natural drainage, labour supply, transport facilities, occurrence of timber and seasonal distribution of rainfall. The following notes embody preliminary observations made by the writer during tours of inspection in the Dongola, Berber, Khartoum, Blue Nile, White Nile, Upper Nile and Mongalla Provinces, and represent a provisional attempt to systematise the agricultural problem.

Rain-farming over areas with a normal precipitation of less than 300 millimetres is of so speculative a character as to call for suppression rather than encouragement. The total or partial failure of crops with attendant losses of seed and labour at longer or shorter intervals, must necessarily discount any effort to introduce improved methods of cultivation. The periodic starvation of livestock dependent on a precarious rainfall for grazing, must similarly prohibit the introduction of improved types showing early maturity, fine carcase or better milk-producing qualities. Such characteristics can only be displayed where there is abundance of suitable food and proper conditions of management, including protection from extremes of climate.

Northern Province.—North and north-west of a line drawn through Erkoweit, Kassala, Kamlin, Kawa, El Rahad and El Obeid, all our efforts and resources should be concentrated on the development of improved systems of agriculture based on garf, sakia, basin and pump irrigation respectively. It should be recognised at the outset that each system has its distinctive problems and difficulties calling for individual examination. The staple crops in this province will probably continue to be Egyptian and American cotton, dura, wheat, beans and dates. Evidence is accumulating in support of the contention that dairying and the finishing of store cattle and sheep drawn from the southern districts, must play an important part in this area as a means of exploiting restorative crops, such as lubia and berseem, to the best advantage. The breeding of horses, ostriches and an improved type of milch goat should also figure largely in future developments.

Central Province.—South and south-east of the former area, a second agricultural province may be demarcated as characterised by a mean annual rainfall ranging between 300 and 600 millimetres, with a southern boundary passing through Gedaref, Mafaza, Abu Naama, Melut and Telodi. The seasonal distribution of some 15 to 20 inches of rain within seven consecutive spring and summer months, renders possible satisfactory rain cultivation in many parts of the area. Supplementary irrigation is, however, a marked feature, and includes the control and distribution of delta floods at Tokar and Kassala. In the southern Gezira a rainfall of some 400 millimetres occurring during the planting season and early growth of cotton, complicates the problems of perennial irrigation.*

The Central Province should be our principal stock-breeding area, as enjoying relative freedom from the more tropical types of disease, and good grazing over a lengthy season. Large numbers of butchers' stock should be annually drafted for fattening and finishing to irrigated areas in the north abutting on the railway system. Natural grazing should be supplemented on the spot by the provision of hay, silage and catch crops. Many areas should carry improved grasses, such as paspalum, teff and Rhodes grass. The gradual introduction of better blood for the grading up of native stock would also be profitable as soon as an approved system of feeding and management had been evolved. The valuable control of endemic diseases already organised by the Veterinary Department, would do much to ensure rapid and successful development of a livestock industry.

Useful lessons may be drawn from current development of the Tripolitain and Tunisian hinterlands, with direct application to the Central Sudan. A very similar rainfall and comparable conditions of soil and climate obtain in all three countries, but while hundreds of square miles have been planted to olives, carobs and other food and revenue-producing trees in the two former areas, this, the only finally approved system of dry farming, is unknown in the Sudan.

Southern Province.—A region embracing the White Nile basin south of Kaka, the Sobat River basin to the Abyssinian border, the Nuba Mountains and the northern districts of the Bahr-el-Gazal and Mongalla Provinces, is characterised by a rainfall adequate to the requirements of most sub-tropical staples. When fully developed it should constitute the granary of the Sudan and furnish large shipments of such oil-seeds as ful-sudani, simsim, hemp and cotton seed. A fibre industry might be built up on the cultivation of American long-staple cotton, sisal and manilla hemp, jute and ramie. Citrus, pineapples, bananas, mangoes and other tropical fruits would flourish in selected areas from evidence already available, while tobacco of good pipe-leaf type should replace the extensive crops of rank native weed.

The education of native labour and the organisation of efficient river-transport are necessary preliminaries to the work of development.

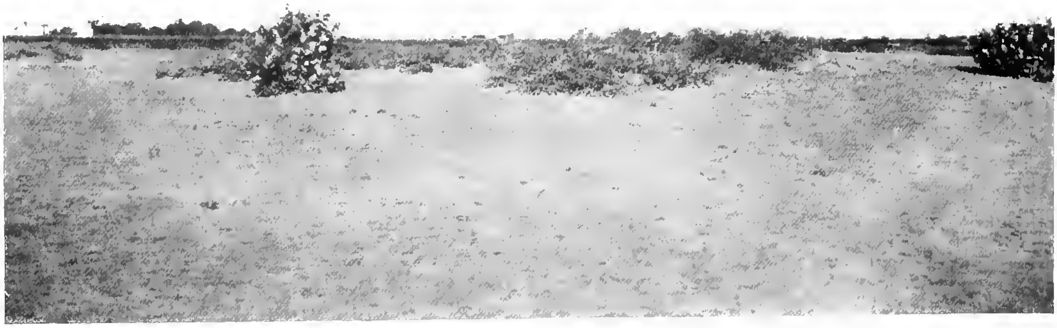
* If ploughing be done prior to the early rains, weed-growth assumes a serious character before planting can be completed, while if postponed until the ground is sufficiently moistened to furnish a good tilth, the time factor is involved and operations may be impeded by wet weather. Such an issue would limit the area planted, and with it the earning capacity of the ploughing outfits. This question has arisen in serious form at Barakat during the past season, and may be further complicated by the effects of heavy rains on the young cotton. Egyptian types are notoriously susceptible to damage by rain during early growth, and this consideration may influence a decision in favour of long-staple American varieties for this district. A partial solution would be found in a supply of summer water for ploughing purposes, and earlier planting. Preliminary irrigation would germinate weed seeds, and this growth would be largely destroyed by the plough. Earlier planting would similarly place the young cotton crop out of danger from heavy rains. Such a system would, however, only be possible after removal of the restrictions imposed by Egypt on our use of summer water.

Equatorial Province.—In the southern districts of the Bahr-el-Gazal and Mongalla Provinces are found purely tropical conditions with a mean precipitation exceeding 1,000 mm. It should here be possible to extend largely the existing areas planted to sugar, rubber, coffee and tobacco and to introduce tea. Such products, from their intrinsic value, could carry the necessarily heavy costs of haul to port of shipment. Rice would ultimately constitute the chief grain food of the native population.

Agricultural Research.

Financial considerations have very unfortunately limited the work of agricultural research to a systematic examination of the problems of riverain irrigation in the northern provinces. Rain-farming in the southern districts, basin irrigation, the breeding and management of improved types of livestock, dairy and poultry farming, horticulture and other subsidiary branches of the agricultural industry still await attention and development. An attempted exploitation of the Northern Sudan with its negligible rainfall, excessive mean temperature, high winds, abnormal evaporation, cutting desert sands, absence of natural grazing and scanty fuel supplies can only be justified by the relative advantages of railway transport and access to a deep-water harbour. Whether these features sufficiently offset the economies in production offered by an ample rainfall, equable climate, good grazing and timber, as found in the south, can only be determined by experiment and the possibilities of railway extension and improvement in river transport.

The Desert Environment.—The cultivation of crops of economic value can be effected in the Northern Sudan only by the artificial modification of a desert climate and soil, in which naturally nothing but the scantiest vegetation can exist. Such vegetation has a xerophytic character and structure. Here and there are dotted little greyish-green plants with large intervening stretches of soil utterly devoid of plant life. Only when a shower of rain moistens the surface do numerous annual herbs germinate, bear fruit and die a few weeks later. Perennial plants show a number of structural features which are adaptations to an exceptional need for protection against unfavourable conditions. They may include diminution in size, or suppression, of leaves, thick-walled epidermis and strong development of cuticle, hairy coating, thorns, the production of aqueous tissue for water storage, and excessive development of the fibrous and woody elements. Neither rapidly of growth, scattered distribution nor such morphological features are compatible with profitable cultivation, and a new environment must be created to meet the requirements of commercial agriculture.



The Desert before Irrigation.

The Desert after Irrigation.

The Introduction of Commercial Crops.—The problem can only be satisfactorily approached by way of a preliminary and exhaustive examination of the conditions actually obtaining ; followed by a study of research in other regions directed to a determination of the circumstances of climate and soil best suited to the growth of specific crops. An attempt may then be made to secure comparable conditions locally. The degree of control over the various factors involved, which may be assured by ordinary and commercial measures, is strictly limited, and the results can only approximate to a previously determined optimum. From this circumstance will arise the need for further inquiry as to the separate and combined effects of temperature, moisture and sunshine, both in their normal and abnormal proportions, upon the annual yields of staple crops. With this must be coupled a determination of the tolerance or adaptability of exotic plants to the altered conditions which will furnish a measure of their acclimatisation.

A Problem of Acclimatisation.—Three methods are available in the latter connection. The statistical system is an early-established means of ascertaining the effect of climate, by comparing the statistics of the successive annual harvests in the country at large with the annual meteorological returns. It lacks definition and scientific accuracy and has a very limited value. A second method is based upon the experimental cultivation of plants in rooms or other structures where temperature, moisture and other conditions are under control. Successive slight changes in each of the factors of the artificial climate will furnish data for the establishment of laws of acclimatisation. A less perfect application of this system is found in comparative field experiments where a serial modification of one factor is applied with a maintenance of uniformity, as far as possible, in other conditions. A final method lies in the detailed study of the individual plant accompanied by delicate measurements and microscopic examination of the processes of growth, nutrition and transpiration, as affected by sunshine, temperature and moisture. The following report reflects a preliminary inquiry into the nature of the desert environment, modifications effected therein by irrigation, drainage, cultivation and manuring, and the character of crop growth in the amended conditions as revealed by comparative plot work, experimental cultivation of individual plants and a physiological examination of growth processes. To ensure reliability the field and laboratory experiments have been conducted independently and the records only subsequently associated. By such means mutual control and a reduction in the margin of experimental error are assured.

The Desert Soils.—The outstanding features of all desert areas are, firstly, the aridity of the soil. Loam is here as dry as sand or stony soil, for all kinds of soil are alike inadequately supplied with moisture. The soil varies greatly in nature, but is apparently always very rich in nutriment, as the salts that arise by weathering of the soil are only very incompletely washed out. Yet dryness of the soil checks absorption of nutriment by the roots, and this necessarily reacts upon the dimensions and numbers of the plants present. The abundance of nutriment may be such that the soil is supersaturated with salt, and the amount present increases with increasing aridity of the climate. The various kinds of soil behave differently in this connection. Salts are readily washed out of sandy soil, so that, *ceteris paribus*, sand is poorer in salts than is clay, which is relatively impervious to water. Finally the soil is utterly devoid of humus, for sun and drought burn it up completely.

The Desert Climate.—The air is very dry, and the variations in its temperature are very great. Nowhere else has the atmosphere been observed in day time to be drier than in North Africa, where the relative humidity may be 10 to 25 per cent. During the summer the temperature of the air may exceed 50 deg. C., and at day time the soil is considerably hotter than the atmosphere.* In the Sudan evaporation from water-surfaces and irrigated soils reaches extraordinary figures, the absolute maximum reading for twenty-four hours, during the three years under review, in the desert screen adjoining the farm amounting to 41·2 mm. In this connection specially constructed evaporimeters have been found necessary, those in use in Egypt having proved of inadequate capacity for the climate of the Northern Sudan.

Where practically the whole of the water required by the crops for their growth and development has to be raised from the Nile by pumps or water-wheels, the question of unnecessary losses and wasteful use of this supply has an enhanced importance. Evaporation from water surfaces can hardly be prevented by human foresight or energy; seepage losses from canals and the evaporation of water from the soil on the other hand are, in a large measure, under the control of human agencies. Such operations as the frequent surface cultivation of the land, closer planting of crops to ensure early shading of the surface, the establishment of hedges and brakes to limit the desiccating effects of high winds and blown sands, the introduction of humus in the form of green manures to act as soil sponges, coupled with efficient construction, grading and lining of canals, merit the most careful examination as means of minimising preventable waste and increasing the duty of our costly water supply.

Irrigation and Drainage.—The absolute necessity for the natural or artificial drainage of an arid soil, and the constant or periodic application of water in excess of the actual requirements of the crop, is not immediately obvious even to many experienced cultivators, and it is a noteworthy fact that the excessive

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* Warming: "Œcology of Plants."

development of alkalies in Egypt, India and California is the result of irrigation practices modern in their origin and methods, and instituted by people lacking in the traditions of the ancient irrigators, who have worked these same lands for thousands of years. Alkali, or " salt " as it is locally known, is produced *in situ* from the decomposition of the soil and subsoil under the action of water and air. Where conditions are persistently maintained which allow the formation of salts without permitting them to be removed by any cause whatever, there must come a time, sooner or later, when the amount produced and accumulated in the soil reaches a degree of concentration which is intolerable to cultivated crops. In the natural conditions of rainy countries there is usually a sufficient amount of leaching to permit of the alkalies being borne away in the country drainage with sufficient completeness to prevent their effects attracting general attention. In arid countries some method must be devised by which periodically, at least, sufficient water is applied to the cultivated lands to bring into solution and carry out of the country the soluble alkali salts which are fatal to cultivated crops.*

Among other advantages attaching to an adequate system of drainage is the reduction of the water-table to a minimum depth, and the consequent avoidance of root destruction during the period of high Nile which has been so conclusively demonstrated by recent experiments in Egypt. The elimination of malarial infection which is unfortunately rife on all undrained irrigated areas in the Northern Sudan, is in itself ample justification for the expenditure involved, while numerous agricultural considerations, such as the better aëration of our stiff clay soils, a more equable soil temperature, and the removal of the finest silt which is largely responsible for " pan " formation, would lend additional weight, if necessary, to the essential argument for the removal of salt.

The Nitrogen Problem.—Stress has been laid on the total absence of " humus " in desert soils. We are thus faced with an almost universal excess of the mineral constituents and an abnormal deficiency of organic matter as agents of soil fertility. Moisture, the humus-body and the mineral particles of the soil, however, affect fertility principally, if not entirely, through the agency of vitally active organisms, which have been provisionally grouped as soil bacteria, though including forms which must be relegated to such other groups as the fungi and protozoa. That the vital activity of bacteria is essential to sustained fertility may be readily proved by sterilising a soil at a temperature sufficient to destroy organic life, by treating it with an antiseptic such as bichloride of mercury, or by applying an anæsthetic such as chloroform. In all cases the soil will be left virtually unaltered in composition, but sterility early ensues as a result of the destruction of living soil organisms ; the decomposition

* Wilcox : " Irrigation Farming."

of organic matter is suspended, and the mineral food supplies are curtailed with the exhaustion of such quantities as are present in immediately-available form.

The fixation of atmospheric nitrogen by bacteria living in nodular structures in the roots of leguminous plants is already a matter of common knowledge. Apart from this symbiotic relationship with bacteria, plants are unable to assimilate nitrogen gas, and there is no natural supply of nitrogen salts from the underlying rocks. Another source of organic nitrogen is, however, found in the direct fixation of nitrogen by bacteria existing independently of other plants in the soil, of which Azotobacter may be taken as a typical form. Nitrogen-recuperation may thus ensue even when no leguminous crop has been introduced into the rotation, but such activity is directly dependent upon the presence of organic matter in the soil which furnishes the bacteria with a food supply in the form of carbonaceous matter. Arid soils lacking in humus consequently display a remarkable preponderance of leguminous forms in their flora, of which the Acacia is an outstanding type, as such are rendered independent of external supplies of organic nitrogen by the activity of nitrogen-fixing nodules on their roots.

The successful cultivation of non-leguminous crops, such as cotton, in desert soils will consequently be determined either by the regular introduction of legumes as rotation staples, the constant application of organic matter to sustain the activity of such free soil forms as Azotobacter, or the use of such artificial fertilisers as nitrate of soda.

Nitrification.—The nitrogen, as fixed by soil or nodule-inhabiting bacteria, as well as that found in the humus of the soil, takes the form of complex organic compounds which are no more available to the higher plants than is the nitrogen gas. The intervention of other micro-organisms is consequently necessary to the process of nitrification or decomposition, which should be carefully distinguished from nitrogen-fixation. To be capable of yielding good crops the land must contain a supply of nitrogen which can be dissolved in soil water. A first stage in decomposition is due to organic ferments, known as peptonisers, similar in action to the pepsins of the digestive juice, which reduce proteid substances to simpler forms. A group of bacteria, known as ammonifiers, then split up the still complex nitrogenous substances and derive therefrom ammonia. A second group change ammonia into nitrous acid, and a third oxidises the latter substance into nitric acid or nitrate, in which form it is readily soluble in water and most available for the use of plants. It should be carefully noted that this beneficial function of the nitrifying bacteria is essentially a process of oxidation or combustion, and is dependent upon the presence of free oxygen. The organic matter rapidly changes in a well-aërated soil, darkening in colour, losing all structure, and being finally resolved into ammonia, carbonic acid gas and mineral salts, with much the same final results as if it had been placed in a furnace.

Tillage and Aëration.—The primary object of all tillage and drainage is the aëration of the soil, and fertility is the direct result of the processes of oxidation already described. The presence of oxygen is a first essential to the activity of the beneficial bacteria, and in the natural or uncultivated soil aëration is effected by the permeation of a mass of fine roots and microscopic plants, which are constantly growing and dying, thus creating a spongy or porous layer, of which the open pores represent the spaces formerly occupied by vegetable matter, since decomposed. This is the natural soil, which is just sufficiently aërated to support native grasses, &c. To increase aëration and consequent fertility, recourse is taken to ploughing and surface cultivation, which has the effect of bringing a larger surface into contact with the air, and of facilitating the work of the oxidising bacteria. Lack of aëration may be due either to the compactness of the soil particles or to saturation by moisture. An example of the former condition is frequently found in our heavy cotton soils, and of the latter only too frequently in irrigated and undrained areas. In the former case, micro-organisms are conspicuously absent; in the latter bacteria are present, but their action is of an injurious, rather than beneficial, character. In lieu of oxidation, or decomposition, a process of reduction is set up; oxygen is withdrawn from, and not added to, decaying organic matter, and loss of fertility is involved. The beneficial, or aërobic, bacteria rely upon atmospheric oxygen, and by their activity add this to the substances with which they come into contact; the injurious, or anaërobic, bacteria, in the absence of air, withdraw oxygen from the medium in which they exist. Drainage can almost be measured by the rate of nitrification.

A Bacteriological Problem.—With more than ample supplies, in most cases, of the mineral constituents of plant food, the problem of fertility in desert soils is resolved into the provision of conditions necessary to the vital activity of the different groups of beneficial bacteria, and the ascertaining how such conditions may be secured by systems of irrigation, drainage, cultivation and manuring.

The results can be most easily read in terms of crop reports which reflect the relative activity of the soil bacteria acting as intermediaries between the soil particles and the absorbent plant roots, and as purveyors of soluble nitrates.

The Biological Factor.—Having ensured a general amelioration of the unfavourable desert environment, it remains to examine the idiosyncracies of the tropical and subtropical crops which may find in the new conditions a not unfavourable medium of growth. Crops grown on the same land will vary in composition, and consequently in the character of the demand they make on the mineral ingredients of the soil. Thus, the principle of "dominant ingredients" is the keynote of all scientific manuring, and while nitrogenous manures will have a relatively important effect on wheat and barley, maize makes greater demand for phosphates, and leguminous crops and potatoes for potash. Similarly, while wheat flourishes on a firm seed-bed and will rarely repay deep cultivation, subsoiling is well-nigh essential for the greatest nett profit on sugar-beet and potato cultivation. Again, the relative requirements of moisture and the tolerance of drought exhibited by the different staples, to which may be added the comparative tolerance of various plants for the salts common in alkali soil, will markedly influence irrigation practice. A seasonable range in mean temperature will also permit the adoption of planting seasons which will ensure to each crop the most favourable conditions of growth within the limits obtaining.

Plant Tolerance and Variation.—Plants or such artificial plant communities as crops, however, adjust their forms and modes of behaviour to actually operating factors, such as the amounts of available water, heat, light, nutriment, and so forth. To an examination of the initial demands made on their environment, we have therefore to add an investigation of the means they employ to utilise the surrounding conditions and to adapt their external and internal structure and general form for that purpose.*

Existing staples, such as Egyptian and American cottons, are displaying marked departures from the characters originally evidenced, and the possibility of fixing new and desirable features by hybridisation on Mendelian lines opens another valuable field of research. On the other hand a demand has arisen for cotton of the greatest possible uniformity, as a feature of the first importance to spinners, and the control of variation by similar means in the seed-plots, coupled with the systematic distribution of seed of uniform character, should go far to ensure a favourable reception for our crop in the European markets.

A better understanding between planters and spinners has of recent years facilitated the profitable introduction of cotton as a new product to our tropical colonies and dependencies. The earlier sequence of events whereby the grower has grown what chanced to grow, and the spinner has adapted his machinery to deal with it, has largely passed. Efforts to improve the cottons grown are based upon the known requirements of the spinner, and considerations of value are constantly associated with those of productivity. "There is no necessary conflict in cotton between quality and quantity. The Sakelarides cotton in Egypt, and the Cambodia in India, have proved that it is possible to make cotton more valuable to a spinner and at the same time more prolific and therefore less expensive to the grower."†

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* This study of acclimatisation gains an enhanced importance from the paucity of economic plants at present represented in the northern Sudan. The work of introduction and experimental trial of numerous types of potential value is occupying attention, and should later relieve the poverty and monotony of current agricultural effort.

† J. W. McConnel: "Commerce and Science and Cotton Growing."

The Demand for Uniformity.—The demand for improvement is associated with the insistence that uniformity, regularity and fixity of type are the most important of all qualities both to growers and spinners.

"In all the qualities a spinner wants in cotton—namely, fineness and strength and length and adhesiveness, and colour and freedom from waste—in each and every case uniformity is essential, if the quality is to be worth money. To be partly fine is to be coarse, to be partly strong is to be weak; to be irregular in length or colour or anything else is to be so far poorer and less valuable. Also irregularity in plant habit is a certain bar to big production. Now I believe that this virtue of uniformity, this *sine qua non*, without which no goodness is good, I believe that this is now for the first time in the history of cotton within reach of attainment. Uniformity can only be hoped for from plants that will breed pure. A pure plant may conceivably fail in uniformity, but without purity uniformity is inconceivable. Now it is well known to all students of cotton-growing from the work of Mr. Lawrence Balls in Egypt, and of others elsewhere, that it is possible to cultivate cotton on a commercial scale from pure parents . . . I commend to all who are practically engaged in cotton breeding or cotton growing that purity should be their principal objective. Hitherto the whole character of the plant has been a chance entanglement of qualities, and improvement a nearly insoluble problem. When pure strains become generally available the processes of improvement in quality or in quantity, or of gradual modification in any desired direction, will become possible, and growers and spinners will both be benefited."—(*Ibid.*)

The above considered statement of a leading fine-cotton spinner defines a problem with direct local application, not only to our cotton crop, but to every staple in actual cultivation or of possible introduction. Reports on samples of Sudan wheat bring to light the fact that every parcel included more than one variety of wheat with a consequent reduction in the market value. An attempt to isolate types revealed the same "entanglement of qualities" which characterises existing cotton crops. Improvement in the value, as distinct from the productivity, of our crops, can be secured neither by manuring, improved tillage, nor the field selection and cultivation of chance variations, or "sports," but only by the systematic application of approved scientific methods to what is necessarily a very difficult problem. An example of the futility of haphazard choice of natural hybrids occurring in the field, has been afforded locally by the so-called "Makhsus" cotton, boomed some years ago in the Sudan. This field hybrid, which was somewhat extensively planted on its reputation for productivity, has since been abandoned after exhibiting all the irregularity and lack of uniformity which characterise uncontrolled hybridisation. The breeding-plot, the seed-plot and continuous and exhaustive field and laboratory observations afford the only means of combating the natural tendencies of all cottons to deteriorate. The good qualities of a cotton are either given to it by human agency, or, if occurring naturally, have to be isolated and fixed as a uniform character by the human agent.

Agricultural Production.

The introduction of an approved system of agriculture, based upon the systematic control of environment and crop, has, as ultimate object, reduced costs of production, enhanced yields and a larger margin of profit to capital and current expenditure. The costs of agricultural production in any country will be determined by the collective capacity of the cultivators and by the facilities at their disposal. Under the former heading must be included personal experience and knowledge of local agricultural practice, coupled with the degree to which the agriculturist can avail himself of advice based on departmental research and education. His facilities will include the terms on which he can obtain the use of land, the cost and character of hired labour, the nature of the seed supply, the implements with which he may be able to stock his farm, his draught cattle and livestock and his capital fund or access to credit.

It has been urged that research without education is barren, but education without a corresponding improvement in the instruments of production can only spell both wasted effort and active discontent. To advocate the substitution of the plough for the " seluka " to a man who can obtain neither cash nor credit for the purchase of the implement and animals to draw it, is to convict oneself of futility, and it should be clearly recognised that progress in any direction will be necessarily limited by the provision of capital and facilities for borrowing at reasonable rates. As the borrowing powers of the agricultural community must ultimately depend upon the value of the land and the nature of tenure, these factors will largely determine development and costs of production. Peacock remarks* that " it is claimed on behalf of a Land Settlement that it brings many benefits to a district. Perhaps not the least of these benefits to the Gezira will be the strengthening of credit which must follow registration of titles. The borrowing powers of the people of the Gezira have been affected by uncertainty of title and security, and also by the custom of the mortgagee entering into possession."

Rain and Irrigation Farming.—The current report has no direct bearing on the problems of rain-farming, but the latter system affords a very useful basis for comparison with irrigation farming, and a means of determining at least approximately the relative advantages of the two systems. In both cases peasant proprietorship resulting from the Mohammedan law of inheritance has been confirmed by the Government in the policy of land settlement, and its maintenance has been ensured by strict limitations on the permanent alienation of agricultural lands. In present circumstances, while population is scarce and the recent manumission of slaves has severely limited the supply of casual labour available for field work, it will not be denied that the small owner working his land with the assistance of his family has an enormous advantage over the large proprietor.

* *Op. cit.*

Rental Values.—Peacock* states that the average area of ownerships in Mesellemia district, a typical rain-farming centre, is about five "*gadaas*," or 25 feddans (27¼ acres), and "it is probable that, according to the present methods of cultivation, this is the economic holding of the district." Figures relating to sales and mortgages of rain-land, collected since 1898, give an average value of land of rather more than 500 millièmes† the gadaa (100 millièmes, or 2s. 1d. the feddan), while the mortgage value is not much less. "The usual custom between owner and cultivator in the Gezira has been for the cultivator to be tenant for the season either on payment of an agreed rent, or more usually on payment of '*ushur*' or a tithe of the crop." The rain-land population is migratory in character. "Before the rains it is altogether insufficient for the work of cultivation, but when the rains come, immigration proceeds in proportion to the amount of the rains. As a general statement it is correct to say that if the rains are sufficient the whole district is under cultivation and the population is sufficient. Without special demand, the population in rain-land villages is unlikely to increase largely." It is estimated that an area of 2,025,710 feddans was cultivated with rain crops in 1913, an increase of 442,970 feddans on 1912,‡ which clearly indicates the adaptability of the system to a very uncertain rainfall.

Costs of Sakia Cultivation.—On the other hand, the security afforded by a reliable, if inefficient, means of irrigation, such as the "sakia," is reflected by the size and value of holdings, a very limited fluctuation in the irrigated area, and a far higher standard of cultivation than that obtaining on rain-lands. The number of sakias in use during the year 1913 has been returned as 10,075, while the area irrigated amounted to approximately 100,000 feddans. An outstanding feature of the system is the degree to which subdivision of lands has been effected, for with an average area of 10 feddans, which is equivalent to the capacity of a single water-wheel in most circumstances, a sakia will frequently be shared by the "samad," or officially recognised owner, with five or six "partners," who are all title-holders to a larger or smaller share. A census taken over a typical area of 150 feddans revealed the existence of fifty-five titles, while an adult population of 120,000 finds employment and livelihood on 100,000 feddans. The average land-tax payable on sakia cultivation amounts to 400 millièmes per annum, and, while disinclination and disability to sell render the establishment of a market price almost impossible, the current value of these lands is certainly not less than £E.20 a feddan.

In lieu of the tithe payable by the tenant of rain-lands, the sakia tenant or partner by local custom surrenders approximately half his produce for the use of the land and for the water required by his crop, in addition to which he is

* *Ibid.*

† £1 Egyptian = £1 0s. 6d. = 1,000 millièmes.

‡ Annual Report, 1913, Department of Agriculture.

responsible by convention for half the land-tax. The details of such an arrangement and its working in actual practice are discussed in the body of the report. For the purpose of the present review it will suffice to state that in the case of both rain-lands and irrigated areas, " *ushur* " or a tithe of the crop is regarded as a fair rent for use of the land, while in the latter case four-tenths is regarded as the mean cost of the water supply. Irrigation costs include purchase and feeding of four bulls (for a 10-feddan sakia), construction and upkeep of the water-wheel and payment of the " baseer," who keeps the sakia in repair. On average crops of cotton, wheat and dura at normal prices, the tenant would annually pay per feddan £E.2.900 for land and water, and 200 millièmes as his half share of the land-tax, from a gross average return of £E.5.800. From the meagre balance remaining provision has to be made for seed and implements which local customs regards as absorbing four-thirtieths of the crop, leaving, say, four-tenths of the crop, valued on the above basis at £E.2.320 to cover the costs of actual cultivation and compensate the owner for his labour.*

Costs of Rain Cultivation.—The cultivator of rain-lands, on the other hand, has no such heavy bill of costs, for his expenses directly reflect the primitive methods in vogue. Ploughing is rarely practised, the seed being dibbled with the " seluka " in the freshly-moistened soil; the " hush," or cleaning, is completed with the " touriya," or hoe, and subsequent operations are limited to harvesting and threshing. Peacock† estimates the average cost of cultivating and harvesting one "*gadaa*" of land under dura feterita as £E.1.250, which, with good rain should produce 15 ardebs, worth, on the previous estimate, £E.9.000, or a nett profit of £E.1.550 per feddan after all expenses have been paid. A useful commentary on these figures is, however, found in the returns of rain-land assessed for land-tax, which in 1912 amounted to 78,656 feddans, and in 1913 to 4,366.‡ The speculative character of the crop is further evidenced by the violent annual fluctuations in the market prices of such typical rain crops as dura. The total or partial loss of crop, seed and labour, at more or less frequent intervals, goes far to discount the profits of good years, and to limit attempts in the direction of improved cultivation.

The Irrigation Problem.

The outstanding problem of rain-farming in the North and Central Sudan is the speculative character of cultivation dependent on a very uncertain rainfall, while the sakia cultivator is burdened by almost prohibitive costs of irrigation. The provision of an adequate water supply at a reasonable rate would consequently remove in both cases the principal obstacle to development, and pave

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* W. A. Davie : " Report on the Gezira Agricultural Experiment Station."

† *Op. cit.*

‡ Annual Report, Department of Agriculture.

the way for the introduction of improved methods which must necessarily be based upon a broader margin of profit. In present circumstances the rain-farmer is a gambler with all the gambler's instincts, including aversion to thrift, while the samad and his partners on the sakia are working in a vicious circle, raising by dint of sustained effort a bare livelihood for themselves, their families and the sakia bulls.

The possibility of substituting modern pumping machinery for such an anachronism as the sakia compels consideration, and commercial tests of a variety of driving machinery and pumps have figured prominently in the work of the Research Farm. The enquiry has necessarily assumed a two-fold character, the establishment of the cost and duty of pumped water paving the way for a consideration of its employment on a large scale.

The chequered career of agricultural estates in the northern provinces had been attributed variously to extravagant pumping costs, an unfortunate choice of crops and varieties, the difficulty of obtaining satisfactory tenants, inadequate and costly labour supplies, and everywhere to the difficulty of collecting arrears from debtors who could offer no preliminary security for water supplied on credit. Of these drawbacks the first two are directly attributable to the absence of exhaustive preliminary enquiry, while all other aspects of the problem involve the question of tenure.

The Fuel Problem.—The choice of pumping plant will necessarily be determined by the relative costs and values of available fuel supplies. A basis of comparison is furnished by wood, which is obtainable from local sources at a cost of approximately 500 millièmes a ton delivered to the pump. The cost of imported coal, which in normal times can never be purchased for less than £3 a ton in Khartoum, has proved almost prohibitive, even when employed in such high efficiency plant as the super-heated steam locomobile installed at the Gezira Test Stations.

Recording a loss of £E.6,000 on current expenditure and receipts for the first and second agricultural years at the Tayiba Station, the manager attributes this result exclusively to a cost of £E.3.400 per ton for coal. To the same factor one is inclined to attribute in large part the disappointing returns and lack of progress on a majority of the six estates in the Khartoum and Berber Provinces, for which land has been granted by the Government with a view to the encouragement of cotton cultivation. Five of these plantations had collectively, in 1910, only about 1,000 feddans planted with cotton, and have not extended the area since then.* Indeed, a steady reduction in the area of cotton cultivated under artificial irrigation, and consequently not affected by the character of the rainfall, has been recorded, coupled with the abandonment of several estates. A decrease in the total from 10,772 to 8,903 feddans is noted for the years 1912-13.

* Report of the Ninth International Cotton Congress, 1913.

Crude Oil.—In a search for means of cheapening the cost of water pumped for irrigation purposes, it has been impossible to ignore the widespread adoption of the internal combustion engine, adapted to the use of crude oil. This fuel with a theoretical value of four to six times that of coal by weight, and a very low production cost, has been offered at Suez at a price of less than £3 a ton, and promised to afford a solution of the excessive water bill sustained by all estates in the Northern Sudan. Further, its transport in bulk is incomparably easier and more convenient than that of coal. Authority was consequently sought to experiment with a recent pattern of semi-Diesel engine, pending completion of current negotiations for the establishment of oil tanks at Port Sudan and a system of bulk carriage on the railways. A trial shipment* of twenty-five tons of the liquid fuel was obtained duty-free from Suez, but was called upon to carry the prohibitive charges of £E.4.910 per ton for freight and handling.

Despite the excessive handicap of the transport charges imposed, the semi-Diesel engine installed at Tuti in April, 1914, furnished cheaper water to the initial trials than had been obtained by the use of any other plant. Faulty construction and material unfortunately resulted in an early loss of efficiency and ultimate breakdown, but this issue does not affect the position established for the type of fuel. Imported in bulk and employed in a reliable and efficient type of engine, its use would undoubtedly reduce the cost of agricultural production in the Northern Sudan, and widen the disappearing margin of profit, by notable figures.

Wood Fuel.—In these circumstances, it was determined to conduct a belated enquiry into the value of local wood fuel, supplies of which are adequate for any such period as is likely to elapse before the advantages of liquid fuel compel recognition of the necessity for suitable facilities. As far as can be ascertained, comparative trials of coal, liquid fuel and wood have now for the first time been locally completed in modern and efficient steam boilers, and the findings have not only afforded considerable encouragement, but have also warranted an immediate extension of our operations. Briefly, in an ordinary locomotive boiler wood has been found 46 per cent. cheaper than imported coal, and the average cost of water pumped to a mean height of 22 feet 6 inches over a season of nine months, 260 millièmes per thousand cubic metres. With a mean duty of water established as 482 millièmes, including all losses from seepage and evaporation, the average cost of irrigation per feddan amounts to 125.7

* It is regretted that the question of bulk shipments has again been allowed to fall into abeyance, while the fuel problem remains the principal obstacle to all development. It may be mentioned in this connection that a pipe line for crude oil 400 kilometres long has been laid from Matadi to Leopoldville on the Congo, by means of which our neighbouring colony will be provided with motive power for agricultural and transport enterprises and other industries which can in consequence now be established. The United States Commercial Agent recently called attention to the fact that in the Sudan "the high price of coal is creating a demand for crude-oil engines of 20 to 100 horse-power for use in driving pumps and in operating the flour mills in various parts of the country."

millièmes (2s. 8d.) on actual running expenses, including all labour. The cost of the experimental plant, landed at Khartoum, and including erection, was £E.1,645, and if 10 per cent. depreciation be allowed on this figure, the cost of water per feddan is increased to 128·2 millièmes or 266 mm. per 1,000 mm.

Relative Efficiency of Sakia and Pumping Station.—It will be of interest to compare such a figure with the cost of sakia irrigation in the case already cited. With the three-course rotation, cotton, wheat, beans or dura, a third of the land would receive twelve waterings for cotton, a third seven waterings for wheat and the balance five waterings for dura or lubia, or an average of eight waterings per feddan. It has been shown that the sakia tenant would pay for this irrigation two-fifths of his crops with a normal value of £E.2.320, representing very nearly the actual cost of supplying the water by means of the water-wheel. The same irrigation has been effected with the steam pump at a nett cost of £E.1.005, and a gross cost, including depreciation, of £E.1.025. The effect of the extension of this system in the form of a chain of pumps along the whole length of sakia cultivation and the ultimate elimination of the water-wheel, should result in an annual economy on costs of production amounting to, say, £E.132,000 in present circumstances, while this figure should be further enhanced by the provision of facilities for the importation of liquid fuel.

Wider Range of Pump Irrigation.—Sakia irrigation is moreover confined to a very narrow belt on the crest of the river bank, as the maximum range of flow for the small quantity of water delivered by the wheel, rarely exceeds 200 yards. The conformation of the riverain lands, however, lends itself to the economic watering of a far wider belt, corresponding with a gentle slope inland from the flood bank to the "karoo." It has consequently been found possible in the case of the experimental area, which is typical of the Nile banks in the northern provinces, to extend irrigation on 1,500 metres of river-front from about sixty feddans previously served by water-wheels to approximately 500 feddans under the pump. On a conservative estimate it should be feasible to quadruple the total area of irrigation and reduce the cost of production by at least a fifth. Such additional margin of profit would constitute the capital fund for improvements in cultivation proper, from which further economies and better yields may confidently be expected. Among incidental benefits to be derived from the introduction of steam pumping, would be a large increase in taxable areas and a far closer approximation between assessment and actual collection of land-tax.

Finance and Administration.

A *prima facie* case for the establishment of modern pumping machinery on the Nile banks based on actual experiment leads to a further enquiry for the best means of capitalising and administering such a scheme. Happily, a considerable fund of experience is available, much of which serves to indicate the difficulties attaching to any agricultural enterprise in existing conditions, and the directions in which modification should be ensured. The question whether large or small ownerships can be cultivated to the greater advantage is undoubtedly determined by the present sparsity of population in favour of peasant proprietorship, and this situation has been recognised by a majority of estates. Elsewhere attempts to cultivate large areas by the exclusive use of hired labour have been sooner or later abandoned.

Leaseholder and Freeholder.—It is to be noted in this connection that the actual banks of the river, comprising the rich silt soil of the new alluvium, are everywhere occupied in freehold by the sakia population, and that the estates in European or Egyptian holding are based on concessions of "karoo" land lying at a lower level between the flood bank and the desert plateau, beyond the range of water-wheels operating from the river. The problem of finding labour for the development of such estates has been solved on our largest cotton plantation at Zeidab, near Atbara, by the granting of leases for 30 feddan holdings to tenants drawn from all available sources. In 1910 the Zeidab area was divided up among 234 tenants, of whom 109 were Berberines, 60 came from Upper Egypt, 18 from Dongola, 24 were Greeks, 2 Assyrians and 1 Englishman. Owing to the failure of the Egyptian cotton crop in 1909, exceptionally high prices were paid for the first local crop, and the Zeidab Syndicate was encouraged to supply water to 1,400 feddans of neighbouring land in native ownership, "in the hope that this trial on a co-operative basis would be welcomed by the natives, and to further stimulate private initiative in this direction, and finally to cause an entire disappearance of the ineffective water-wheels."

"The season of 1911 was, however, very unfavourable for Zeidab. The cotton crop had to suffer much from cold weather, and from the attacks of boll-worm, so that the company, besides having suffered direct losses, was also suffering from the fact that the natives were not in a position to pay for the water rent. Therefore the water supply was refused them temporarily. The season of 1912 was again more satisfactory, and a first dividend of 12½ per cent. was paid by the Syndicate."* During the following years great fluctuations in the yield of the various crops of the rotation, coupled with no less marked lack of stability in prices, continued to constitute a problem which has only been partly solved by the gradual introduction of types of cotton showing greater resistance to unfavourable climatic conditions. The yields over the whole estate during the six years ended 1913 were 3 kantars, 3½ kantars, 3 kantars, 4 kantars, 1 kantar, and 2¼ kantars.† In 1914 crops were again unsatisfactory

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* Proceedings of the Ninth International Cotton Congress, 1913.

† "Cotton Growing in the Sudan, 1913."

Native Landowners at Shambat.

Native Method of Threshing Wheat by Treading and Hand Winnowing.

and prices were low. As a consequence the second dividend was reduced to 2½ per cent.

Credit and Security.—It is generally recognised that the small owner or tenant must be able to obtain credit, and that his command of borrowed capital will be determined by the security he may be able to offer. Force of circumstances, however, at Zeidab has compelled the acceptance as leaseholders of cultivators who in a majority of cases could offer no *quid pro quo* for extensive advances on their account. The tenant, taking up new land, had to clear it first from bushes and roots, for which he obtained a fixed price. He then received oxen and implements in order to level the country; or if the soil was heavy, it was worked first by the steam ploughs belonging to the Company. The cultivation was then begun, and tenants received advances every fortnight in proportion to the quantity and quality of their work. These advances were made on account of the crop to be gathered. No interest was charged on these crop advances, as it was intended to encourage the tenant in every way possible and in order to make him prosperous.* As the land is let, and the water supplied to tenants without security, and as the latter receive in a majority of cases cattle, implements and seed on loan, the incidence of risk is entirely on the Company, which is called upon to finance not only all capital expenditure but even the current costs of cultivation. The possible incidence of consecutive unfavourable seasons consequently calls for a further capital reserve, and the entertainment of the additional risk that tenants with nothing at stake may prefer to break their agreement rather than face the burden of heavy arrears.

Co-operation with the Freeholder.—A more equitable distribution of risks would appear to be ensured by the alternative tentatively essayed at Zeidab, whereby the owner of sakia lands was furnished with water and facilities for the handling and marketing of his crops in return for fixed payments. The coincidence of an abnormally unfavourable season with the initiation of this policy, and the Company's inability to grant additional credit for a second season's irrigation, unfortunately postponed an exhaustive trial of the system. It has, however, since been elaborated as an important aspect of the work of the Research Farm, and a brief account of early developments has been furnished in the body of the current report.

Regarded as an effort to introduce an element of co-operation into local agriculture, the system is essentially based on the security afforded by freehold title for water supplied on credit and for such loans as may be needed by the landowner for the development of his holding. The agreement embodies a clause providing that all operations shall be conducted in accordance with advice based on the results of field experiments conducted on the farm, and thus

* Proceedings of the Ninth International Cotton Congress, 1913.

ensures a valuable medium of education. The responsibilities of the administration are limited to the provision, running and maintenance of the pumping station and the construction of head works, while control of irrigation is effected as part and parcel of the work of field instruction. The landowners are collectively responsible for the provision of canals and distributory channels, which are constructed and maintained by the administration against loan funds. Implements, livestock and seed may also be provided to the limit of available funds and approved security, while the granting of advances on stored crops, the financing of transport and disposal are legitimate administrative functions pending the organisation of local markets for such staples as cotton.

Profit Sharing.—The establishment of new agricultural stations in the Gezira at Tayiba and Barakat has afforded an opportunity for the trial of a co-operative system calculated to obviate many of the difficulties experienced at Zeidab. Organised with a view to determining the commercial possibilities of the Gezira plain as a cotton area, pending construction of the projected dam at Sennar and complementary irrigation works, these estates are administered on behalf of the Sudan Government by the Sudan Plantations Syndicate, which also controls the destinies of the Zeidab Estate. Under existing arrangements the Government provides the land and the water and receives 35 per cent. of the proceeds of the crop. The Syndicate provides the financing, direction and management, and receives 25 per cent. This leaves 40 per cent. to go to the tenant for his time and trouble. This bold attempt to cut the Gordian knot of credit, tenure and administration has the all-important merit of simplicity, and pending the education of tenants in cotton cultivation, their accumulation of a capital reserve and the organisation of a local cotton market, the arrangement may be considered equitable. Whether, however, in the future the trained cultivator with reserve funds adequate to his current expenses and the cost of placing his crop on a local market, may be able to justify a claim to a larger share in the proceeds, remains to be seen. Subsequent adjustment of profit-sharing is doubtless contemplated under the scheme, when a skilled tenantry has been called into being.

The Irrigation Unit.—In the case of our own undertaking, financial considerations have restricted the scale of initial experiments, and the question arises as to what may be an economic minimum in size for the irrigation unit. Assuming that operations are to be confined to riverain lands for which title has been granted, the topography of the river bank affords an irrigable area sloping back from the flood bank with an average width of about half a mile. The main canal will consequently parallel the bank and deliver water to distributory canals at right angles to the former. Seepage and evaporation impose an economic limit on the length of the main canal, varying with its capacity, as determined by cross-section and fall. Similarly, an economic limit in the size of the pumping plant will be based on mechanical considerations. Questions of control and supervision, together with that of the association of a number of units in one general scheme, should also receive consideration. Avoiding reference to technical details, it may be provisionally stated that early experience would point to the unit of 1,000 feddans irrigated by 100–120 H.P. engine and 18-inch pump, being one of a continuous series of similar areas, as affording collective opportunities of most economic working. While little additional economy can be effected by increasing the size of the pumping plant, which in most cases would take the form of additional power units, the losses from seepage and evaporation in an unduly extended canal system would be enhanced by the difficulty of obtaining an adequate fall for the main canal. In the case cited, however, the cost of expert supervision should be divided over a series of adjacent units, which arrangement, coupled with the use of floating and interchangeable pumps, would obviate the necessity for a stand-by plant, which costly experience has indicated to be essential on the self-contained estate. In the absence of such provision even temporary engine trouble in the middle of the cropping season may spell disaster and the loss of a year's work and outlay.

The Cost of a Pumping Station.—In existing circumstances, a pumping station to serve an area of 1,000 feddans can be organised in the neighbourhood of Khartoum at a total cost of approximately £E.1,800, including landed cost of machinery, erection and provision of a float to carry the plant. The cost of headworks will naturally vary with the contour of the land, but should not exceed £E.100 in a majority of cases, while canalisation has been actually completed for such an area at an outlay of £E.300. Preliminary surveys, the provision of bridges, modules and weir-gauges and other incidental expenses may involve an additional expenditure of £E.200, making a capital charge in all of £E.2.400 per feddan on land which is worth at least £E.20. The remaining mortgagable balance should suffice as ample security for the cultivator's working capital, as soon as agricultural credit has been placed upon a sound footing. Pending consideration of this vital requirement, local experience has shown that he is often borrowing money at impossible rates of interest and burdening himself irretrievably with debt.*

Demarcation.—The irregular size and shape of sakia holdings constitute a somewhat serious difficulty, and complicate canalisation and accountancy.

* "As long as there was no bank in existence in the Sudan the Government granted to the peasants small advances, mostly for a period of three years, against payments of 7½ per cent. interest per annum, under the supervision of the local authorities, provided the money was required for the purchase of cattle and agricultural implements, and for the construction of water lifts. In 1906, the National Bank of Egypt, which has agencies in Khartoum, Suakin, and Port Sudan, introduced the system of granting peasants advances against mortgage of their crops, and of protecting them against usurious rates of interest and artificially kept-down prices. Generally speaking, however, agricultural credit in the Sudan is very difficult to obtain for the small farmer, except at an excessive rate of interest."—(*Cotton in Egypt and the Sudan.*)

The alternative would be compulsory expropriation and redistribution of land, the objections to which would, however, appear to outweigh the advantages. The local cultivator is peculiarly attached to his holding and jealous of his land marks, and the disturbance and discontent which would result from any such policy might jeopardise the scheme for years. On the other hand it has been found possible, by following sakia boundaries, to divide the irrigation unit into "hoshes" of approximately 100 feddans, each served by a module which automatically regulates the water supply and ensures a uniform and known discharge. Distribution of water within the hosh is effected by one honorary sheikh chosen from the leading samads. Liability for the payment of water rate on a fixed area in each sakia is covered by a contract signed by the samad on behalf of himself and his partners. The "sakia" thus becomes the ultimate unit, and all implements, livestock, seed, &c., distributed on credit are issued on the security of sakia ownership.

The Fiscal System.—If, however, the greatest obstacle to extended production remains the absence of a loan fund and the machinery for its administration, the situation is little relieved by the costs of importing agricultural requisites.

The current fiscal system is reflected by a flat customs rate of 8 per cent. on the c.i.f. values of practically all imported goods, and by railway rates which yielded in the year 1913 profits of £E.152,000 on a total overseas trade of £E.3,295,000. As no question of the protection of local manufactures has arisen, such a system is admittedly a form of taxation, and its incidence on the instruments of agricultural production and consequently on agricultural development, is of obvious importance. Its effect on the local price of fuel has already been noted.

Import Costs.—It has been urged that the cost of production can best be reduced in the rainless north by the substitution of modern pumps for the sakia, and the result of a first demonstration was sufficiently encouraging to warrant the recent importation of a second plant to serve an additional area.

The following statement of cost of importation is instructive :—

	£E. Mills.	£E. Mills.
F.O.B. Cost of Engine	—	359.775
Sea Freight	51.012	—
Railway : Port Sudan-Khartoum	62.400	—
Transport : Khartoum to Site	9.000	—
Customs Dues	37.448	159.860
		519.635

Of these figures sea-freight is alone affected directly by a state of war, though advances in freight enhance customs dues based on a c.i.f. valuation. The example is typical, for the would-be producer has in most instances to add 50 per cent. or more to the catalogue prices of all his machinery and implements to cover freight, customs and charges.

At the time of writing the operation of ploughing is almost unknown to cultivators on our rain-lands, and is still the exception rather than the rule in sakia areas. That this is due, not to any disinclination on the part of landowners, or failure to appreciate the advantages and economies of such tillage, is evidenced by reports from numerous centres of the eagerness with which ploughs are borrowed or bought when offered on reasonable terms.*

The substitution of the steam pump has the immediate effect of releasing four trained sakia bulls from each holding previously cultivated, for work in the plough, their collective capacity being not less than a feddan of land a day, equivalent to the work of ten labourers armed with hoes. The immediate result of a supply of cheap implements would be a large extension of the cultivated area, better crop returns due to improved tillage, and enhanced returns from land-tax and ushur.

An attempt was consequently made to obtain a cheap but efficient plough from the United States of America, specially devised to replace the native "mihrat" in Egypt and its equivalent in other countries. This implement is catalogued at 5 dollars, or £1 Egyptian, and is sold by thousands throughout Tropical and South Africa at about 25s. Its landed cost at Khartoum in parcels of one dozen is £E.2.200, which is a prohibitive figure.† Local Government workshops were consequently invited to avail themselves of the opportunity afforded by the extreme measure of protection afforded, but the excessive costs of imported materials and the high wages commanded locally by skilled labour were reflected by the cost price of £E.3.440 for a similar plough with inferior wearing qualities, and of £E.8 for ridging ploughs catalogued in England at 50s. While hundreds of ploughs, harrows and cultivators could be sold to natives in the immediate neighbourhood at reasonable prices the "*turiya*," or native hoe, and the "*mihrat*," or primitive wooden plough, remain the sole implements

* Writing from Tokar, the Inspector of Agriculture, Mr. Macdonald, reports that "the keen desire on the part of the better class of cultivators to use labour-saving implements in the preparation of their lands for the cotton crop is most gratifying. Hitherto cultivation of the land prior to the reception of the Baraka flood has only been practised to a limited content. On the removal of this season's crop very considerable work was done by fassing, but it is specially pleasing to note that over 500 feddans have been ploughed for the first time within living memory at Tokar."

The Commercial Agent of the Department of Commerce, U.S.A., has also pointed out that "the development of the country's agricultural resources and the shortage of the supply of labour are bound to create a demand for agricultural implements . . . Only the simpler implements are likely to be in demand for some time to come, but a good business might be built up in such lines as cotton planters, plows, cultivators and harrows."

† Transhipment and agency charges at Alexandria or Cairo figure largely in costs of importation. Manufacturers have consequently been approached with requests for direct shipment of implements to local ports. The reply has always been that pending the establishment of reputable firms in the Sudan, they have been compelled to entrust their local interests to Egyptian offices, and are unable to entertain direct orders.

in use pending a removal of disabilities on import exemplified by an 8 per cent. customs duty.

In a neighbouring colony free grants of land, free carriage of settlers' goods, including implements, livestock and seed, and nominal rates for the transport of produce to port of shipment for a period of years, have been largely responsible for remarkable rural progress, and a rapid subsequent growth in railway traffic receipts. A would-be competitor in the Northern Sudan, working in a rainless country, has to face a water-bill which absorbs one-third of the proceeds of his crop, the actual costs of irrigation, a heavy fuel bill for his steam ploughs and other power-plant, the expenses of hand-feeding his working stock in the absence of grazing, and, in addition to these heavy natural disadvantages, customs impositions on his implements and machinery, excessive transport rates and export dues. It remains to examine the facilities offered for the profitable disposal of his produce.

The Commercial Aspect.

During the four months, August to November, 1914, the local price of our staple grain crop, dura, fell from £E 2.000 to 400 millièmes per ardeb, as the result of good rains throughout the area from which the local market draws its supplies. During the same period the gross tonnage of imports carried over the Sudan railways amounted to 23,000 tons, while exports were limited to 2,896 tons. In other words, empty trucks with a capacity of over 20,000 tons were hauled to the coast, and empty tonnage in similar amount left the port, while grain prices were mounting to war rates in Europe. That such an issue was due, not to any lack of encouragement on the part of the railway administration, but to an undeveloped market, will appear from the context. A large proportion of our grain surplus was in the meantime converted into the intoxicant "*merisa*" in the absence of local demand, old grain was even given away in producing areas, a marked shortage in the labour supply and a universal disinclination to work or cultivate were experienced, together with inability to meet taxation and other liabilities. For in existing circumstances, though good rain crops throughout the country may relieve distress and prevent actual want, the resulting fall in the monetary value of produce spells financial disaster to the sakia community and heavy loss to the estate owner if involved to any extent in dura cultivation. The character of the rainfall can hardly be forecast in any way, and such a slump in prices as has been recently experienced reduces the value of the samad's grain and forage to a point considerably below the cost of production, and he has the alternative of selling at a loss, or, if he can stave off his official and private creditors, of holding his crop during a period of penury for a rise in price. That he should effect cash savings during years of good prices is a counsel of perfection and a practice entirely foreign to his nature. On the other hand, to eliminate all grain crops from irrigation farming would be to intensify the disastrous effects of a total or partial failure in rain-cultivation, such as has been experienced during the seasons 1912–14, and render the whole country dependent on imported foodstuffs. Whether it may not be possible by enlarging the areas of supply and demand to modify the unfavourable incidence of alternating surplus and deficiency is a leading commercial and agricultural problem in the Sudan.

Equilibrium Prices.—The equilibrium value of dura, which will ultimately determine the place of the crop in the irrigation system, has been obscured by three years of famine prices and by the effects of speculation, which culminated during 1914 in local "corners" in grain. An attempt should be made, however, to estimate the various factors now controlling the course of prices, and the influence of possible improvements in market organisation and transport facilities.

The following statement is instructive as further illustrating the speculative and unhealthy character of grain-farming in present conditions :—

January Market Prices for White Dura.

(Millièmes per 100 kilos.)

Market.	1907	1908	1909	1910	1911	1912	1913	1914	1915
Wad Medani ...	160	170	180	160	330	750	870	1,400	210
El Dueim ...	200	240	190	150	350	760	890	1,157	208
Omdurman ...	270	300	300	220	390	910	980	1,220	300
Port Sudan ...	—	790	970	700	920	—	—	—	650

Selection has been made of four markets representing, respectively, centres of production, consumption and export. Wad Medani serves as a commercial centre for a wide area of rain-farming on the Gezira plain, while El Dueim is an important grain market on the White Nile to which are brought large riverain crops. The two markets are equidistant 110 miles from Khartoum, and while Wad Medani has been in direct railway communication with the capital since 1910, El Dueim enjoys the advantage of a regular service of river transport; the Omdurman "suk" functions as a distributory centre to a population of 130,000 resident in the group of towns, including Khartoum and Khartoum North, which surround the junction of the White and Blue Niles, and Port Sudan, distant 500 miles by railway, is the only harbour furnishing deep water wharfage and modern facilities for the handling of grain cargoes.

Excessive Fluctuations in Value.—The outstanding feature of the local grain market is the uncontrolled and excessive fluctuation in value. Demand is naturally inelastic, exhibiting, however, a steady increase with the growth of population, and the price curve follows very closely that of production, modified only by the release of stocks from the "matmuras" or native grain pits. Imported grain only figures as a controlling factor when prices approach a famine level. Similarly, the downward trend following seasons of good general rainfall, is checked at a very low level by the temporary organisation of an export trade. The year 1910 coincided both with the lowest mean prices recorded during the period under review and the opening of the Sennar Railway, and 48,000 tons of dura were exported *via* Halfa and the Red Sea ports. In the following year values hardened and exports were limited to 26,000 tons. During 1912 and 1913 imports of dura were in excess of exports, but the quantities were negligible and neither exercised an influence on the course of prices nor served to relieve the prevailing distress.* In 1914, however, the Government was compelled to import large quantities of Indian dura† for distribution to famine areas, which had the incidental effect of releasing grain "cornered" by native merchants in the Omdurman "suk." The slump in prices which followed the breaking of the drought in 1914 further demonstrated the isolated character of the market and the absence of machinery for dealing with unexpected grain surpluses.

Producer and consumer are alike concerned in securing a market organisation which will smooth out feverish fluctuations in prices and permit a healthy and sustained expansion of trade. Unfortunately, a season of deficient rainfall generally coincides with a poor Nile flood, the failure of basin crops and enhanced costs of sakia irrigation; good rains, on the other hand, spell a high flood, large basin-crops and cheap sakia-water.

Storage and Forced Sale.—A primitive method of dealing with the situation thus created is found in "*matmura*" storage. The surplus grain of good years is placed in pits dug in the ground and lined with a plaster composed of mud and cow-dung. The climate of the Sudan is particularly favourable to this method of storage, and the system has undoubtedly served a useful purpose. Protracted storage, however, in such pits results in damage, more or less serious, from

	1912. (Nine months.)	1913. (Nine months.)
	Tons.	Tons.
*Exported	720	2,005
Imported	4,439	5,083

(*Annual Report : Director of Customs.*)

† 11,038 tons, valued at £E.85,814, in addition to 16,198 tons, valued at £E.127,511, imported by the public.

moulds, discoloration, and the attacks of rats and such insect pests as weevil and grain-moth. It is, moreover, obviously inadequate to the situation created by such a succession of lean years as have recently been experienced, for it is limited in application by the cultivator's actual want of ready money. Harvest finds him as a rule deeply involved in liabilities for taxes, rent and loans, and immediate realisation of a large proportion of his crop is compulsory. Thus, on the one hand, he suffers the loss resulting from forced sales at harvest time when prices normally reach their lowest level, and, on the other, locks up part of his capital in a form which is both insecure and profitless. Actual experience has universally demonstrated that the loss attending such storage outweighs any gain that could be anticipated from the usual annual rise in internal prices.

Prospects of an Export Trade.—The uncertain character of our rainfall, however, and the preponderating influence of rain crops on the grain market, render the retention of the reservoir principle essential; but the point should be made as to whether the substitution of the elevator system would not only furnish less costly storage, but also serve as a foundation for a future export trade, which is regarded as the only available solution of the problem outlined above. It may be noted in this connection that pit-storage of grain is similarly characteristic of isolated areas and markets in India, and becomes everywhere less prevalent when improvements in communications enable cultivators to sell their grain for export. In the Sudan low costs of production are still associated with an undeveloped market and inflated forwarding charges, and shipments have hitherto been practically limited to the periodic market created by the Mecca pilgrimage and occasional abnormal demands from Egypt.

Analysis of the annual prices given above affords the following normal values for the staple white dura for the nine years ending 1915 in millièmes per 100 kilos :—

Wad Medani.	El Dueim.	Omdurman.
470	460	543

If, however, the famine years of 1912–14 be excluded from the calculation and the export factor be taken into account, the following values may be accepted :—

Wad Medani.	El Dueim.	Omdurman.	Port Sudan.
210	228	302	806

The normal value of dura on the European markets may be taken as approximately £E.5.500 c.i.f., per 1,000 kilos, which closely approximates the figure obtained for Omdurman as the mean for the last nine years, and would apparently preclude any possibility of profitable export. During six of these years, however, dura was sold on the Wad Medani and El Dueim markets at an average price of £E.2.190 per ton, leaving a margin of £E.3.310 to cover freight and charges to the European markets. A special through railway rate of £E.1.055 Wad Medani to Port Sudan has been offered for truck loads, while homeward freights from Port Sudan to London/Liverpool have been fixed at £E.1.200 for this grain. With nett transport costs of £E.2.255 and a margin of £E.3.310 between local and European prices, the growth of an export trade will depend, firstly, upon the maintenance or reduction of present values, and, secondly, upon market organisation and the limitation of costs and charges incidental to shipment.

A Limited Area of Supply.—It is to be noted that the area at present served by the railway, which furnishes supplies of grain to the principal centres of consumption, has been geographically classified as one of inadequate rainfall. Pending completion of projected irrigation schemes for the Gezira plain, the grain market of the Sudan continues to rest upon the output of undeniably precarious rain-farming on the lower reaches of the White and Blue Niles, supplemented by limited supplies from the northern sakia and basin lands. Steadier values and the growth of an export trade must necessarily await the free movement of grain from south-eastern and southern rain-lands, and the question resolves itself into one of improved and cheaper transport facilities, coupled with the organisation of commercial intelligence.

The removal by export of any proportion of the crop within the present railway area inevitably results in an immediate hardening of prices and a reduction to vanishing point of the very narrow margin of shipping profits. In other words, the railway is inadequately fed, and a progressive policy of liberal "through" rates will fail of its purpose until the gap still existing between rail-heads at Sennar and Kosti and the southern grain fields be bridged by cheap transport, and a vast extension of cultivation and supply thus ensured. For the purpose of this discussion, Kaka on the White Nile, with a mean annual precipitation of 650 mm., may be taken as representing the northern limit of reliable and adequate rainfall and as a market tapping an extensive but undeveloped grain country. The possibility of effecting profitable shipment from this centre may be taken as a gauge of the immediate prospects of an export trade.

Kaka is situated 412 miles by river from Khartoum, and grain is carried by the Sudan Government steamers, which enjoy a monopoly of river transport, at a flat rate of 3 millièmes per ton mile to rail-head at Kosti (708 mm.), with a special rate of 335 mm. Kosti to Khartoum, making a total charge of

£E.1.043 mm. per ton. This, unfortunately, is a prohibitive figure, and the discrepancy between a railway rate of 2 mm. and a river rate of 3 mm. requires explanation.

River Transport.—That the cost of transport by water is cheaper than transport by rail is uncontradicted, and transport by navigable river is cheaper than by canal. In the Sudan the employment of wood fuel by river steamers and imported coal by the railways should enhance this economy. The average cost per ton mile of moving freight by rail, including long and short hauls, in the United States, has been ascertained to be about 6 mills of a dollar, or 1.2 mm., with which local export rates, in view of all existing circumstances, compare not unfavourably. On the other hand, some 25 million tons of freight are annually carried on the Mississippi and its tributaries at a cost per ton mile of 2.3 mills or 0.4 millièmes, being less than a seventh of our White Nile charges.* In this connection a quotation from the last annual report of the Steamers Department is of interest:—

> The wood consumed was nearly 100,000 metres, which is estimated to be about 600,000 kantars. Allowing one piastre per kantar as a fair price for cutting and stacking, nearly £E.20,000 is left for the expenses of the Agriculture and Forests Department in connection with the fuel supply and royalty to the Government.

Should the general financial situation ultimately warrant the diversion of this unearned royalty to a reduction of river freights and the modernising of river transport, an invaluable stimulus to southern agriculture would be afforded, and a balanced development of the country, as a whole, ensured. It might be confidently expected that an adequate return to such investment would take the form of traffic receipts enhanced at all points by a steady export in dura, and a corresponding increase in the taxable capacity of producing areas.

Handling Charges.—The official prices of dura† in January of the current year at Wad Medani and Port Sudan were £E.2.100 and £E.6.500 per 1,000 kilos, respectively, while the net cost of railage between the two points was £E.1.055. The discrepancy of £E.3.155 can be attributed variously to the lack of commercial intelligence and market organisation, the absence of a capital fund for the financing of grain movements, the lack of competition reflected by excessive commissions and charges, and finally to the costs of handling grain in sacks. In actual practice, however, grain could be shipped from Khartoum to British ports prior to the war, at a total cost of £E.3.000‡, of which 915 millièmes were

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* Proceedings of the Conference of Governors, U.S.A., 1909.

† Monthly Report of the Central Economic Board.

‡ Report of the Central Economic Board, September, 1914.

payable as railage, Khartoum to Port Sudan, 110 millièmes as handling charges at Port Sudan and £E.1.250 to the shipping company. The balance of 725 millièmes was absorbed by various incidental expenses, commissions and forwarding charges ; and upon a careful analysis and reduction of the latter figure the future of the export trade will certainly depend.*

The Elevator System.—All the circumstances of the local grain market, including the absence of commercial firms of standing and a command of credit, the character and capacity of the native merchant and the isolation of trading centres, point to the fact that in the work of building up an export trade the initiative must be exerted by the Government and particularly by the railways and steamers. Safe storage, cleaning, grading, adjustment of stocks in the cause of steadier values, economies in handling and forwarding, and the assembly of bulk shipments are among the functions for which the Government is alone qualified in existing conditions, and upon the adequate performance of which the future of the industry must necessarily depend. That such purposes are best served by the establishment of an elevator system is a contention supported by a very convincing body of testimony and evidence unequivocally favourable to elevators as the only really efficient means of handling grain.

A change from bag to bulk loading would undoubtedly entail considerable initial expenditure. A country elevator capable of holding 400 to 500 tons at a time would probably cost in the Sudan £2,000, while a port elevator with a capacity of 16,000 to 20,000 tons could hardly be constructed and equipped for less than £60,000. Compensation would be found in a measurable saving of 6s. 3d. per ton on costs of bags and numerous other economies which, although they cannot well be expressed in figures, are none the less real. The establishment of elevators in Canada, the United States and Argentina has been due to railway administrations who found that if their railways were to be made to pay they must take steps to create traffic. "To this end they erected, and for a time operated, grain elevators ; they inspired confidence in the farmers to settle and

* A useful comparison is afforded by the facilities ensured to the South African farmer. These are to be attributed directly to the far-sighted policy of the Natal Government, which had determined to secure a profitable outlet for surplus grain and build up railway traffic, and the agricultural industry *pari passu*, as has been done elsewhere, by accepting at the outset the smallest possible margin of profit. In 1907 the Minister of Railways secured from the Conference lines a freight rate for maize of 10s. per ton Durban to two European ports, *via* the Cape. This was subsequently extended to beans and ground nuts. The Government Agency in London made a small charge for sale, commissions and other expenses, amounting to 7d. per sack of 200 lbs. A rebate of 3d. was allowed on each new sack, reducing these charges to 4d. The Manager of Railways reduced railage on grain to a half-penny a ton per mile. A system of Government grading at the port was established and forward sales on certificate were arranged. Within six months of the introduction of this system 51,000 tons left Durban for Europe, as compared with a total shipment of 430 tons in the previous year, while as the result of official grading the price for maize advanced to 30s. 3d. a quarter, as compared with 26s. 3d. paid at the same date for Danubian maize. These shipments consequently realised 12s. 7d. per sack of 200 lbs., or £6 5s. 10d. a ton. Transport costs from Maritzburg in the midlands of Natal, including cartage, railway carriage, handling, freight, banking charges and all other incidental items of expenditure, including commission on sale in the home market, amounted according to the published tariff to £1 1s. 2d. per ton, or 2s. 0½d. per sack.

till the land by ensuring their getting a ready market and equally prompt payment at the current ruling corn exchange rates, less rail carriage for their grain; and they assisted in various other ways."

"The main functions of the elevator are the expediting and cheapening of handling and the preservation of the grain crop from damage; and in these respects the saving to the country must be absolute irrespective of movements of the market."* The holding of grain in safe storage to meet and control the recurrent rise in prices is in the Sudan a hardly less important, though different, function, and a study of the annual range in figures would point to such an undertaking as a means of covering a large proportion of operating costs, and returning an adequate interest on capital expenditure.

Dura as an Irrigation Crop.—Whether in existing circumstances the growth of dura under pump or sakia irrigation should be encouraged is largely a question of the probable future course of price. It has been noted that normal European values oscillate round a mean price of £E.5.500 per ton; that normal prices at centres of production served by the railway, excluding the incidence of famine values, can be taken as £E.2.100 to £E.2.200 per ton, and cost of shipment as £E.3.000 to £E.3.250. It will thus appear that a downward trend in local values will be checked more or less effectively by the organisation of export, when market values approach £E.2 a ton. As this ton weight, however, represents a bumper yield from the feddan unit, and convention demands the surrender of half the crop as payment for land and water, dura will only be grown under irrigation for domestic supplies, or as a purely speculative effort to obtain abnormal prices during seasons of deficient rainfall. And it is to be noted that every improvement in transport facilities and commercial organisation should lead to the maintenance of values at an export level, and a further limitation of the irrigated area planted to dura.

Substitution of Wheat for Dura.—Happily, however, this staple is not essential to a satisfactory rotation of irrigation crops, and the substitution of wheat as the "grain course" has much to recommend it. From the agricultural standpoint, the white straw crop is far less "punishing" to the ground, and as a winter "stand" has nothing to fear from rain-land competition. Commercially, its position is even stronger, for the Sudan continues to import large quantities of wheat and flour even in favourable seasons, and a preference for white meal bread and a consequent increase in consumption of the cereal is being everywhere manifested, and is reflected by the following customs returns :—

* F. Noel-Paton: "Indian Wheat and Grain Elevators."

Value of Wheat and Wheat Flour imported to the Sudan 1909-13, and Average Value 1909-12.*

	1909	1910	1911	1912	Average 1909-12	1913
	£E.	£E.	£E.	£E.	£E.	£E.
Wheat ...	2,716	3,775	4,358	23,009	8,464	15,654
Wheat (flour)	66,901	55,590	77,005	87,699	71,799	86,168
£E.	69,617	59,365	81,363	110,708	80,263	101,822

Wheat values, derived from the costs of production and importation, are only indirectly affected by the character of the rainfall, as such influence is limited to the possible substitution of the normally more expensive flour for dura meal in times of great scarcity. For the purpose of the present statement, however, the year 1910 may be selected as subject to few disturbing factors, and likely to afford a reliable estimate of values. Analysis of the official monthly statements of highest and lowest prices affords a mean value of £E.10.005 per ton on the Khartoum market for the twelve months ended December, 1910. With this figure may be compared a ten years' average price of 6s. 6d. per cental on the Liverpool market, or, approximately, £E.6.500 per ton. Wheat is consequently little likely to figure on the Sudan export schedule for years to come, and a nett profit of £E.2.913 per feddan from a relatively poor stand harvested on the Research Farm during the current year may be taken as a fair index of the position of the crop. Additional profits obtainable from the use of modern threshing machinery have been indicated in a later report.

The Export of Cotton.—It is frequently urged that, in view of the undoubted difficulties at present attaching to the export of dura, and the absence of any prospects for the shipment of wheat in the near future, agricultural effort should be concentrated on the production of such crops as cotton, with a relatively high value as compared with weight or bulk. It has even been stated that our position and that of Egypt is unassailable in the market for long staple cottons other than Sea Island, and that in view of such virtual monopoly the handicap of transport rates should not be felt. Unfortunately for this contention, Mr. J. W. McConnel, President of the "Fine Cotton Spinners' and Doublers' Association," who recently visited the Sudan, has pointed out that Brazil, Peru, Georgia, and the several States of America producing long-staple upland lint, are now competing on more than equal terms with the Afifi, Ashmouni and

* Central Economic Board: Annual Report, 1913.

Sakel cottons of Egypt. He writes, forwarding samples, and states, "The J. H. P. Brazil is a dirty cotton but very useful, better in every respect except dirt and waste than Ashmouni from Upper Egypt. The long-staple American again is in many respects better than Afifi, though also neppy and wasty. The Georgias compete with Sakel, and the West Indian is of course better than anything ever grown in Egypt."

In view of this direct and growing competition, the question of relative costs of production and marketing become of vital interest. The cottons mentioned above are grown almost exclusively under rain-cultivation, and from this standpoint the delta areas of Tokar and Kassala are alone in a position to compete on equal terms. In addition to the handicap of a heavy water-bill, our smaller cotton estates have to meet charges for transport which reduce any enterprise to the character of a forlorn hope. And it should be remembered that a large proportion of estate cotton has been, and is being, produced at a loss, while the abandonment of considerable areas is evidenced by the official returns of cultivation.

It may be well in these circumstances to compare the proportion of the value of cotton which goes to the producer, the middle man, the railways and steamers. For 1 cent, or 2 mm., per lb., many interior towns in North Carolina, as a typical cotton State, can put cotton into the ordinary course of transit and deliver it through port of shipment in England or on the Continent at the consumer's mill. In shipping cotton to Japan by way of Galveston the distributor does the work for about 5·3 per cent. of the cost to the consumer in Japan, and the producer gets 94·7 per cent. of the cost to the consumer. At a period of high freight rates on ocean trade, a pound of cotton was carried from New Orleans to Chemnitz, Saxony, direct to consumers, for the combined expense of 1.25 cents, corresponding to 3 millièmes of our currency (Report of the Industrial Commission, U.S.A.)

Details of the last-named case furnish a useful basis of comparison with the local system, and may be quoted in full. It has been selected as a route necessitating much re-shipment and handling in transit.

Expenses of sending Cotton to Chemnitz, Saxony.—The following statement shows the expenses of sending 430 bales American cotton shipped from New Orleans to Hamburg, thence to Chemnitz :—

	$
430 bales gross, 224,058 pounds, at 6⅞ cents	15,403.98
Charges in New Orleans, carriage, pressing, commission (2½ per cent.), marine insurance, $13,500, 1¼ per cent.	1,005.82
	16,409.80

	£	s.	d.
Sixty days' sight on London ($4.82½ = £1)	3,400	19	10
Bankers' commission (1¼ per cent.)	8	10	0
	3,409	9	10

	Marks.
Due January 6th, at 20.50 marks	69,894.60
Freight, New Orleans–Hamburg–Riesa (Elbe)–Chemnitz	5,847.55
Expenses in Hamburg	412.20
Petty charges	271.00
Brokerage	87.00
	76,512.35

	Pounds.
Gross	224,058
6 per cent. tare	13,443
	210,615

This statement analysed shows that the gross cost of this shipment from New Orleans to Chemnitz was 76,512.35 marks. Reduced to its United States equivalent, this amounts to $18,217.22. Deducting from this the cost of the cotton at New Orleans, we have $2,813.24 as expenses incurred from New Orleans to Chemnitz. Dividing this total expense by the gross weight of the cotton, we find that the expense of the entire transaction between New Orleans and Chemnitz was 1¼ cents per pound.

With the above statement may be compared freight and charges on a consignment of cotton shipped from Khartoum to Liverpool and sold through the agency of a local bank in June, 1914.

COST OF SHIPPING 142 BALES (22,675 lbs.) OF COTTON, KHARTOUM TO LIVERPOOL.

	£E. Mills.
Expenses, Khartoum to Liverpool :	
Cost of pressing, weighing and baling, including bales at 70 m/ms. a kantar	15·873
Transport to station at 8 m/ms. a kantar	1·814
Freight—Khartoum to Port Sudan at £E.2.620 a ton	29·704
Customs export dues	4·535
Freight—Port Sudan to Liverpool at £E.2.610 a ton	29·477
Insurance	9·070
120 days' sight on London at 6%	9·100
Difference in weight between Khartoum and Liverpool, 1½% ...	10·204
	109.777

	£	s.	d.
Expenses at Liverpool (from Account Sales) *:*			
Charges on 142 bales—			
Porterage	0	12	9
Dues	1	0	11
Housing, mending and storing...	7	2	0
Rent	6	6	11
Insurance	2	12	0
Brokerage and Commission	8	11	6
	26	6	1

	£E. Mills.
Khartoum Charges :	
1% Commission and Brokerage	8·113
½% Exchange	4·057
	12·170

Summary :

Packages.	Nett Weight, lb.	At per lb.	£ s.	£ s. d.
70	11,410	$9\frac{5}{8}$d.	457 11	
72	10,264	$9\frac{3}{8}$d.	400 18	
				858 9 0
Charges at Liverpool				26 6 1
				832 2 11
				£E. Mills.
				811.342
Brokerage, Commission and Exchange				12.170
				799.172
Expenses, Khartoum to Liverpool				109.777
Nett Proceeds				689.395

The cost of this consignment to the consumer was £E.837 ; the producer's share was £E.690, being 82·4 per cent. ; while 3·5 per cent. went to the railway, a similar share to the steamship company, and no less than 10 per cent. to middlemen. It is submitted that no additional argument is needed for the early establishment of a Government agency in Great Britain to relieve the small producer of these extortionate and unnecessary charges, and enable him to compete on more equal terms with agriculturists in other areas who enjoy the assistance of consular and commercial agencies. Thanks to such assistance the American cotton planter growing " long staple uplands " in Louisiana, can market his crop in Japan and obtain 94·7 per cent. of its selling value, while the small estate owner in the Sudan, shipping through the only available agency, obtains only 82·4 per cent. Similarly while American cotton shipped from New Orleans to Saxony carried gross transport and selling charges of $1\frac{1}{2}$ cents, or 3 millièmes per lb., it has cost 6.4 mm., or more than double the former figure, to ship and sell Sudan cotton on the Liverpool market. Here again are evident the undesirable influences of a virtual monopoly, enjoyed in this case by the middleman, and the need for a radical modification of the whole system of distribution. In other cotton belts, where marketing organisation is highly developed, the main tendency is to eliminate unearned charges. The telegraph and mail bring to the grain and cotton producers the prices of the world's markets day by day. The shipper simply ascertains by what ways and means the transfer from producer to consumer can be effected most economically. To err is to eliminate himself. There is no important class of dealer that can interpose itself at any point or place in the distributive process and exact compensation regardless of services rendered. If the compensation is greater than the service is worth, competition of capital will seek to supplant the favoured agency. In almost every trading centre and for almost every leading farm product handled largely, it has been necessary to lump charges in order to keep trading during the past ten years. An attempt to impose even a trifling small excess of charges on cotton or grain at one distribution point will be taken advantage of by competing points.

Unfortunately, conditions in the Sudan have been little favourable to the introduction of either capital or the resulting competition, and, as the President of the British Cotton Growers' Association was moved to remark, after fourteen years' occupation, there is not a single commercial firm of reputation or standing represented in the country. As early at 1904 the Association requested Messrs. Carver Bros. & Co., of Alexandria, to send buyers to the Sudan and establish some definite market. Fixed prices on a very low scale were promised, and until recently furnished an artificial basis of values. Later on, Messrs. Carver & Co. limited their direct purchases to Tokar, " because the quantity grown in the interior of the Sudan was not important enough." To the present day no cotton market has been organised outside that centre, and the small producer is at the mercy of local banks.

In these circumstances, which appear likely to obtain for an indefinite period, the establishment of an agency in Great Britain to act as a commercial intelligence bureau and assist in the disposal of shipments to the best possible advantage, and at minimum charges, should secure many benefits for, and remove heavy burdens from, the hard-pressed producer in this country.

Restorative Crops and the Livestock Industry.—The introduction of the cotton crop with its glamour of high but elusive profits, has possibly obscured the vital importance of the livestock industry as a means of raising the average returns from agricultural areas, and of ensuring the maintenance or improvement of soil fertility. Reaction has, however, been marked at more than one centre in the northern provinces, where estate owners are seeking to recoup losses in cotton cultivation with profits secured from the fattening and finishing of livestock. For this purpose lubia and other leguminous crops have been grown no longer as the least expensive system of manuring for cotton, but as bidding fair to rival the latter in revenue production.

That shippers of livestock have availed themselves of every facility offered in the form of cheaper transport rates, would appear from the export schedule, and the growth of trade might well justify an exhaustive enquiry with reference to the problems of breeding, feeding and management. In the case of all classes of exportable stock the exacting conditions obtaining in the Northern Sudan lend importance to such an investigation, the postponement of which is likely to cost the country little less than the extensive adoption of untried systems in field agriculture.

Indirect advantages to be derived from the establishment of the livestock industry as an integral element in local farming may be detected in the distribution of risks over a number of undertakings, a reduction in the monotony of present operations, and a supply of prime meat and dairy produce at all seasons to the exclusion of imported supplies.

Résumé.

It is submitted in view of the conditions obtaining in the Sudan that sustained development of an agricultural industry, as distinct from the exploitation of natural resources, can only be ensured by exhaustive and decentralised research, supplemented by a comprehensive system of agricultural education. Private enterprise has served to define numerous problems, the solution of which still awaits active intervention on the part of official agents.

An extraordinary range in conditions of climate and soil requires that local systems of agriculture be evolved *in situ*, with a clear recognition of the restricted application of field results ; while a diversity of native races exhibiting varying degrees of mental and social development demands localised instruction and much elasticity in educational methods. The field mission and the residential school should alike find a place in such a system.

The natural advantages attaching to rain-farming in the southern provinces, coupled with the exceptional costs of production in the arid north, emphasise a need for improved river transport and cheaper water carriage. The former area figures in the trade schedules only as a source of supply for such natural products as ivory, and a balanced development of the country as a whole depends upon a removal of prohibitive freights on southern produce. The available margin of reduction is derived from a comparison of railway and steamer rates.

Taxation of the instruments of production, including fuel, by means of customs dues, railway rates and royalties, has hitherto handicapped irrigation farming in an unsuccessful attempt to compete with areas enjoying relative natural and fiscal advantages. The removal of incidence to the final stages of production would not only effect an absolute saving of cumulative interest, but facilitate the substitution of modern pumping machinery and efficient field implements for the primitive native contrivances still in general use.

The burden of taxation on the development of agricultural holdings is enhanced by the absence of any adequate loan fund or the machinery for loan administration. Agricultural credit in the Sudan is very difficult to obtain for the small farmer, except at an excessive rate of interest. An extension of irrigation farming to areas beyond the range of the primitive native water-lifts, but within the radius of modern pumping machinery, will be determined by the possibility of exploiting freehold title as security for loan capital.

The absence of organised markets in the Sudan and the lack of an adequate system of distribution constitute serious obstacles to rural development. These drawbacks can only be removed by official intervention pending the establishment of reputable commercial firms with a command of capital and a standing on the European markets. The introduction of the elevator system is indicated as an essential facility to the profitable export of grain in bulk.

In the development of the livestock industry must be sought not only a means of raising the average returns from agricultural areas, but also of ensuring the maintenance and improvement of soil fertility. The exacting conditions obtaining in the Sudan create a demand for an exhaustive investigation with reference to problems of breeding, feeding and management.

E. R. SAWER,
Principal.

REPORT I.

THE AGRICULTURAL ENVIRONMENT.

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SECTION I.

Meteorological Conditions.

KHARTOUM is situated on the Blue Nile near its junction with the White Nile, at an elevation of 378 metres above sea level.

The degrees of latitude and longitude are respectively Lat. 15 36′ 20″ N. and Lon. 32 32′ 30″ E.

From the banks of the river a wide expanse of arid sandy soil stretches in all directions, which for the greater part of the year is devoid of vegetation. No elevated areas occur sufficiently near to affect the climate appreciably.

Typical desert conditions prevail from October to May with cloudless skies and high temperatures, the latter showing a large diurnal range. The winds are north-easterly, and very constant both in direction and force. The atmosphere is extremely dry.

For the remainder of the year, during the so-called rainy season, the prevailing winds are southerly, and with the change of direction humidity increases perceptibly, the temperature falls and a slight rainfall is experienced.

The meteorological observations taken at the Central Research Farm have for their object the elucidation of the relation existing between climate and crop.

Temperature.—Except where otherwise stated, the instruments have been housed in a double-louvred screen similar to the type used throughout Egypt. The thermometers were supplied by the Egyptian Survey Department, and are of standard pattern. The readings are therefore comparable with records taken at other stations in Egypt and the Sudan.

To permit of comparison between cultivated areas and the surrounding desert, the official readings from Khartoum are also given. The latter represent extremely arid conditions, for the screen is surrounded on three sides by desert. On the fourth side, a small garden intervenes between the screen and the river, which is distant about 900 metres. The Blue Nile and three miles of desert separate the two stations.

Temperature Readings.

Month.	Farm Screen. Mean Maximum.	Farm Screen. Mean Minimum.	Farm Screen. Absolute Maximum.	Farm Screen. Absolute Minimum.	Gordon College Screen. Mean Maximum.	Gordon College Screen. Mean Minimum.	Gordon College Screen. Absolute Maximum.	Gordon College Screen. Absolute Minimum.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1912.								
July	101·5	80·0	105·0	70·0	103	80·0	108·0	74·2
August	95·2	80·8	101·6	72·5	99	77·0	105·0	69·0
September	98·6	80·0	103·0	73·5	103	78·0	107·0	70·0
October	96·5	76·0	102·2	70·0	101	74·2	107·5	70·4
November	91·2	69·8	96·8	65·8	96	69·0	99·0	65·0
December	85·0	61·0	97·0	49·0	85	60·2	96·0	49·0
1913.								
January	87·7	56·9	93·5	49·0	87	58·0	93·0	49·0
February	88·5	58·6	98·5	50·0	88	59·0	103·0	50·0
March	89·3	59·8	100·0	49·5	91	60·0	102·0	49·5
April	99·6	70·5	106·0	62·0	104	73·0	109·0	62·0
May	105·1	68·5	110·0	61·0	106	78·0	112·0	65·5
June	103·5	66·4	110·0	62·0	105	71·0	112·0	66·0
July	103·0	69·6	107·0	65·0	104	79·0	108·0	67·0
August	99·2	64·5	103·0	64·0	102	71·0	106·0	67·0
September	102·1	69·4	106·0	68·0	104	79·0	109·0	70·0
October	102·0	76·5	112·0	60·0	102	76·0	108·5	65·0
November	91·8	60·7	97·0	56·0	91	66·0	98·0	51·5
December	84·2	57·4	103·0	45·0	84	58·0	102·0	46·0
1914.								
January	90·0	60·0	98·4	53·5	90·5	62·0	98·0	53·0
February	91·5	56·2	103·0	50·0	90	59·4	103·0	49·5
March	98·8	65·7	110·0	55·0	98	68·0	111·0	54·0

Temperature Readings—*continued.*

Month.	Farm Screen.				Gordon College Screen.			
	Mean Maximum.	Mean Minimum.	Absolute Maximum.	Absolute Minimum.	Mean Maximum.	Mean Minimum.	Absolute Maximum.	Absolute Minimum.
1914.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
April	101·0	67·8	112·0	61·4	101	70·5	112·5	62·0
May	105·8	77·0	110·0	68·0	107	78·4	114·0	69·0
June	107·0	78·0	110·0	71·5	109	80·0	115·0	73·0
July	100·4	73·0	104·0	68·0	102	71·7	107·0	69·0
August	94·0	74·0	104·0	68·0	96	75·3	105·0	69·0
September	100·0	74·0	104·0	67·5	102·5	77·4	108·0	69·0
October	100·0	70·0	103·0	65·0	102·5	74·0	107·0	67·0
November	95·0	68·0	102·0	61·0	93	69·0	103·8	62·0
December	89·0	63·0	95·0	52·0	89	62·0	98·5	53·0
1915.								
January	88·0	60·0	101·5	48·0	91·0	61·0	102·0	50·0
February	92·0	62·0	100·0	58·0	92·4	62·5	103·8	56·5
March	96·0	65·0	106·0	56·0	96·0	66·0	109·5	56·0
April	105·0	70·0	108·5	61·0	103·2	72·0	111·2	63·4
May	107·0	74·5	112·0	68·0				

The one outstanding and important feature of the above tables is the reduction in temperature obtained by the irrigation of even such a small area as the Central Research Farm. It will be noted that this reduction is most pronounced during the period when it is most desirable, *i.e.*, the summer months. There are few areas in the world where work is being carried on amid such trying conditions as in the Northern Sudan. A glance at the following tables will show that in the cotton-growing districts of both America and Egypt the climate is much more favourable to continuous effort than in the arid plains of the Northern Sudan.

Mean Monthly and Annual Temperature, 1912.

Month.	Khartoum.	Alexandria.	Cairo.	San Antonia Texas.	Montgomery Alabama.	Yuma Arizona
	°F.	°F.	°F.	°F.	°F.	°F.
January ...	70	58·8	55	51·5	48·3	54·1
February ...	73	59·4	58·5	55·8	52·7	58·8
March	79	62·1	63·1	61·9	57·0	64·5
April	81	65·8	70·3	70·1	65·4	69·8
May	92	70·7	75·2	74·9	72·8	77·2
June	93	75·6	81·0	80·7	79·4	84·9
July	89	80·1	84·0	83·3	81·5	91·5
August	86	79·9	82·4	82·2	79·8	90·7
September ...	88	76·5	77·2	77·5	75·6	84·4
October ...	87	73·2	73·9	69·7	65·2	73·0
November ...	82	68·9	65·1	59·1	55·2	61·9
December ...	72	62·6	58·3	54·9	49·6	56·0
Year	83	70·3	68·5	68·5	65·2	72·2

It is obvious that with an extension of the cultivated land, still further reductions in mean temperature would be obtained, the benefit of which would be reaped, not only in improved conditions of living, but also in larger and finer yields from the crops.

Solar Radiation.—The temperature of the soil is almost entirely due to the radiant heat emanating from the sun, the measurement of which is impossible by means of the ordinary thermometer, as the bright bulb possesses little absorptive power, and losses of heat are inevitable from conduction and convection induced by air currents. A special instrument, therefore, is necessary for the measurement of solar radiation consisting of a sensitive maximum thermometer having the bulb and a portion of the stem coated with lampblack, the whole being enclosed in a glass tube from which all air and moisture have been removed. The following record serves to show the intensity of the solar rays in the Northern Sudan :—

Solar Radiation : 1913 and 1914.

	1913.	1914.
	°F.	°F.
January	145·3	154·6
February	151·8	154·0
March	154·5	164·0
April	165·6	167·6
May	168·7	—
June	167·4	—
July	163·0	—
August	164·6	—
September	163·8	—
October	165·1	—
November	153·8	—
December	149·4	—

The Temperature of the Soil.—Observations taken on the temperature of the soil have been somewhat fragmentary, owing to pressure of other work, but conditions are on the whole so uniform that the means taken over a series of years would probably not differ greatly from those given below.

As a starting point, a series of records were taken in June, 1912, at 12 noon each day, from an area which had not been irrigated for four or five months. The soil contained on the average 15 per cent. of water at the depth of a metre, while the upper layers were air dry (3 to 5 per cent. water).

The means of the whole series are given in the following table :—

Soil Temperatures : Unirrigated Soil.

Date: June, 1912. Time: 12 noon. Average air temperature: 100·5 °F.

Depth.	Soil Temperature.
	°F.
2 inches	135
5 inches	107
18 inches	98·6
30 inches	95

The absorptive power of a soil depends largely on the colour, and a dark soil absorbs practically all the incident energy, reflecting very little. The nature of the farm soils will be described later, but it may be stated in explanation of the high temperatures recorded that the soils are without exception very dark in colour, and that this colour is due not to humus but to the presence of ferric oxides.

Subsoil temperatures were taken during the ensuing months and are given below ; the corresponding observations on the upper layers will be recorded when considering the influence of irrigation.

Subsoil Temperatures : Dry Unirrigated Soil.

Monthly Means. Time : 8 a.m.

Month.	50 c.m.	75 c.m.	1 metre.
	°F.	°F.	°F.
June	95·2	94·5	91
July	96	95·1	93·2
August	94	94·2	93
September	92·5	92·5	90·5
October	86·5	89	90
November	78	79	81

When it is realised that the optimum temperature for both the bacteria of the soil and the cotton plant lies about 86 deg. F., the importance of irrigation in maintaining a suitable soil temperature becomes obvious.

The Nile temperature at Khartoum varies between about 65 deg. F. and 82 deg. F., and by the time the water has reached its destination it is a few degrees higher. In June the temperature of the irrigation water was 86 deg. F., in November 75 deg. F.

The result, as will be seen from the accompanying tables, is that in soils under cultivation and irrigation, the optimum temperature is just about realised during the periods of most active growth, *i.e.*, July to the middle of October. (See Growth Curves, Report III.)

Effect of Irrigation on Temperature of the Soil.—The following figures may be taken as representative of the whole of the experimental area of the farm. Very little variation was found between similarly treated areas, except where the texture of the soil was obviously abnormal.

Irrigated Soils : Temperature of Surface.

Date.	Irrigated.	Dry.	Notes.
1912.	°F.	°F.	
July 1st	84·2	95·0	Air temperature 86·0 °F.
July 27th	82·4	100·4	Air temperature 93·2. Nile temperature 80·6. Irrigation water 86·0.
August 3rd	79·0	83·0	Rain night before.
August 23rd	80·0	89·6	Air 84·2. Cloudy weather.
September 10th	89·6	105·8	Air 93·2.
September 16th	89·6	109·4	Air 98·6.
October 20th	82·4	116·6	Air 98·6.
November 26th	77·5	97·0	Air 89·6. Irrigation water 75·2.

The cooling effect of the rains in August should be noted. The heaviest shower rarely penetrates below 25 cm., but a result is produced for a few days similar to winter conditions, *i.e.*, the surface layers are cooler than the subsoil.

The protective influence of the first 2 inches of soil is instructive as showing the safeguard provided by Nature for the germinating seed against the injurious effects of overheating.

Irrigated Soils : Temperature of Surface Layers.

Date.	Air Temperature.	Surface.	2 inches.	4 inches.	Date of Irrigation.
	°F.	°F.	°F.	°F.	
July 1st	86·0	—	—	84·2	June 29th.
July 15th	87·8	—	86·0	84·2	July 8th.
July 16th	87·8	—	86·0	—	July 9th.
July 23rd	93·2	108·0	96·8	86	July 16th.
July 27th	93·2	86·0	82·4	78·8	July 24th.
August 3rd	77·5	82·4	78·8	75·5	Rain.
August 6th	89·6	84·2	86·0	87·0	Rain.
August 8th	82·4	84·2	87·8	87·0	Rain.
August 12th... ...	—	86·0	83·0	84·2	Rain.

Irrigated Soils : Temperature of Surface Layers—*continued.*

Date.	Air Temperature.	Surface.	2 inches.	4 inches.	Date of Irrigation.
	°F.	°F.	°F.	°F.	
August 17th... ...	89·6	88·0	85·0	85·0	Rain.
August 23rd... ...	83·0	83·0	80·6	80·6	Rain.
August 30th... ...	96·6	87·8	82·4	81·0	August 25th.
September 10th ...	93·2	100·4	89·6	82·4	September 8th
September 16th ...	98·6	96·8	89·6	82·4	September 2nd
October 20th ...	98·6	96·8	89·6	89·6	October 13th.
November 26th ...	89·6	82·4	78·0	75·2	
February 26th ...	91·4	93·2	86·5	86·0	

As might be expected, the daily range of temperature in the surface layers of the soil is very great. Owing to the absence of clouds, and to the small amount of aqueous vapour in the atmosphere, the heating of the soil after sunrise, and the cooling due to radiation after sunset, rapidly proceed to a maximum. Some idea of the strain imposed on the heat-regulating centres of the plant during the interval of a few hours will be gathered from the following data :—

Irrigated Soils : Diurnal Variations.

Date.	Time.	Soil Temperature. (1st 3 inches).
		°F.
July 27, 1913	7.30 a.m.	77·5
	12 a.m.	95·0
	5.30 p.m.	87·8
August 11, 1913	8 a.m.	77·0
	12 a.m.	98·6
	8 p.m.	81·0
October 5, 1913	10 a.m.	87·0
	5 p.m.	100·0

Accidents unfortunately robbed us of the soil thermometers, one after the other, so that the records are very incomplete.

The results are, however, sufficient to indicate the nature of conditions at the depths stated, and the influence of irrigation in limiting fluctuation throughout the season.

Evaporation.—The study of evaporation is beset with difficulties. No instruments have yet been devised by which the influence of temperature, air movements, air pressure and humidity may be analytically estimated.

The simplest and most effective plan is to measure the combined effect as expressed by the evaporating power of the air with a standard instrument, which, in spite of many shortcomings, may at least be employed to give comparative results when exposed to different physical conditions.

The instrument used throughout this work has been the Piché Evaporimeter, carrying papers with an effective evaporating surface of 11·2 square millimetres. All the instruments were standardised one with another, but no deductions can be drawn from the readings as to the evaporation from a free water surface. In order that comparison may be made with the Wild Evaporimeter, the figures should be multiplied by the factor 0·7.

At both screens tubes were placed inside, where they were sheltered from the direct heating effect of the sun, and also outside, where full exposure was obtained to sun and wind. Obssrvations were read at 8 a.m.

It is unfortunate that there are not more data available from other countries, as the excessive evaporation at Khartoum would thus be more strongly emphasised. In explanation of the following comparative table it may be explained that the low readings recorded at Cairo are largely due to the influence of the cultivated land of the Delta, while Gambeila and Mongalla lie in the southern portion of the Sudan, and enjoy a much greater rainfall than the regions around Khartoum.

Evaporation as Recorded at certain Agricultural Centres : Millimetres per 24 hours, Piché Evaporimeter.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Notes.
Farm screen ...	13·4	16	—	—	26·5	23·2	18·6	11·1	13·3	15·9	16·4	13·7	1914 means. Inside screen.
	18	21	—	—	29·9	28	24·3	15·6	16·5	20	20	18	1914 means. Outside screen
Desert screen at farm	13·4	17·4	—	—	27·8	26·3	20·7	12	14	16·2	16	13·7	1914 means. Inside screen.
	16·4	21·7	—	—	30·2	29·4	25·1	15·2	18·5	—	—	—	1914 means. Outside screen
Gordon College ...	14·4	16·5	20·8	23·9	21·3	17·9	14·35	10·2	12·4	15·4	16	13·7	1914 means.
Farm screen ...	13·9	19·5	21·3	22·5	25	—	—	—	—	—	—	—	1915 means. Inside screen.
	16·5	20·8	23	25·1	26·6	—	—	—	—	—	—	—	1915 means. Outside screen
Desert screen ...	14·2	17·2	19·4	22	24·4	—	—	—	—	—	—	—	1915 means.
Gordon College ...	13·5	16·2	18·3	22·3	21·4	—	—	—	—	—	—	—	1915 means.
Cairo	2·49	3·22	3·9	5·02	6·52	6·73	6·11	4·98	4·03	3·4	2·73	1·94	1912 means.
Gambeila (Sudan)	—	12·01	13·22	13·14	7·66	4·72	2·93	3·11	3·66	4·83	6·43	6·76	1912 means.
Mongalla (Sudan) ·	10·47	9·58	10·0	8·15	5·63	3·83	3·10	2·9	3·3	3·71	4·42	6·06	1912 means.
Montsouris(France)	1·92	2·42	4·48	5·4	6·1	5·5	6·0	5·5	3·6	2·37	2·18	1·5	1873–1885 means.

Wind and Evaporation.—It has not been possible with the instruments at hand to determine mathematically the relation existing between evaporation and other meteorological factors, but by means of a home-made anemometer in which the wind pressure was transmitted to a pen making a vertical stroke on a revolving drum, the intensity and the distribution was obtained daily over a period of two months. Daily records of temperature and evaporation were taken by instruments placed near anemometer.

Considerations of space forbid that the entire series of readings should be given, but representative readings have been chosen, showing that although temperature does exert an influence, the part played by the wind is relatively important.

Date.	Evaporation.	Max. Temp.	Wind at 8 a.m.	Date.	Evaporation.	Max. Temp.	Wind at 8 a.m.
	mm.	° F.			mm.	° F.	
Dec. 15* ...	13·0	80	3	Jan. 10†...	11·7	—	2
,, 16 ...	13·8	76	3	,, 11†...	11·9	81	2
,, 17* ...	14·4	75	3·5	,, 12†...	11·2	82	2
,, 18* ...	13·8	75	3	,, 13*...	12·6	82	3
,, 19† ...	13·4	80	3	,, 14*...	13·8	87	2·5
,, 20* ...	12·4	80	2·5	,, 15*...	12·1	82	3
,, 21† ...	15·8	76	4	,, 16 ...	15·4	78	4
Jan. 19 ...	12·0	92	1				
,, 20† ...	11·9	95	1·5				
,, 21* ...	11·4	92	2				
,, 22* ...	13·8	102	3				
,, 23* ...	15·4	100	4				
,, 24† ...	17·2	99	3				

The wind force was observed on the Beaufort Scale at 8 a.m. only, the strength being obtained for the remainder of the day from the anemometer.

* Wind throughout 24 hours.

† Calm in afternoon.

It will be seen that, although the evaporation is greater as the temperature increases, the variations from day to day are due to the strength and duration of the air movements.

As a rule the daily curve of evaporation is steepest from 8 a.m. till 2 p.m., although should the wind retain its force throughout the day, evaporation continues at a correspondingly high rate.

Evaporation from Free Water Surface.—The readings of the Piché Evaporimeter are mainly of use for comparative purposes, as they furnish no evidence as to the amount of evaporation from a free water surface. It is obvious, however, that the water requirements of the crop, and the losses of irrigation water by evaporation, will vary directly with the readings of the instrument.

By the courtesy of the Egyptian Irrigation Service we are able to reproduce the readings from a tank evaporimeter placed in the stream of the White Nile some 100 metres above its junction with the Blue Nile.

Evaporation from Free Water Surface.

Daily Means in Millimetres.

Month.	1913.	1914.	1915.
January	6·96	8·4	8·7
February	8·2	8·2	8·7
March	9·6	10·3	9·5
April	12·1	11·09	11·09
May	13·04	13·6	—
June	14·64	12·6	—
July	12·05	No record	—
August	9·3	,,	—
September	9·6	,,	—
October	11·1	,,	—
November	9·6	,,	—
December	7·5	8·9	—

It will be seen that there is little relationship between the two series of readings, in fact, the tank readings are barely half those of the Piché. It must be remembered that the latter instrument is very much affected by wind, for the evaporating surface is small, and is surrounded by an atmosphere which is greedy for moisture, whereas the tank is surrounded on all sides by a water surface, the atmosphere above which is highly charged with water vapour, and consequently possesses a much smaller evaporating power.

A point of considerable interest to the agriculturist is that evaporation is at its highest when the river is at its lowest; consequently the demand for water set up by the crops and the cost of pumping are at a maximum during the same period. This fact will largely determine the nature and the scope of agricultural effort, for the crop must be so chosen, that, *ceteris paribus*, its period of greatest water requirement coincides with the time when the cost of pumping is as near a minimum as possible.

Influence of Vegetation on Evaporation.—The influence of vegetation on evaporation is well recognised, and little need be said in explanation of the accompanying diagram beyond a description of the general arrangement of the instruments in the experiment it is intended to illustrate.

The position of the evaporimeters at the farm and the desert screens has already been indicated. A third Piché Evaporimeter was placed on the south side of a patch of wheat, one metre from the ground, exposed to sun and wind.

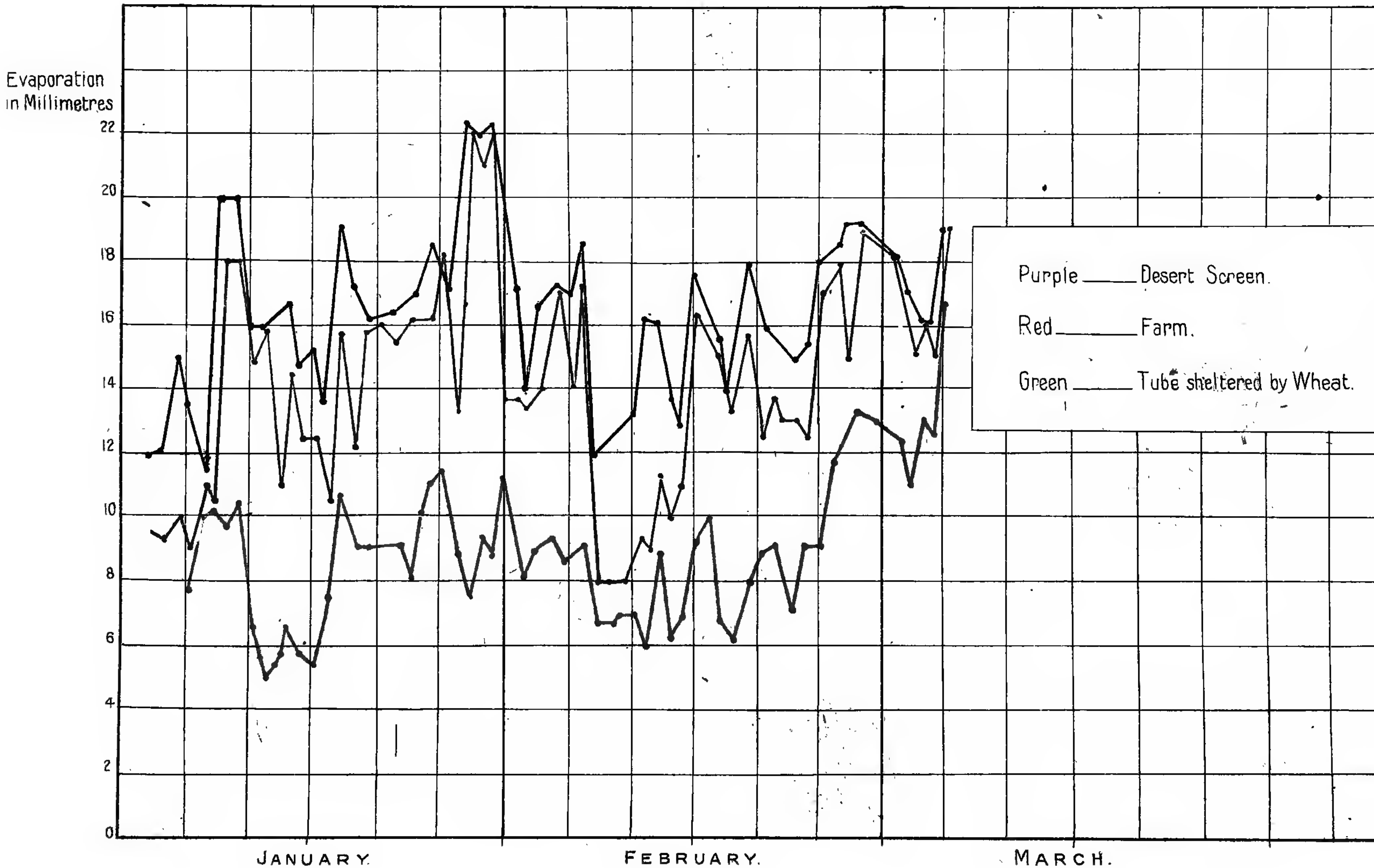
At this period of the year the wind blows constantly from the north, so that the air which impinged on the evaporating disc of the instrument had first passed over an area covered with transpiring plants. As will be seen the effect was very marked, and gives some idea of the reduction in evaporation which would take place, were any extensive agricultural operations undertaken in this region.

Evaporation and the Movement of Water in the Soil.—The most convincing proof of the difficulties attendant on a study of the evaporation of water from the soil is that very few figures exist which can be quoted with any degree of reliability.

Numerous determinations have been made during the past three years of the moisture content of the farm soils, but the figures do not readily lend themselves to an accurate estimation of the losses due to evaporation from the soil alone. In some cases the plots were under cultivation, so that much of the loss of water was due to the transpiring plants of the crop. The figures, however, will serve to indicate some of the changes in water content which occur during the season in cultivated soil similar to that of the farm.

In June, 1912, sixty-three moisture determinations were made over an area of fifty-five feddans, the samples being taken from depths of 15 cm., 45 cm. and 75 cm. The whole of the ground had lain fallow for several months, during the hottest and driest part of the year.

Influence of Crop on Evaporation.



Little variation was found amongst the samples, so that the averages of readings will suffice.

For the purposes of comparison, samples were taken from the adjacent desert soil, the moisture content of which was entirely dependent on the movement of water from the subsoil.

Moisture Content of Farm and Desert Soils.

I. Farm Land Fallow for 4 Months.		II. Desert Soil.	
cm.	%	cm.	%
15	3·5	10	3·5
45	9·3	50	4·8
75	13·5	100	13·5

Shortly after these determinations were made, the farm soil was cultivated and sown with cotton. Three grades of irrigation were employed—(*a*) Heavy : 500 cubic metres every ten days. (*b*) Medium : 400 cubic metres every fifteen days. (*c*) Light : 300 cubic metres every twenty days.

Samples of soil were taken from time to time, and the water content estimated.

Irrigation was stopped at the end of February, so that by the time the last determination was made, desiccation due to evaporation was well marked.

Variations in Water Content of Irrigated Soils.

Date.	10 cm.	50 cm.	100 cm.	200 cm.	Notes.
	%	%	%	%	
December 7th	29·6	25·4	24·4	28	Heavy watering.
January 18th	24·4	20·0	23·4	27·4	
February 28th	20·8	23	26	23	
April 20th	8·4	14	17	15·2	
December 7th	24	21·6	20	23·4	Medium watering.
January 20th	26·6	27	25·4	26·4	
March 2nd	13·6	16·2	19·2	22	
April 20th	8·0	13·0	12·4	16	

Variations in Water Content of Irrigated Soils—*continued.*

Date.	10 cm.	50 cm.	100 cm.	200 cm.	Notes.
	%	%	%	%	
December 6th	19	17·4	18·4	25	Light watering.
January 22nd	15	25	25·8	26	
March 4th	14·2	16·6	17·2	20·4	
April 20th	5·3	8·0	13·5	14·5	

It will be seen that without constant irrigation the soils rapidly revert to desert conditions.

It may be pointed out that it is to the high rate of evaporation that both the comparatively low temperatures of irrigated soils and the consequent possibility of their economic cultivation are largely due.

Interesting light was thrown on the movements of subsoil water by an examination of Tuti Island soils,* and the desert soils near the farm.

Moisture Contents of Tuti Island and Desert Soils.

Tuti Island. Cultivated Soils (Fallow).		Tuti Island. Outside Cultivated Area.	Desert Soil. Outside Farm.
cm.	%	%	%
10	5·3	8·0	3·5
50	8·0	9·8	4·8
100	13·5	17·0	13·5
200	14·5	17·6	23·7
300	32·5	22·8	24·8

In the case of the Tuti Island soils it was found that at a depth of 3 metres and below the moisture content was surprisingly high. It will be seen later that these soils are much sandier and lighter in texture than the experimental plots of the farm. A definite connection between the water table and the upper layers exists, as the open nature permits of free movement of water by capillarity.

* The inclusion of Tuti Island, with an area of approximately 500 feddans, lying at the junction of the White and Blue Niles, in the scheme for the irrigation of native-owned lands, has rendered necessary a detailed examination of the conditions obtaining there, and a useful basis of comparison has been thus established.

The surface of the soil is, moreover, covered with a thick mulch of wind-borne sand, which, being air dry, serves as an effective barrier against the loss of subsoil water by evaporation. Hence the relatively high water content in the intermediate layers.

The level of the water in the wells around the farm naturally varies with the state of the river, but the water table has not been known to rise higher than 5 metres from the surface of the ground during the last three years.

The rate and amount of the rise varies with the distance of the well from the river, and the permeability of the intervening soil, but the maximum height is always attained some time after the Nile flood has reached its highest point. Indeed the water level in unused wells is often higher than the river, when the latter has begun to subside.

Humidity.—As the influences of the humidity factor is most clearly demonstrated by the character of crop growth, little comment is called for at this point. Graphs showing the daily variations of the relative humidity throughout the year will be given when considering the physiology of the cotton plant.

It will be sufficient to point out that for nine months in the year the relative humidity is very low, and that only during the months of July, August and September does the percentage of moisture in the atmosphere attain to that degree usually associated with agriculture in the tropics.

The great variability from day to day is also remarkable for, although this phenomenon also exists in Egypt, it is not found in the cotton-growing districts of the United States.

Wind and Rainfall.—Owing to the extreme flatness of the vast expanse of the Sahara Desert, and its slight elevation, very little disturbing influence is imposed on the general atmospheric movements. The result is that the prevailing winds are very regular in direction and strength.

A definite monsoon effect is experienced over the Central and Northern Sudan during the months of June, July, August, September and part of October, during which time the southerly trade winds, deflected into a south-westerly direction by the rotation of the earth, bring in their train a greatly increased humidity, and, in these latitudes, a light rainfall. For the rest of the year the north-easterly trade winds blow without interruption, and are remarkably constant in strength.

Khartoum lies on the extreme edge of a rainbelt whose precipitation decreases as one proceeds north from the equator, and as there are no elevated areas to influence the regularity of this decrease, the rainfall becomes a negligible factor so far as agriculture is concerned.

The mean yearly rainfall for a period of seven years is given as 107 mm. by Captain Lyons in his "Physiography of the Nile Basin."

As a rule the rainfall is associated with severe heat, thunderstorms and high wind ; in fact, the phenomenon has all the appearances of a small cyclone. Occasionally the rain may continue for some hours, but generally the showers are of short duration.

Exposure.—The exposed position of the farm has accentuated the influence of desiccating winds and driven sands from the adjacent desert. A remedy is being sought by the formation of wind breaks in the shape of hedges and belts of trees. Their influence in mitigating the climatic extremes within the enclosed area is both mechanical and physiological, for not only do they break the force of the wind and check the sand drift, but the relative humidity of the atmosphere is increased and evaporation lessened by the transpiration of water vapour from the foliage.

SECTION II.

The Soils of the Central Research Farm.

In the present section a brief account will be given of the main features of the farm soils. Two distinct areas are involved, representing different geological formations, with a corresponding variation in composition and texture.

The experimental plots of the farm are situated on the right bank of the river, and are of ancient alluvial origin. The soil consists of a loam containing a rather high percentage of clay. The texture is close, and the penetration of water slow. Considerable shrinkage occurs on drying, and large cracks are formed which in some cases extend to a considerable depth.

This area is representative of the sakia lands throughout Khartoum and Berber Provinces.

Tuti Island soil is of much more recent origin, and similar formations may be seen in the making every year, whenever for any reason a slackening of the current of the river occurs, with the consequent deposition of silt.

The surface layers are mainly wind-borne from the desert behind, and contain a large percentage of sand, in consequence of which the texture is much more open, and little cracking occurs on drying.

This type constitutes the most fertile soil in the Sudan, for not only is it naturally rich in soluble salts, but the formation of nitrates is vigorous, so that both the quality and the quantity of the crop exceed that obtained on the older soil.

Mechanical Analyses of Farm Soils, 1912.

		Coarse Sand.	Fine Sand.	Silt.	Clay.
		%	%	%	%
Sample I.	1st foot	4·3	30·6	16·5	48·6
	2nd foot	4·8	30·2	18·2	46·8
	3rd foot	5·3	32·1	20·1	42·5
	4th foot	5·4	22·6	24·1	47·8
Sample II.	1st foot	5·0	30·3	18·1	46·6
	2nd foot	3·3	29·3	19·8	47·6
	3rd foot	2·6	25·4	22·6	49·4
Sample III.	1st foot	7·9	29·1	18·6	44·4
	2nd foot	7·4	27·3	18·9	46·4
	3rd foot	5·2	23·0	21·6	50·2

The mean of twelve analyses of the surface (first foot) soils worked out as follows :—

6·5	30·3	18·4	43·6

from which it will be seen that great uniformity obtains throughout the whole area.

Chemical Analyses of Farm Soils, 1912: First Foot only.

	P_2O_5.	K_2O.	N.	Humus.
	%	%	%	%
Sample I.	0·23	0·6	0·026	0·39
Sample II.	0·27	0·67	0·027	0·45
Sample III.	0·24	0·60	0·025	0·44
Mean of 12 samples	0·24	0·63	0·025	0·42

The above analyses were made in March, 1912. After three years of continuous cultivation, an analysis was made of a typical plot in order to ascertain whether any change had been affected in the principal chemical constituents of the soil.

Chemical Analyses of Cultivated Farm Soils, 1915.

	$CaCO_3$.	P_2O_5.	K_2O.	N.	Humus.	Gypsum.
	%	%	%	%	%	%
1st foot	2·3	0·20	0·62	0·032	0·50	0·01
2nd foot	1·8	0·24	0·64	0·031	0·15	0·06

The appreciable gain in nitrogen and humus content is the more noteworthy in view of the fact that the plot from which the figures were obtained had borne a heavy crop of cotton, and the nitrogen content would naturally be at a minimum.

Tuti Island soils are, as stated, much lighter in texture; samples were taken at different points and mixed together, as no apparent difference in texture occurs within the cultivated area.

Mechanical Analyses of Tuti Soils, 1915.

	Coarse Sand.	Fine Sand.	Silt.	Clay.
	%	%	%	%
1st foot	5·8	64·1	13·7	16·4
2nd foot	5·3	59·9	14·9	19·9
3rd foot	5·7	46·0	18·6	29·7

Chemical Analyses of Tuti Soils, 1915.

	$CaCO_3$.	P_2O_5.	K_2O.	N.	Humus.	Gypsum.
	%	%	%	%	%	%
1st foot	1·3	0·14	0·67	0·029	0·40	0·24
2nd foot	1·6	0·17	0·60	0·027	0·12	0·03

It is an interesting fact that in spite of the increase in sand, there is no obvious diminution in food supply.

The term desert is purely relative, for any change effected by cultivation is of a very temporary nature, as it for the most part consists in an improvement in the texture and biologic conditions of the soil. A sample taken from an area outside the farm, which, as far as is known, has never been cultivated, gave the following figures on analysis.

Desert Soil: Mechanical Analysis.

	Coarse Sand.	Fine Sand.	Silt.	Clay.
	%	%	%	%
1st foot	12	39·9	19·8	28·3
2nd foot	4·3	73·7	15·5	6·5
3rd foot	2·3	74·5	9·3	13·9

Desert Soil: Chemical Analysis.

	$CaCO_3$.	P_2O_5.	K_2O.	N.	Humus.	Gypsum.
	%	%	%	%	%	%
1st foot	3·4	0·21	0·67	0·021	0·35	·06
2nd foot	4·5	0·21	0·69	0·071	0·05	0·12

When these figures are compared with previous analyses, it will be seen that in spite of the increased proportion of sand, the only notable difference occurs in the nitrogen content at a depth of from 1 to 2 feet. It is a surprising fact that in the first foot of depth it is as high as in the cultivated soils. This is borne out in agricultural practice by the exceptionally good crops of wheat obtained from virgin desert soils.

Physical Properties of the Soil.—Owing to the inadequacy of the methods of investigation at present available, little account can be given of the physical properties of the soil. It is probable that in many cases they are of even more importance than the chemical composition, since the vital processes which determine the food supply of the plant are greatly influenced by the texture of the soil. The following notes reflect such enquiries as have been possible with the means at our immediate disposal.

Capacity of the Soil for Water Retention.—A number of wire baskets were made, each holding about 400 grams of soil. These were lined with filter paper and packed with samples of soil which had been dried in the sun and afterwards in an oven at 120 deg. C. for one hour.

The baskets containing the soil were then placed in river water for twenty-four hours, after which they were well drained in an enclosed space to prevent evaporation, and weighed.

No great differences were found, and the means only of the observations are given.

Depth.	Percentage of Water in Saturated Soil.
10 cm.	35·3
50 cm.	35·9
1 metre	34·5
2 metres	37·4
3 metres	38·9

Hall * gives 33·5 per cent. for "Light Loam," and 49·6 per cent. for "Stiff Clay" when saturated.

The upper layers contain more sand than the subsoil, being largely wind-borne particles from the adjacent desert.

Penetration of Water through the Soils.—It has already been stated that the heaviest rain never penetrates locally below 25 cm., and that the soils are naturally very impermeable.

It has also been shown that the water table is below the limits generally reached by the roots of plants, so that the phenomenon of asphyxiation is not likely to occur unless the water supplied by irrigation accumulates in the subsoil and forms an artificial water table.

In order to ascertain to what depth the irrigation water penetrated in the farm soils, a series of borings were made at different intervals in the "Duty of Water" experiment. This experiment possessed the advantage that both quantity of water and the distribution was known. After the land had been prepared for cultivation, but before any water had been added, the water content of the soil at different depths was as follows :—

cm.	%
10	5·3
50	8·0
100	13·5
200	14·5
300	11·0

Determinations were made in every case by heating at 120 deg. C. for one hour in an oven.

After six months, during which period irrigation was continuous, samples were taken at intervals and the water content again estimated.

* "The Soil."

Series I. 500 cubic metres of water per feddan every 10 days.

Depth.	Dec. 6th.	Jan. 18th.	Jan. 24th.	Feb. 28th.
cm.	%	%	%	%
10	29·6	24·4	23·4	20·8
50	25·4	19	17·8	23
100	24·4	23·4	22·8	26
200	28·0	27·4	24·2	23
300	22·6	27·6	26·8	19·8

Series II. 500 cubic metres of water per feddan every 15 days.

Depth.	Dec. 7th.	Jan. 20th.	Jan. 27th.	Mar. 2nd.
cm.	%	%	%	%
10	24·0	26·6	21·6	13·6
50	21·6	27·0	23·0	16·2
100	20·0	25·4	22·0	19·2
200	23·4	26·4	25·4	22·0
300	17·0	18·6	18·0	16·0

Series III. 500 cubic metres of water per feddan every 20 days.

Depth.	Dec. 15th.	Jan. 23rd.	Mar. 5th.
cm.	%	%	%
10	20·0	20·2	15·8
50	—	27·0	13·8
100	18·0	28·8	16·4
200	23·4	28·4	21·4
300	23·6	25·0	22·0

For various reasons irrigation was stopped in February, so that by the time the last set of samples was taken evaporation had commenced to rob the soil of some of its water.

The ground then lay fallow for two months, after which further determinations were made. The results obtained were so similar that only the means of the whole are given.

Depth. cm.	April 30th. %
10	8·4
50	12·0
100	14·0
200	13·5
300	11·0

From the above and many other similar determinations the following deductions were drawn :—

(*a*) That water penetrates readily to a depth of 3 metres, but further penetration is slow.

(*b*) That water tends to accumulate at about 2 metres.

(*c*) That water is rapidly withdrawn from the subsoil by capillarity when irrigation ceases.

(*d*) That deep cultivation hastens the drying of the soil by evaporation.

(*e*) That the heavier waterings produce a greater effect in the subsoil than the surface soil, and that the excess penetrates to greater depth.

Very few observations have been made at Tuti, but there is reason to believe that conditions are very different to the above.

The mean moisture content of the uncultivated soil of the island in March, 1915, was as follows :—

Depth. cm.	%
10	3·5
50	4·8
100	13·5
200	14·5
300	22·8

Samples were taken at the same time from—

(*a*) An area which had been cultivated some eight months previously and had since lain fallow, and

(*b*) An area recently under cotton with light irrigation.

All three samples were similar in texture, and serve to show how remarkably effective a sandy surface soil is in limiting the loss of water from the deeper layers by evaporation.

Moisture Contents of Tuti Island Soils.

	(A) Eight Months Fallow.	(B) Two Months Fallow.
cm.	%	%
10	5·3	8
50	8	9·8
100	13·5	17·0
200	18·2	17·6
300	24·8	32·5

Influence of Cultural Methods on Penetration of Water.—To ascertain the increase in penetrability secured by different methods of cultivation, the following procedure was adopted. A series of glass tubes, 1 metre in length, and 1 cm. in diameter, were fitted with funnels at the upper extremity. The tubes were filled with air-dried and sifted earth, and fixed in a vertical frame. The funnels were then filled with distilled water, and the penetration of the latter noted daily.

The cultural details of the plots from which the samples were taken are as follows :—

Sample I. Ploughed only.

II. A heavy crop of lubia bean ploughed under some months before.

III. Ten tons of stable manure added two months previously.

IV. This plot had been subjected to a prolonged washing by repeated floodings.

V. A crop of lubia ploughed under immediately prior to the investigation.

VI. The soil of this plot which had received normal cultivation was extremely bad ; cotton, wheat and lubia either having grown feebly or failed completely.

Daily observations were made for forty-eight days, but the readings taken on the twentieth day will answer the present purpose.

Penetration after 20 Days.

Sample I.	Sample II.	Sample III.	Sample IV.	Sample V.	Sample VI.
cm. 47	cm. 69·4	cm. 100	cm. 100	cm. 82	cm. 17

The influence of organic matter in improving the texture is well marked in III. and V. In IV. a considerable amount of flocculation had been caused by the alkaline irrigation water.

Some explanation is afforded of the sterility of sample VI. The clay in this area (about ½ feddan) is of so close a texture and so impermeable as to be almost prohibitive of crop development.

Distilled water was adopted in the above experiment so that comparison might be made with salt solutions of various composition. Sodium nitrate (7·21 grams per litre) and ammonium sulphate (3·85 grams per litre) were employed in a preliminary experiment. Work on other solutions and combinations of salts will follow. The penetration of a sodium nitrate solution (7·21 grams per litre) is shown below. The same series of samples were employed with the exception of VII., which was of lighter texture comparable to that of the Tuti soils :—

Time Period.	Sample I.	Sample II.	Sample III.	Sample IV.	Sample V.	Sample VII.
	cm.	cm.	cm.	cm.	cm.	cm.
After 4 days	61	56·6	58	47	31·3	100
,, 9 ,, ...	100	91·8	94·3	78·8	49·7	—
,, 10 ,, ...	—	96·9	100	84	52·7	—
,, 11 ,, ...	—	100	—	87·7	56	—
,, 14 ,, ...	—	—	—	100	61·6	—
,, 36 ,, ...	—	—	—	—	100	—

Very similar results were obtained with the ammonium sulphate solution:—

Time Period.	Sample I.	Sample II.	Sample III.	Sample IV.	Sample V.	Sample VII.
	cm.	cm.	cm.	cm.	cm.	cm.
After 5 days	100	65·6	52	33·1	41	100
,, 10 ,, ...	—	100	79·6	52·5	60·7	—
,, 24 ,, ...	—	—	—	88	96	—
,, 25 ,, ...	—	—	—	90	100	—
,, 30 ,, ...	—	—	—	100	—	—

The more rapid penetration of these salt solutions is presumably due to their power of flocculating the clay particles. The practical importance of this question lies in the possible employment of artificial manures and their subsequent distribution through the soil.

Capillarity and Surface Tension.—Of the physical forces which determine the rate of movement of the soil water against gravity, surface tension stands pre-eminent. Reference has been made repeatedly to the relation between the capillary power of a soil and the moisture content, and it has been shown that if the continuity of the water column is broken by the intervention of a layer of loose dry soil, evaporation from the subsoil ceases, or at all events is considerably reduced.

The amount of water retained against gravity depends on the size of the soil particles; when these are small, as in a clay soil, the total surface area is enormously increased, and the water capacity of the soil becomes relatively high.

Since the effects of cultivation are to improve the texture of the soil, a considerable modification in the capillary power of a given area may be expected according to the cultural treatment allotted to it.

In the following experiment the same series of soils was used as when studying penetration. The tubes were, however, immersed at one end in a bath containing distilled water, and the rise of the water noted daily.

Capillary Power of Farm Soils.

Time.	Sample I.	Sample II.	Sample III.	Sample IV.	Sample V.	Sample VI.
	cm.	cm.	cm.	cm.	cm.	cm.
28th day	50	76·8	71	100	72	41·9
50th ,, ...	57·6	85·7	79	—	83	48

The influence of organic matter in improving the texture is again well marked. On the whole, however, the capillary power of these soils is feeble, and explains the rapid desiccation of the surface layers which ensues when irrigation ceases.

Hygroscopic Moisture.—Although subjected to extremely high temperatures and drying winds, the soil always contains a small quantity of water, which can only be driven off by the application of temperatures over 100 deg. C. for a prolonged period of time.

This hygroscopic water, as it is termed, varies in amount according to the size of the component particles, and is naturally highest in clay and fine alluvial soils.

A series of determinations of the moisture content of air-dried soils from the experimental area of the farm gave the following results :—

		%
Moisture content of first 6 inches of soil	... ...	3·9
,, ,, ,, ,,	another sample	4·2
,, ,, ,, ,,	rather sandier	2·9
,, ,, ,, ,,	stiffer clay	5·0
,, ,, ,, ,,	sandy loam	3·5
,, ,, ,, ,,	clay	5·3

Wilting Point.—Hygroscopic moisture is valueless to plant life, and indeed wilting begins when the water content of the soil is far in excess of these figures. Although no estimations of the amount of water vapour transpired have yet been made, it is obvious that in such arid conditions very great demands are made on the root system of all plants, and since the movement of water in these clay soils is slow, it is not surprising that plants begin to wilt when from all appearances the soil still contains a fair quantity of moisture.

The development of the root system of plants is extraordinary in this climate. The tap root of seedlings of such common weeds as Calotropis procera, Senna obovata and Crotalaria senegalensis, has often been traced down to nearly a metre in depth, whilst the root of full-grown plants often penetrates 3 metres and probably more.

It has been found impossible to grow cotton plants in small pots suitable for laboratory experiments on account of the limited space afforded to root development. In pots containing 500 grams of dry soil, cotton seedlings never grew more than 15 cm. high.

Such seedlings, however, grown in sealed wire baskets, under the shade of a verandah, wilted when the moisture content of the soil was between 14 per cent. and 15·5 per cent. Death occurred when moisture content fell to 8 per cent.

All the seedlings placed outside died so soon after germination that no determinations were made, but the wilting point must be higher.

Root limitation is, in the writer's opinion, responsible for much of the straggly stunted cotton that exists on heavy clay soils in the Northern Sudan. Roots that have been dug up from such soils showed little lateral development, and had not penetrated much below a metre.

On lighter soils the cotton is much more luxuriant, and the root system correspondingly well developed.

Salt, Drainage and Attendant Problems.—The experimental area of the Central Research Farm is too small and too isolated to furnish figures with reference to the permanent accumulation of irrigation water, but it has been shown that water tends to accumulate about 2 metres, at which depth serious damage may be inflicted on the cotton plant should saturation occur, or an excess of salts appear.

Conditions favourable to the development of alkali exist in all arid countries. Indeed the extraordinary fertility of some arid soils when irrigated is due to the large percentage of soluble salts which have not been washed into the subsoil by rain. It must be remembered that the water supplied to the land also contains salts in solution which are left behind in the soil as the water evaporates, and even if the excess of the irrigation water should continue to penetrate to depths at which no harm can be done to the crop this water will eventually be brought to the surface, by capillarity, richer than ever in soluble salts, and thus in a short time the surface layers will be rendered unsuitable for agriculture.

The only remedy for this evil is drainage. It has been abundantly proved in India, Africa and the United States that irrigation without adequate drainage must ultimately end in failure.

During the past three years a number of analyses have been made of the salt contained in the farm soils, and also of the drainage water resulting from the irrigation of these soils.

Composition of Irrigation Water.—To permit of logical sequence, an examination was first made of the river water supplied to the farm. The pumping station is situated between three and four miles below the junction of the White and Blue Nile, and so receives water from both sources in a proportion which varies with the time of year.

As might be expected considerable changes in composition occur according to the state of the river, but the most noteworthy feature is the increase in the amount of solid matter held in suspension by the Blue Nile during the period of flood.

In the following table typical analyses are given of the waters of the two rivers. The samples were taken in January when the flood had passed, and also in August when the river was rapidly approaching its maximum height and volume :—

Analyses of Nile Water, 1906.

	Blue Nile.		White Nile.	
	January.	August.	January.	August.
	Parts per million.		Parts per million.	
Solids in suspension	7·9	1964·0	61·5	167·27
Solids in solution	166·10	135·2	191·00	161·8
Free NH_3	—	0·034	—	0·020
Albuminoid NH_3	—	2·256	—	0·345
O absorbed in 10 min. at 100° C.	1·75	56·00	5·49	9·77
NO_3	—	0·707	—	0·285
NO_2	—	Nil	—	Nil
Cl	1·7	1·89	5·48	4·34
So_4	5·06	11·52	Nil	5·43
Co_2	44·93	54·54	56·16	62·21
Ca	16·15	25·82	11·68	21·06
Mg	5·81	7·7	6·43	8·48
K	2·19	2·02	9·56	4·59
Na	9·61	7·7	25·32	12·48
SiO_2	22·3	16·8	20·4	6·40

The Salt Content of the Soil.—The distribution of soluble salts throughout the soil is irregular. As a rule, under normal conditions, a greater concentration exists at the third or fourth foot than in the surface layers. A complete survey was made in 1912, typical results of which are given below :—

Total Soluble Salts per cent., 1912.

	1st Foot.	2nd Foot.	3rd Foot.	4th Foot.
A	0·07	1·44	2·18	2·09
B	0·09	0·33	1·35	2·05
C	0·39	1·85	2·20	2·05
D	0·11	0·33	1·10	1·85
E	0·06	0·11	0·19	0·12

The mechanical analyses throw no light on the reason for the above differences, the proportion of clay and sand being much the same in all the samples.

The Chemical Constitution of the Salt.—The white efflorescence which collects on the surface of irrigated soils represents in some measure the nature of the salts present in the soil. It must not, however, be concluded that the relative components exist in any definite proportion throughout the soil, as the percentage composition is entirely determined by local conditions.

Analysis of Efflorescence from Bottom of Drain.

	%
Sodium sulphate	76·9
Sodium chloride	6·5
Sodium bicarbonate	4·2
Magnesium sulphate	5·7
Calcium sulphate	6·4
Nitrates	traces
	99·7

The Composition of Drainage Waters.—It is impossible to state how far the drainage water represents the composition of the soil solution. The translocation and segregation of soluble salts, the texture and structural properties of the soil, the relative rates of diffusion, the selective absorption of the salt solutions and the absolute solubility of the various individual salts all affect the final concentration of the solution on which the fertility of the soil so largely depends. Given a series of solid phases or salts, the relative proportions will remain constant in a solution until some one phase permanently disappears, provided that sufficient time has elapsed to form a saturated solution.

In practical irrigation the amount of water present in the soil must differ from time to time, so that with a large quantity of water a saturated condition may not be arrived at. Any difference in amount of soluble salts found in the resulting drainage water may be traced to this cause.

The normal drainage water consists of a solution of almost constant constitution, representing the ionic saturation of the various salts contained in the soil over and above the amount held by the absorptive power of the particular soil mass through which it has been moving.

Following the examination of the salt given above, an analysis of the drainage water was made with the following results. It should be noted that no determination was made of the proportion of potassium, as the bases not calcium and magnesium were calculated to their equivalent in sodium :—

Calcium carbonate	34·3	parts per million.
Magnesium carbonate	37·8	,, ,,
Sodium sulphate	186·4	,, ,,
Sodium chloride	98·9	,, ,,
Sodium carbonate	15·5	,, ,,
Sodium bicarbonate	196·7	,, ,,
Nitrates	traces	
Nitrites	none	

A confirmation of the statement made above that the alkali deposit does not necessarily coincide with actual salt content of the soil is clearly afforded by these two analyses, for the relative proportions of the components are by no means the same in each.

Up to the present no investigations have been made on the absorption of the mineral constituents of the soil solution. It will be noticed that there is no phosphate in either the drainage water or the alkali deposit. This is, of course, in accordance with general experience, and is mentioned merely to emphasise the fact that all the inorganic soluble salts of the soil are not represented in the drainage water.

In 1913 an attempt was made to ascertain the rate at which soluble salts are washed out of the soil by heavy flooding. An area was chosen near the central drain of the farm, and sufficient quantities of water were run on to keep the surface continually covered by a layer of water. Samples of the drainage water were collected over a period of twenty days, and analyses were made with the following results, which are tabulated in the order in which the samples were taken.

Parts per Million.

Sample No.	Total Solids.	$CaCO_3$.	$Mg\ CO_3$.	NaCl.	$Na_2\ SO_4$.	$Na_2\ CO_3$.	$Na\ NO_3$.
1	650	30	12·2	84·5	262	227	13·3
2	814	46·5	15·7	111·0	481	182	9·1
3	780	37·5	6·3	114·0	395	253	6·6
4	428	85	25·5	46·9	138	108	trace
5	648	38·2	5·6	94·5	267	196	12·1
6	700	21·5	11·2	81·8	339	246	10·9
7	1191	81·7	22·7	130·5	738	162	13·3
8	743	25·0	9·4	82·7	390	220	trace
9	684	19·5	15·4	62·5	373	217	10·3
10	476	39·0	11·9	54·9	180	151	trace

No determination was made of bases other than calcium and magnesium, the acid radicles being calculated to the equivalents of their sodium salts.

It will be seen that the composition of the drainage water has not materially altered during the period of investigation. Such changes as have occurred are probably due to variations in the quantity of water added, and to other outside influences such as evaporation in the drain, and unavoidable irregularities in the collection of the samples.

It is impossible to predict how long the composition of the drainage water would remain at these figures, but it is probable that washing would have to be continued over a lengthy period before any one of the soluble components of the soil was permanently removed.

The experiment was, however, of importance, for at the end of the washing the salt content of the upper layers was appreciably lessened.

Salt Content Before Washing.

6 inches.	18 inches.	30 inches.
%	%	%
0·14	1·4	1·6

Salt Content After Washing.

0·044	0·069	0·079

The effectiveness of drainage as a remedy against the increase of salt may be further illustrated by figures obtained from a plot of land adjacent to the drain. In March, 1912, before the drain was cut the salt content was as follows :—

1st Foot.	2nd Foot.	3rd Foot.	4th Foot.
0·09	0·33	1·35	2·05

In January, 1913, a further series of samples were taken, the salt content of which was :—

10 cm.	... ...	·07
50 cm.	... ...	·19
1 metre	... ...	·52
2 metres	... ...	·34
3 metres	... ...	·12

From which it will be seen that a considerable reduction in the salt content has been effected with quantities of water not exceeding those used in ordinary irrigation.

Movement of Salt under Irrigation.—The experiment from which the following figures were taken, was conducted in 1913 and 1914, and was intended to demonstrate the effect of varying quantities of water on the cotton crop. Advantage was taken of the fact that the quantities of water were added at regular intervals and in known amounts, to ascertain the penetration and accumulation of the water, and also the distribution of the soluble salts.

It is unfortunate that more complete investigation has not been possible, but several interesting points are brought out by the figures at our disposal. Irrigation was commenced about June, 1913, but samples were not collected until December.

During this period irrigation had been constant. The accumulation of water in the subsoil and the upward movement of salt were precluded by the close proximity of the drain, which at this point had a depth of 2½ metres.

A most important feature was introduced into the analyses by the adoption of a new method,* whereby the calcium sulphate is estimated separately from the other soluble salts. The great value of this is obvious, for it is the possible increase of the soluble salts other than gypsum that concerns us most. As is well known, calcium sulphate is in many cases very beneficial, especially in the presence of toxic magnesium salts. It has, moreover, an ameliorating influence on the texture of the soil.

* Beam and Freak : "An Improvement in the Electrical Method of Determining Salt in the Soil."

The Distribution of Soluble Salts and Gypsum in Farm Soils.

SAMPLE A. HEAVY IRRIGATION, 500 M^3 EVERY TEN DAYS.

Date, December 6th.

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
cm.	%	%	%
10	29·6	·02	·01
50	25·4	·02	·02
100	24·4	·02	·02
200	28	·04	·02
300	22·6	·05	·08

The same, February 28th.

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
cm.	%	%	%
10	20·8	·03	·07
50	23·0	·08	·32
100	26·0	·37	1·18
200	23·0	·36	·46
300	19·8	·26	·35

SAMPLE B. MEDIUM IRRIGATION, 400 M^3 EVERY 15 DAYS.

December 10th.

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
cm.	%	%	%
10	21	·04	·04
50	16	·27	·43
100	23	·46	·11
200	23	·22	·05
300	19	·15	0

SAMPLE B. MEDIUM IRRIGATION, 400 M³ EVERY 15 DAYS—*continued.*

The same, March 3rd.

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
n.	%	%	%
0	15·8	·05	·07
0	15·0	·26	·29
0	20·0	·62	1·01
0	23·8	·32	·3
0	20·6	·20	·22

SAMPLE C. LIGHT WATERING, 300 M³ EVERY 20 DAYS.

January 23rd.

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
n.	%	%	%
0	17·0	·01	·03
50	23·8	·32	·23
0	27·0	·36	·01
0	28·6	·10	13
0	33·4	·21	·05

The same, March 5th

Depth.	Moisture Content.	Soluble Salts.	Gypsum.
n.	%	%	%
10	13·4	·03	·06
50	15·0	·09	·09
0	10·4	·23	·23
0	20·2	·10	·09
0	20·4	·04	·08

The first important point brought out by the above figures is the efficacy of drainage in preventing the waterlogging of the soil by heavy irrigation.

The decrease in the water content in March was due to the fact that irrigation ceased in February.

The second point is that the amount of soluble salts has not appreciably increased during the experiment. A marked accumulation of gypsum has occurred, but this is of minor importance from an agricultural point of view.

Lastly, if the figures given for the salt content of the same samples in 1912 are compared with the above, it will be seen that irrigation with drainage has actually lessened the amount of soluble salts present in the soil.

SECTION III.

Soil Bacteriology and the Nitrogen Problem.

Green Manures and their Effect on the Soil.—The frequent introduction of organic matter into the arid soils of the Sudan is a vital necessity, for the amounts of humus and nitrogenous matter existing naturally are extremely small. Analyses of twelve samples of soils taken from the farm in March, 1912, showed the percentage composition to be as follows :—

Depth.	Nitrogen.	Humus.
1st foot	(Mean) ·025 %	(Mean) 0·42 %

Hilgard and Jaffa found the average percentage of humus in arid soils to be 0·75 per cent., while semi-arid soils contained 0·99 per cent.* The average humus content of the Gezira soils is 0·57 per cent. in the first 12 inches.† These figures may be contrasted with results obtained at Rothamstead, England, where the percentage composition of soluble organic matter ranged from 2·7 per cent. to 1·04 per cent.

The improvement effected in the physical properties of the farm soils by the introduction of organic matter has been demonstrated in the preceding pages ; it remains to indicate its necessity from a bacteriological and physiological standpoint.

It is from the carbohydrates and proteids of plant and animal residues that food is provided for micro-organisms and ultimately for the plant. The degradation products of the proteid matter furnish nitrogen in a soluble form, whilst the energy for the metabolic processes involved is largely supplied by the carbohydrates.

* Hall : "The Soil," p. 46.

† Beam : Wellcome Tropical Research Laboratory. Vol. B, 1911.

Stable manure, oil cake and various other nitrogenous manures are not available in the Sudan, so that the use of green manures becomes imperative.

Up to the present only three plants have been tried on a large scale, all of which, being leguminous, have the important property of increasing and storing the nitrogen supply of the soil.

Arabic Name.	*Botanical Name.*
Lubia afin.	*Dolichos lablab* : Linn.
Lubia hellu.	*Vigna sinensis* : Endl. (*V. catyang*).
Lubia saidi.	*Vigna sinensis* : Endl.

All are cultivated for food and fodder throughout the Sudan, and exist in a semi-wild condition in the southern districts.

A detailed analysis was made of specimens from the farm, a tabulated record of which is given below :—

THE NITROGEN CONTENT OF

Lubia afin = *Dolichos lablab* : Linn.

Weight when Dry.		Nitrogen.	
		%	Total Weight.
Leaves	... 13·2 gram.	2·6	... 0·341 gram.
Stems	... 28·5 „	0·63	... 0·179 „
Roots	... 2·47 „	0·93	... 0·023 „
Nodules ...	... 2·02 „	5·36	... 0·108 „

Lubia hellu = *Vigna sinensis* : Endl.

Pods	... 1·3 gram.	1·13	... 0·137 gram.
Stems and leaves	... 10·8 „		
Roots	... 0·87 „	4·0	... 0·041 „
Nodules ...	... 0·17 „		

A second analysis gave the following results :—

Lubia afin.

Weight when Dry.		Nitrogen.	Total N.
		%	
Air-dry tops ...	... 520 gram.	1·2	6·333
Air-dry roots, with six nodules ...	... 51 „	1·37	0·700

Lubia hellu.

Weight when Dry.		Nitrogen.	Total N.
		%	
Air-dry tops	57 gram.	3·3	1·886
Air-dry roots, with three nodules	18 „	1·08	·194
Lubia saidi.			
Air-dry tops, including 47 pods....	430 gram.	1·8	7·95
Air-dry roots (no nodules)	22 „	0·56	0·123

If may be of interest to add an analysis of the beans which was made at the Imperial Institute (vide Bulletin of the Imperial Institute, Vol. XI., No. 2.).

	Lubia afin.	Lubia hellu.
Moisture	7·4	7·95
Crude Proteins	23·53	20·61
Consisting of—		
True Proteins	22·7	18·53
Other Nitrogenous Substances	0·83	2·08
Fat	1·05	1·63
Starch	56·28	64·07
Fibre	7·95	2·76
Ash	3·79	2·98

A glance at these figures will show that where practicable the greatest yield of nitrogen will be obtained by ploughing in the whole plant. Lubia afin has proved the most satisfactory crop on account of the luxuriance of its growth.

The formation of nodules varies greatly with the texture of the soil, light open soils being more favourable than heavy clays. In fact, a prolonged search among plants growing in the latter may not disclose a single nodule.

Inoculation of the seeds with artificial cultures has not resulted in any appreciable success. The nodules are so numerous naturally that where no formation occurs the fault obviously lies with the soil. Inoculation of a plot in which soy beans were growing, with soil from the country of origin was, however, distinctly successful.

It has been found possible to isolate the organisms directly from the soil by means of a synthetic medium containing mannite. The individual organisms of a number of leguminous plants have thus been isolated, but a detailed description of their morphology must form the subject of another paper.

A series of analyses were made in February, 1913, to ascertain the effect produced on the nitrogen content of the soil by ploughing under a heavy crop of lubia. For comparison, samples were taken also from fallow land, land under cotton, and land which had previously grown a crop of berseem. These figures may further be compared with the Rothamstead records for 1885.

Farm Soils.	Nitrogen Content.	Rothamstead.	Nitrogen Content.
First 12 *Inches.*	%	*First* 9 *Inches.*	%
Lubia ploughed under	·053 ·038 (Bad patch) ·058	Hoos Field— Wheat, fallow	0·1021
Fallow soils	·034	White clover	0·1269
Fallow soils after cotton ...	·028	Bokhara clover	0·1151
Cultivated soils on cotton plot	·029	Lucerne	0·1219
Berseem plot	·049		

It will be seen that a distinct increase in the nitrogen content was obtained by the use of leguminous crops, but scarcely what would be expected from the large amount of organic matter ploughed in. The actual gain is as great as in the Rothamstead soils, although the amount present is only about half that found in the latter.

The excessive loss of organic matter which takes place in arid soils is a well-established fact. After the lapse of a few months little trace can be found of a green crop previously ploughed under. White ants are doubtless responsible in part, but rapid decomposition by bacterial processes is the predominating cause.

An attempt was also made to estimate the rate and amount of the loss during a given period in the plots from which the samples employed in previous investigations were taken. Two separate experiments were conducted simultaneously, so that the temperature conditions should be similar. In the first, lubia cellulose freed from carbohydrates and proteins was added to known quantities of soil contained in closed glass vessels. The water content was kept constant, and the loss of organic matter estimated from time to time by incineration.

In the second experiment, the entire plant was added to the soil after it had been reduced to a fine powder by drying and pulverisation. The carbon dioxide evolved was measured by collection in lime water, and subsequent titration against a standard solution of oxalic acid.

In the following table the percentage loss of cellulose and the total number of milligrammes of carbonic acid evolved during a given period are recorded :—

	Percentage Loss of Cellulose. Period of Time, 48 days.	Milligrams of CO evolved. Period of Time, 21 days.
Sample I.—Fallow, no manure	40·0	48·3
Sample II.—Lubia ploughed under some months previously ...	66·2	240·5
Sample III.—Stable manure added previously	58·7	232·1
Sample IV.—Soil washed by repeated floodings	47·5	203·1
Sample V.—Lubia ploughed under recently	40·0	191·1
Sample VII.—A lighter sandy soil, no manure	59·4	224·4

It will be seen that the loss is in every case high, and that even under experimental, which are probably slower in action than field, conditions, the whole of the organic matter would be lost in three months. There is some evidence to show that during this period of bacterial activity the nitrates also suffer, and are partly lost either as ammonia or as gaseous nitrogen.

The Formation of Nitrate in the Farm Soils.—It is difficult to reconcile at first sight the obvious fertility of the Sudan soils when brought under cultivation with the poverty of nitrogen as revealed by chemical analysis. The extent of this poverty can be gauged by comparison with typical English soils.

Farm Soils.		Rothamstead Records, 1893.	
First 12 inches of Soil.	Nitrogen.	First 9 inches of Soil.	Nitrogen
	%		%
1912 Records (average of 12 soils)	·025	Plot 2A. Farmyard manure since 1884	0·1628
1913 Fallow soil	·034	Plot 2B. Farmyard manure, 14 tons per annum ...	0·2207
1913 Fallow soil (after cotton)	·028	Plot 3. Continuously unmanured	0·0992
1914 Soil under cotton ...	·029	Plot 4. Continuously unmanured since 1852	0·0982
1914 Berseem plot ...	·033		
1915 Soil after cotton ...	·032		
1915 Tuti soil	·029		
1915 Desert soil	·021		

A brief reference was made to these facts when considering the enrichment of the soil by green manures, but no explanation was afforded of the processes whereby the insoluble organic material becomes capable of assimilation by the plants of the crop.

The question is purely bacterial and involves the co-operation of no less than four different groups of micro-organisms.

Considering only the formation of nitrate, the first step is the fixation of nitrogen from the atmosphere by the nodule-forming organisms, whereby complex nitrogenous bodies are built up within the substance of the nodule. These by reason of their insolubility cannot be used as food by plants, but owing to the activities of a certain group of bacteria they are quickly oxidised, or hydrolysed, into simpler bodies and ammonia.

The ammonia is converted into ammonium carbonate by interaction with either the carbonate present in the soil or the carbon dioxide of the soil atmosphere.

This is transformed by the nitrosomonas group into nitrite, and finally the nitrite is changed to nitrate through the agency of the nitrobacter group.

Bio-chemical investigations conducted with farm soils seem to show that they are deficient in nitrite and nitrate-forming organisms, or at any rate conditions are not favourable for their successful development.

Synthetic media inoculated with soil invariably show that while the ammonification of peptone and the denitrification of potassium nitrate is very rapid, the formation of nitrite from ammonia and its subsequent oxidation to nitrate is feeble, and that if any nitrate is formed it is rapidly decomposed. A typical series of sixteen samples gave the following results :—

Formation of NH_3 from Peptone ...	... Positive after seven days.
Formation of Nitrites from $(NH_4)_2$ SO_4	... Negative after one month.
Formation of Nitrates from Na No_2	... Negative after one month.
Denitrification of KNO_3	... Positive after seven days and complete in three weeks.

It has been stated that the thermal death point of the nitrosomonas group is 45 deg. C., and of the nitrobacter group from 50 deg. C. to 55 deg. C. If this were the case with the Sudan type, the top layers of soil would be quickly sterilised whenever fallowing occurred.

In the writer's opinion it is the poor aëration of the heavy clay soils, and not deficiency of bacteria which is responsible for the poverty in nitrogen, for in lighter soils quite different results were obtained.

Bio-chemical Reaction of Tuti Soils.

(*a*) Fallow Soil.

Formation of NH_3	Vigorous after three days.
Formation of NO_2	Positive after ten days.
Formation of NO_3	Positive after ten days.
Denitrification	Incomplete after one month.

The effect of fallowing on the number and kind of micro-organisms has already been mentioned. That a very real effect is produced by the partial sterilisation involved, is shown by the fact that after cultivation for a season the reactions obtained with the same soil were as follows :—

(*b*) Cultivated Soil.

Formation of NH_3	Vigorous after three days.
Formation of NO_2	Positive after ten days.
Formation of NO_3	Positive after ten days.
Denitrification	Complete after twenty days.

A sample taken from a spot just outside the cultivated area, where, as far as is known, arid conditions had prevailed for many years, gave the following results :—

(*c*) Desert Soil.

Formation of NH_3	Vigorous after ten days.
Formation of NO_2	Positive after one month.
Formation of NO_3	Positive after one month.
Denitrification	Complete after twenty days.

In the case of the cultivated soil the decomposition of the NO_3 is believed to be due to an increase in the denitrifying bacteria, while in the desert soil it was obvious that the nitrogen-forming bacteria were deficient.

The samples were taken in every case from the first foot.

Generally speaking it may be stated that, as with soils in England, continuous cultivation is detrimental to the production of nitrogen, but the fallow period should not be too prolonged, or a reversion to desert conditions quickly ensues with a predominance of fungi and a deficiency of the useful organisms of the soil.

As distinct from the formation of nitrate, sketched above, there exists a means by which the supply may be replenished without the intervention of leguminous crops. An organism, *Azotobacter chroococcum,* is widely distributed throughout the Sudan soils, which has the power of directly fixing or assimilating the nitrogen of the atmosphere.

It is particularly abundant in light open soils, while clay soils are not so favourable as a result of deficient aëration.

In morphological characteristics the type found in the Sudan does not differ greatly from the European form. It resists desiccation to a remarkable degree, although no definite sporing stage has ever been found. A dried-up culture was found to be still active, after having been kept in an incubator for eighteen months. The distribution of this type at various depths was studied in the "Duty of Water" experiment where the effect of irrigation could also be ascertained.

Soil was taken aseptically from three plots :—

No. I.	was	receiving	500	cubic metres	every	10 days.
No. II.	,,	,,	400	,,	,,	,,
No. III.	,,	,,	300	,,	,,	,,

In each case samples were taken from the surface, 50, 100, 200 and 300 cm. The results were as follows :—

	No. I.	No. II.	No. III.
Surface	×	+	+
50 cm.	×	+	+
100 cm.	traces	×	traces
200 cm.	traces	×	×
300 cm.	×	×	×

+ equals growth ; × equals no growth. A medium containing mannite was used exclusively for this work.

During experimental work with this organism it was found that, although a luxuriant growth might be obtained, nitrate could rarely be detected in such mixed growths as result from the addition of soil to the culture medium, but that a large amount of ammonia was always formed. In pure cultures, the formation of nitrate occurred after a period varying from a week to a month.

The reason was at once obvious when the flora of these mixed cultures was examined. Bacillus fluorescens, B. butyricus, and other bacteria capable of rapidly decomposing nitrate were always found.

It was at once suggested that in view of the relatively large number of these organisms, the low nitrogen content of the soil might be due to their activities.

The ammonia resulting from the decomposition of protein or nitrate would be quickly dissipated as the soil became dry, or would be leached out in the irrigation water. It has, however, been found that when an ammonium salt is added to a soil, the whole can never be recovered, but some is retained, the amount varying with different types of soil. Russell * suggests that this stability is caused by the formation of a compound which is not a true ammonium salt.

To ascertain what percentage of an added ammonium salt is retained by the farm soils despite the leaching effect of the irrigation water, the following experiment was devised. Samples of soil were left in contact with a solution of NH_4 Cl (1 cc. =1 cc. N.) for forty-eight hours. A measured portion of the supernatant solution was then taken, and the nitrogen content measured by means of a strong solution of hypobromite of soda and a Hempel's Gas Burette.

The samples were eight in number, six of which were the same as have been used in previous investigations. The history of the plots was as follows :—

Sample.	Plot History.	NH_3 absorbed.
		%
I.	Fallow, no manure	40·0
II.	Lubia ploughed under some time previously	31·2
III.	Stable manure added previously	40·2
IV.	Washed soil	39·5
V.	Unwashed soil adjacent to IV.	44·5
VI.	Lubia ploughed under recently	42·5
VII.	Fallow soil for 18 months	33·0
VIII.	Soil sandier than above	30·0

The accuracy of this finding remains to be confirmed by future work. A continuous formation of available nitrogen must, however, occur, coupled with almost simultaneous assimilation. One form in which the nitrogen is utilised by the plant is at present undetermined, but evidence points to the activities of the Azotobacter group as the source of supply, and it is probable that in the presence of numerous denitrifying organisms, no accumulation in soluble form ensues.

Summary and Conclusions.—(*a*) The bacterial content of the farm soils is low as compared with that of English soils.

(*b*) The actual number of organisms bears little relation to the fertility of the soil, but the distribution of species exerts an important influence.

* Journal of Agricultural Science, Vol. III., p. 241. Russell found that stiff arable land retained 50 per cent., subsoil 28 per cent., pasture soil 50 per cent., sand 14 per cent.

(*c*) Bacteria may be found in diminishing numbers in the subsoil, the number and species present being influenced by the texture of the soil and the amount of water added.

(*d*) Fungi are numerous in uncultivated soils, and tend to develop in heavily-watered soils.

(*e*) The introduction of organic matter in the form of green manures is essential for the improvement of the texture of the heavy clay soils, and to provide food for micro-organisms.

(*f*) The loss of organic matter and nitrogen is rapid in Sudan soils.

(*g*) So far as can be determined by laboratory methods, the formation of nitrate from proteid *via* ammonia is feeble.

(*h*) The amount of nitrogen found in the soil at any one time is considerably below that required for the successful cultivation of a crop.

(*i*) A short fallow is beneficial to the soil, but after a prolonged fallow soils tend to revert to desert conditions with a deficiency of nitrate-forming organisms and a predominance of fungi and organisms capable of denitrification. So long, however, as the moisture content has not become too low, the formation of nitrate takes place, but this process is always limited by the rapid desiccation which ensues.

(*j*) Marked changes can be effected by cultivation and methods of treatment, and these changes are capable of intelligent investigation by the laboratory methods at our disposal.

(*k*) The resistance, as distinct from the activity, of many organisms to desiccation is very great.

REPORT II.

FIELD EXPERIMENTS IN THE KHARTOUM DISTRICT.

ERIC SLATER, *Farm Manager.*

THE Central Research Farm is situated on the right bank of the main Nile two miles north of the junction of the Blue and White Niles, and comprises in all 230 feddans of irrigable land. In conformation and soil characters it is fairly representative of the narrow belt of cultivation which extends almost continuously along the river banks through the Khartoum and Berber Provinces. The rainfall throughout this area is negligible, and crops are dependent on artificial irrigation effected by means of the primitive Persian water wheel, or "sakia," and recently in certain districts by modern steam pumps.

Irrigation is facilitated by the existence of a flood bank, built up by the river to a higher level than that of the adjacent areas, providing a natural slope inland. An explanation for this almost universal feature is found in the following note from a report by the Government Geologists, Messrs. Grabham and Dunn.*

> As the stream widens its bed by cutting into one bank, a sand-bank is often formed on the opposite side, and if conditions are suitable, subsequent floods build up this bank until vegetation is able to maintain a footing on it all the year round. As soon as plants get a hold they aid the flood water to deposit silt, which forms a surface soil. The accretion of sand and silt takes place more rapidly on the river-side edge of the bank, as that is the region where the velocity of the silt-laden water of the parent stream is checked.
>
> The consequence is that the edge of the alluvium is built up to the level of the highest flood, while a depression is left between it and the original river bank behind.

Demarcation.—The chemical features of the farm soils and their bearing upon the crops grown has been dealt with in another report. The following extracts from Mr. S. C. Dunn's preliminary report on the site will explain the manner in which the farm has been partitioned :—

> The soil of the Central Research Farm may be roughly divided into three parts :—
>
> (1) The strip adjoining the river bank. This is loamy in nature, patchy in quality, with areas containing marked quantities of salts scattered over it. The soil from the sagia-land on the river bank has been washed over this area causing a difference between the superficial coating of surface soil and the silt subsoil already *in situ*. Further, this portion has from time to time been built on by natives, and the low mounds representing the sites of their houses have been levelled, thus increasing the probable variety of the surface soil and adding to the salt content of the whole.

* "Report on the Sennar District."

(2) The strip of soil lying between the above-mentioned area and the centre line of the farm. This is patchy—in part loam, in part clay loam. Salt occurs in some areas, and by seepage from the old main canal of the farm it is more than probable that the salt contents generally have been increased.

There is also a khor or depression running diagonally through these two sections. Consequently in the past rains have washed salts from both the river bank and the high land on the east, and by evaporation increased the percentage in this depression.

(3) The eastern strip of the farm. In this section there is less variation than elsewhere. The soil appears to be in a state that may be termed "natural" in comparison with the other sections described. Also it seems to be soil belonging to the "old alluvium" and not to the "new alluvium" as on or near the river bank; and in many ways, by its mechanical construction, it should provide better comparison with the great mass of soil to be found through the principal agricultural districts of the Sudan, and, above all, the Gezira.

This third or eastern section has therefore been set apart for comparative experiments with cotton, wheat and beans.

The second or middle section is partly occupied by a road running the entire length of the farm and partly by the lateral drain which occupies the position of the old main canal. The remainder and half of the first or western section is utilised for the growth of stock feed, trees, vegetables and breeding plots which do not require a uniform soil, as no comparative data are sought. The other half of the western section is planted for revenue purposes with the same rotation of crops as is found on the experimental area, but no comparative figures are taken from it. The whole of the southern end of the farm is occupied by trees, staff houses, stores and grazing paddocks for stock. (See Plan of Farm.)

Canalisation.—The farm is divided into twenty-three "Hoshes." These contain a varying number of feddans as the east and west boundaries are not parallel.

The main canal from the pumping station runs along the west boundary of the farm until it reaches Hosh 13, when it turns and runs eastward as a high level canal across the central depression, ending on that boundary. A branch canal continues from Hosh 13 to the south end, and another from the end of the main canal runs along the east boundary.

The hoshes are arranged in groups of four. Each group is irrigated by a secondary canal and separated from its neighbour by a path. (See Plan.)

The hoshes are demarcated into feddans by "Gadwels," or watercourses, which draw their water from the secondary canals, and distribute it to the land through smaller distributory channels. In the case of the wheat crop the feddan is divided by low earth banks into 100 beds, or "hods"; for cotton and beans, however, the land is ridged to facilitate cleaning, and the feddan divided into forty ridges and furrows intersected by the distributory channels. (See Plan.)

Under this system the distribution of labour for irrigation is very simple. A man is told off to each distributory gadwel, and waters alternately the hods or the sections of four ridges, as the case may be, on either side of the channel.

It has been found that a man with a fair knowledge of the work and the right amount of water at his disposal, under this system can irrigate 100 hods or one feddan per diem.

In practice, however, figures taken over a whole season show that on an average he only waters seventy hods per diem. This is due to irregularities in the water supply, and a certain amount of additional work in repairing banks and gadwels before watering. Further, as the season advances, the erosion of the distributory gadwels becomes very marked, and the growth of the crop prevents mechanical aid being utilised in repairing them. Such repairs as are necessary have to be effected by the workman before he begins irrigating. The cost of actually leading the water and effecting such repairs works out at 49.5 millièmes per feddan per watering.

The large quantity of silt carried by the river during the flood causes all the gadwels to become more or less choked. This is aided by the luxurious growth of grasses on the banks. It is necessary, therefore, thoroughly to clean out all permanent water channels twice a year, once just before the flood in June, and once about October. The cost of this operation, which consists of digging up the grass on the banks, ploughing up the bottom and removing the earth thus loosened, is somewhat expensive, and works out at 7.2 millièmes per metre per annum.

Whenever contour permits, the permanent gadwels are raised above the surface of the surrounding land. Although this demands a stronger bank and more labour and expense in construction, it enables all the water to be drawn from the channel after irrigation is finished, thus allowing the gadwel to dry rapidly, and thereby preventing mosquitoes from breeding.

In lieu of borrow pits the soil excavated to form the gadwel has been cut to form infiltration drains. As the gadwel is raised the banks are subjected to a certain amount of pressure seepage ; and if this water is not carried off, it collects along the base of the earthwork, rendering the land, if not actually water-logged, decidedly boggy and unworkable. It would be advisable to point out that seepage occurs to the same extent in sunk channels, and an even greater area is affected, if no infiltration drains are cut. Aëration of the soil is in such cases obviously diminished, and consequently the activities of nitrogen-fixing and nitrifying bacteria are retarded. Excessive evaporation over this boggy area increases the salt content of the soil, and mosquitoes find a convenient breeding ground amongst the rank grasses which abound therein.

In some cases the soil composing the banks of the gadwel is so porous that the amount of seepage forms a serious factor of waste. An impervious lining of some description has then to be inserted. A single burnt brick lining laid in lime mortar has been found very efficient and inexpensive. The cost of a small section laid down on the farm worked out at 161 millièmes per metre. This figure may easily be reduced if a considerable length of gadwel, say, two or three thousand metres, is treated.

Savings of the first importance result from the employment of brick-lined canals :—

(I) There is a permanent decrease in the loss between headworks and field, because :—

(*a*) There is little seepage.

(*b*) There is less evaporation as the section can be reduced and the surface of water exposed to the sun thus limited.

(II) The canal does not become choked with silt, as reduced friction spells greater velocity with a given fall; and the water does not stand in the gadwel after irrigation is completed. A direct result is that the land benefits by the increased amount of silt carried on to it during irrigation.

(III) Infiltration drains are rarely necessary. The land occupied by them is thus available for the growth of crops.

(IV) The risk of mosquito-breeding is almost eliminated, and a further saving is effected on the wages of a special "Mosquito Boy" and on the cost of the oil he pours over stagnant water.

(V) The risk of a burst gadwel in the middle of the season is reduced to a minimum.

(VI) The biennial cleaning and its attendant cost are obviated.

Care must, of course, be taken to see that the bricks are well laid in the first instance, and that stock are not allowed subsequently to trample over the gadwel. The cost of upkeep is practically *nil*. A section laid down three years ago has not been touched and is still in excellent condition.

Drainage.—An attempt to improve the quality of the soil on the farm by drainage was made in 1912, when a main drain with two lateral branches was cut. (See plan for position.) The bottom section—75 cm.—of the drains remains constant throughout, but the depth increases from a minimum of two metres to four metres where passing through the river bank. The preliminary vertical section of $\frac{1}{2}:1$ made in 1912 has stood remarkably well, though the main drain is beginning to call for an increased width of cut. The outlet of this drain is below the flood level of the river. It was therefore necessary to construct a brick culvert with a sluice gate through the river bank and to erect a small oil engine over it, in order to remove drainage water during the flood. At

A Section of the Main Farm Drain.

Outlet of Main Farm Drain on River Bank with Pumping Engine for Clearance of Drain during the Nile Flood.

other times the water drains into the river. Some difficulty has been experienced in preventing the formation of large cracks on the edges of the drain when the land surrounding it is not continually watered.

These drains have served their purpose admirably. The salt content of the soil is being steadily reduced and seepage water is at once carried off.

Rotation of Crops.—A simple three-course rotation covering a period of two years has been adopted both in the case of the comparative experiments and on the revenue area. Cotton occupies the land from July until April. It is followed by a summer crop of legumes, of which lubia afin (*Dolichos lablab*) gives the most satisfactory results in our heavy clay loams. The bean is fed, cut, or ploughed under in the autumn in preparation for the wheat crop, the planting season for which extends from middle November to middle December. With a growing period of some 120 days, the cereal is off the ground in ample time to permit of thorough preparation for the second planting of cotton in July.

Repeated inter-row cultivation of the cotton renders this an excellent cleaning crop, while the dense growth of the lubia still further checks weed-development. The restorative character of the latter staple is dealt with exhaustively in connection with the problem of the nitrogen supply. The desirability of perennial irrigation and the limitation of bare fallows is recognised by this arrangement, and where circumstances permit a second leguminous catch crop is taken between the wheat harvest and cotton planting.

Scheme of Experiments.—The two-year rotation necessitates the division of the experimental area into duplicate series of hoshes, north and south, on each of which five distinct investigations are continuously conducted with the three staple crops, viz. :—I. Manuring. II. Distance of Planting or Quantity of Seed. III. Times of Planting. IV. Duty of Water. V. Methods of Cultivation. In the southern section an additional hosh has been devoted to a special investigation with green manures. Thus, in any season, cotton experiments are to be found in one area, and duplicate tests with wheat in the other. Manuring, Duty of Water and Cultivation Experiments are continuous on the same plots in order that cumulative effects may be recorded. The Spacing and Times of Planting plots, however, are reversed in series each year to eliminate as far as possible the influence of soil irregularity. In the former cases, a measure of this factor is ascertained by the inclusion of numerous check plots.

The relative advantages of the chequer-board system of plots, as applied to certain field experiments, have not been lost sight of, but with a very limited supply of intelligent and trained labour, it has appeared that the risk of recurring mistakes would be greater than the margin of error obtaining from long and narrow parallel plots with an equivalent number of check, or untreated beds. The remarkable uniformity in chemical and physical characters of the soils under test, coupled with an independent system of laboratory control, whereby

100 plants, or a sample row, in each plot are individually and periodically examined for a distinct record, further warrant the continued adoption of the current system. The chequer-board system is of course inapplicable, for practical reasons, to Times of Planting, Duty of Water and Cultivation Experiments.

The results of a superimposed experiment in the topping of cotton was graphically illustrated last season. The times of planting hosh was divided longitudinally, so that cotton of every age was topped simultaneously. The result was most satisfactory. In every instance the topped cotton yielded more than the untreated. The difference is not so marked in the older plots, and the best time to top was ascertained to be when the plant is from seven to ten weeks old. (See Chart No. 1.)

Modules.—Two " Gibb's Patent Modules " are in use for the Duty of Water Experiment—one on each section of the farm. These modules deliver a uniform flow of water despite a varying head in the supply canal, and thus render the control of the various amounts required by each plot very simple ; *e.g.*, as the module delivers 208·3 cubic metres of water per hour, the full stream of water has to be turned on to a feddan for 1 hour 55 minutes to supply it with 400 cubic metres. These modules represent the only reliable, self-regulating water metre on the market, and are invaluable where a constant and known discharge of water has to be maintained for a given time.

Cultivation.—The ordinary cultivation employed in connection with all crops on the farm consists of the following operations :—

I. Ploughing :

This is done with an " Oliver " mould-board plough, working at a depth of 12 cm. It has been found advisable to flood land before ploughing, as not only can the work be done faster, but a better tilth results. The land is then cross-ploughed. Whenever time permits a Ransom's disc plough is substituted for the mould-board plough, especially after lubia, as it turns the stubble under much more effectively.

II. Rolling or Disc Harrowing :

This is necessary to crush the clods which are invariably turned up during ploughing. The disc harrow is used where clods are not heavy and hard.

III. Levelling :

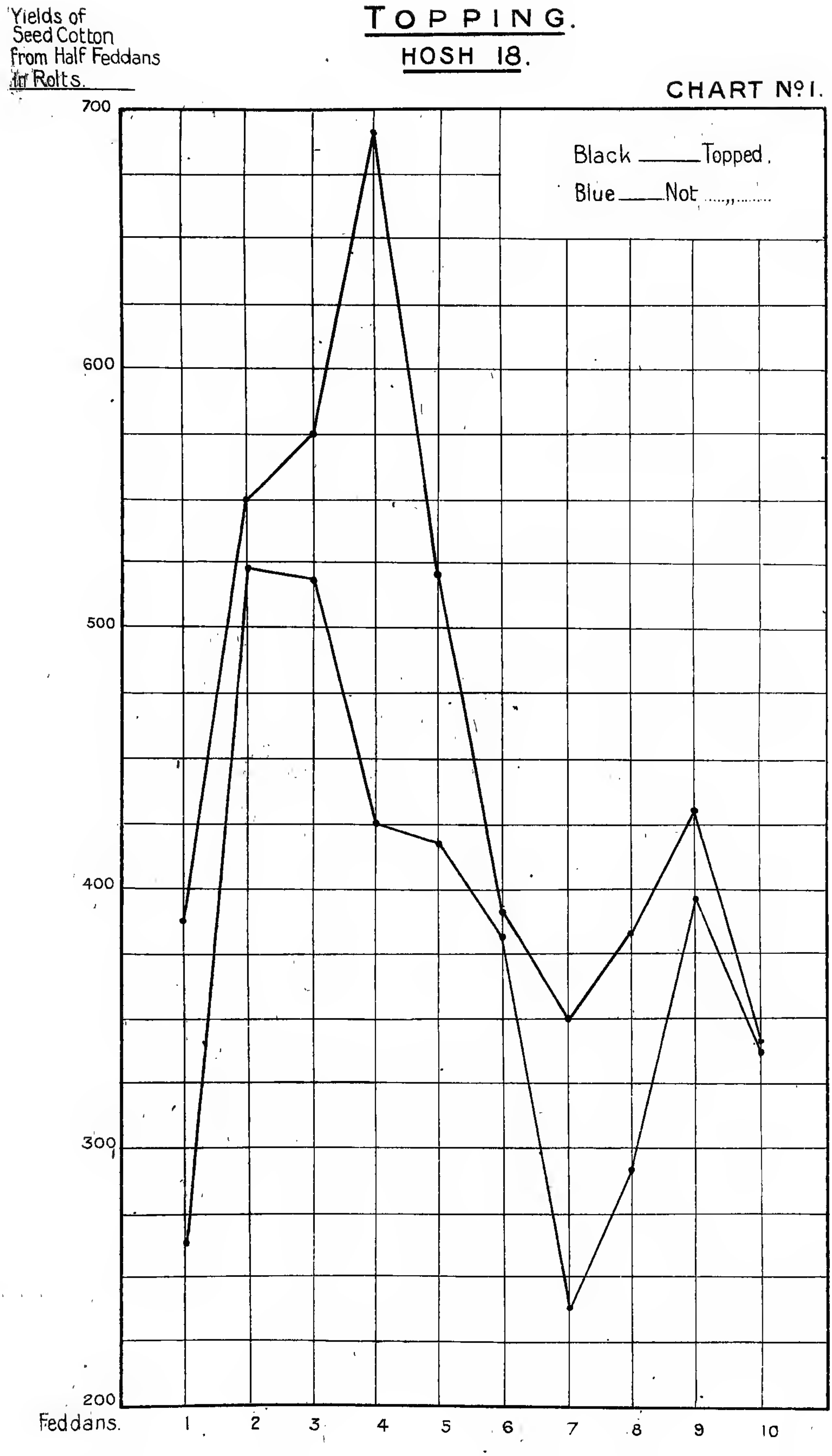
Uneven land is levelled after rolling and a little extra earth is drawn to the lines of the distributory gadwels. For wheat, levelling and the formation of hods proceeds simultaneously.

IV. Ridging :

Ridges one metre apart are thrown up for cotton and lubia.

TOPPING.

HOSH 18.



V. Handwork :

It is often necessary to round off the ridges and hods by hand to make them watertight.

VI. Planting.

VII. Thinning and Repatching take place after the second watering.

VIII. Subsequent Cultivation :

Cotton and lubia are horse-hoed, hand-hoed, and ridged at monthly intervals. The former three times and the latter twice. After that the crop is too high to permit of further cleaning.

Wheat is harrowed as soon as it is well rooted, and again after the next watering.

An experiment to determine the value of additional cultivation was carried out with cotton in the years 1913–14 and 1914–15, and with wheat in 1912–13. In the case of the cereal, as was confidently expected in view of the requirements of this crop for a firm seed bed, deep cultivation had little or no effect on yield. With cotton, however, in every plot except one, better cultivation resulted in a larger yield. The general results for the two seasons are shown in the attached chart No. 2. Taking the last year's experiment in detail, the feddans were numbered consecutively from 1—9. The even numbers—2, 4, 6 and 8—furnished the check plots, and were ploughed dry, harrowed, ridged and planted.

The odd numbers—1, 3, 5, 7 and 9—constituted the experimental area and received additional cultivation, as follows :—

Feddan 1.—Flooded, ploughed, harrowed with disc and tooth harrows, levelled, cross-ploughed with disc plough, sub-soiled, harrowed, ridged and planted. Horse-hoed and earthed up at monthly intervals after establishment of crop.

Feddan 3.—Treated exactly as No. 1, except that it was not sub-soiled.

Feddan 5.— „ „ „ but not flooded before ploughing.

Feddan 7.— „ „ „ but not sub-soiled and not levelled.

Feddan 9.— „ „ „ but was not cultivated after germination.

The results were very satisfactory with the exception of Feddan 1. It is unfortunate that the salty underground khor mentioned earlier in the report, originates in one corner of this feddan, affecting the growth of the plants over a quarter of the area. The corresponding plot in the northern section, 1913–14, clearly shows that the yield recorded in 1914–15 on this plot is to be attributed to this disturbing influence, and a better idea of the result will be obtained if this uneven section is omitted.

	Experimental Area.	Check Plots.
Average Yield of Seed Cotton	936	823
Average Cost of Production	£E.6.792	£E.5.594

The value of the extra yield of 113 rotls per feddan is about £E.1.700. After deducting the cost of extra cultivation the grower is left with an increased profit of 500 millièmes per feddan, as the direct result of additional cultivation.

Such cultivation, of course, demands capital expenditure for the purchase of the necessary implements, and the extra return does not, at the first glance, appear to compensate this outlay. The cost of disc-plough, disc-harrow, subsoil-plough and grader (the possession of mould-board and ridging-ploughs and a tine harrow is assumed) would not amount to more than £E.70. If an area of 100 feddans were cultivated, £E.50 of this capital outlay would be recovered in the first, and a profit of £E.30 shown in the second, season.

It is highly probable, moreover, that continuous cultivation of this nature will have cumulative effects, and that the returns to a first highly-cultivated crop do not represent the full value of the operations.

Undertaken on a large scale with steam ploughs, &c., the cost would be reduced considerably and the nett return proportionately increased.

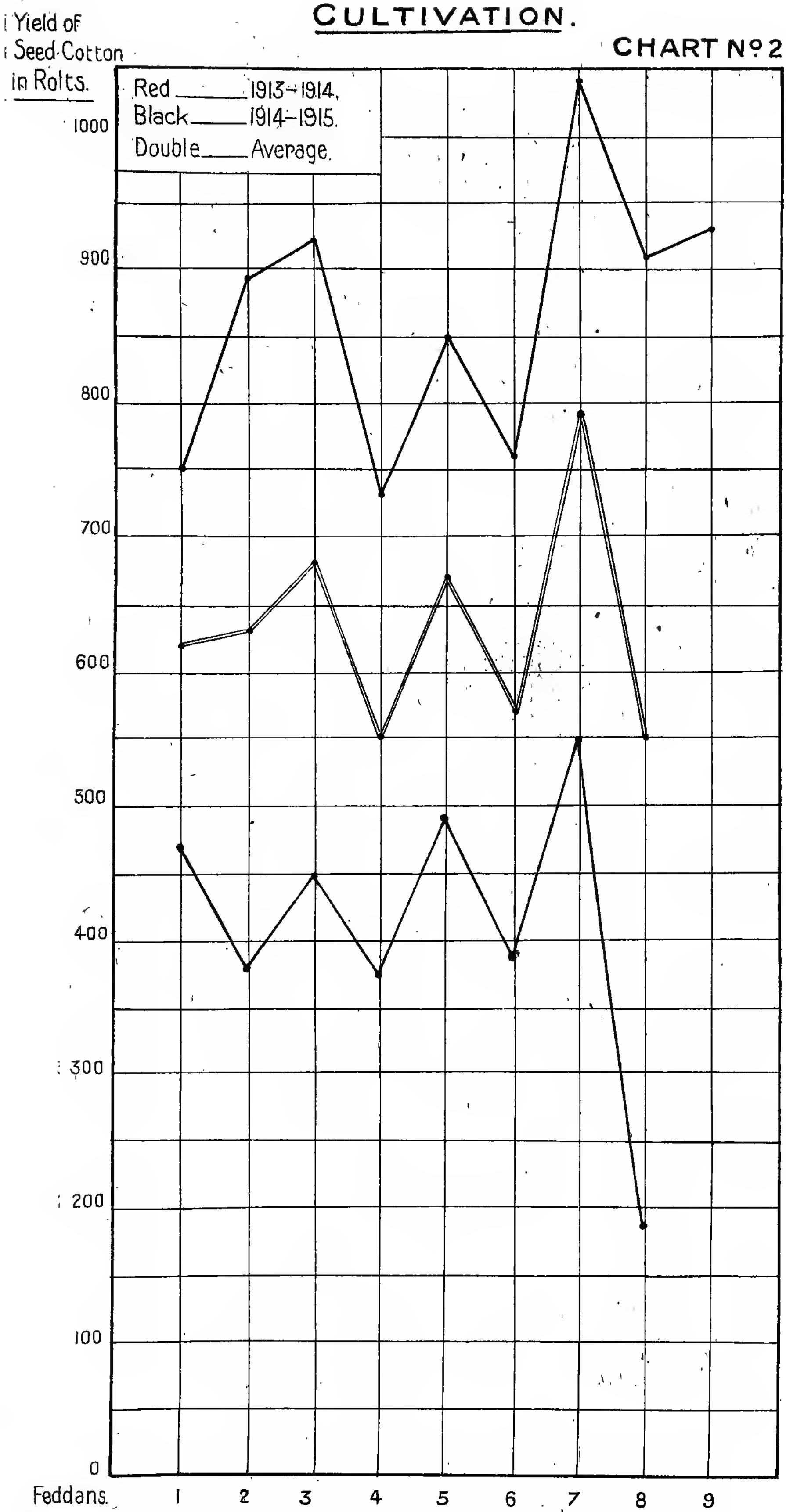
It would obviously be quite impossible on native-owned land, where it is the exception for a man to own more than five or six feddans, to expect this type of cultivation, unless a system of co-operation in the purchase of the implements and the order of use were devised.

Times of Planting.—The best time to plant cotton in the Sudan varies with the locality. It is generally admitted that the farther north it is grown the earlier it may be planted, but data are lacking to show the optimum time for each district. The cotton season in this locality extends over a period of ten months—from June to March. Early planting is limited by the restrictions imposed upon the use of summer water in the interests of the Egyptian crop.

The growth and development of cotton is injuriously affected both by the hot dry winds and sandstorms (" habubs ") which prevail in early summer before the rains commence, and by the cold winter winds generally experienced in January and February and sometimes in December. The greater humidity obtaining during and after the short rainy season on the other hand exercises a most beneficial influence, subject to the condition that there is no very sudden rise in

CULTIVATION.

CHART No. 2.



temperature accompanied by extreme aridity, in September and October as has sometimes been recorded. Such weather is usually coupled with a marked shedding of leaves and bolls as a natural response to the demand for a reduction in the transpiration surface, and accounts for a great discrepancy between flower-formation and boll-development and a consequent serious reduction in the yield of the crop.

The problem is, therefore, whether it be preferable to plant early and expose the tender seedlings to hot, dry winds and have the plants well grown by the time the cold season arrives, or to wait until the " habub " season is over and risk later development being checked by abnormally cold winds. Until this point is settled an element of speculation must always attend the planting of cotton, as obviously it is impossible to forecast the weather for months ahead. In this connection it should be noted that plantations in the Khartoum Province are undoubtedly more favourably situated, and suffer less from excessive changes in temperature and humidity, than estates in the Berber area where remarkable fluctuations in crop returns clearly reflect the importance of the weather factor.

The 1913–14 season on the farm was marked by a premature cold spell in winter, and the early-planted cotton consequently had the advantage. The 1914–15 season, however, was characterised by its high humidity and mild winter. Later-planted cotton which had escaped the " habubs " was therefore greatly superior.

It is unfortunate that all our experiments during the 1913–14 season were rendered unreliable by the breakdown of the pumping plant and the consequent shortage of water. Further, that the Times of Planting Experiment of the 1912–13 season was not commenced until July 10th, thus giving us no check on cotton planted last season on June 1st, 10th, 20th and 30th.

The experiment is carried out annually over an area of 10 feddans, which are sown consecutively at intervals of ten days.

From data at our disposal the best average crop is obtained from cotton planted on July 10th (*vide* Chart 3). It is further obvious that cotton planting after August 20th is out of the question. It is to be remarked that the feddans which produced the best yields last season were sown just as the bulk of the rain was falling.

There were rains on July 28th and 30th and August 1st, 2nd, 5th, 8th, 11th, 21st, 23rd, while the cotton was planted on July 20th and 30th and August 10th and 20th. The crop received no checks, as there were neither early cold winds nor was the young growth subjected to the withering influences of high temperatures, extreme aridity, or " habubs."

Such conditions, of course, represent the ideal, and reason seems to indicate that it is safest to sow cotton during June and the first half of July, as the risks attendant on later-sown cotton more than counterbalance the possible benefits to be derived from deferred planting.

Duty of Water.—Of the first importance is an adequate and exact knowledge of the duty of water for every crop. This varies with the locality and the texture of the soil. Porous, sandy soils require more water than heavy, clay land, but retain their moisture longer. It is therefore necessary to determine the duty of water and method of application best suited to each district. It would be impossible and absurd to expect figures approved for one centre to apply to the entire cotton belt of the Sudan.

As stated previously, the cotton plant is affected by atmospheric changes. When deleterious, such changes may, in a measure, be counteracted by a judicious application of water at the right moment. To be really effective, however, such control should be exercised before the change occurs, and though it may be possible to forecast the weather for twenty-four or even forty-eight hours, it would rarely be practicable to complete the watering of five or six hundred feddans from a single source of supply in so short a time.

It is, therefore, the object of all cotton growers to determine the amount of water and the intervals between waterings which will best meet the vicissitudes of the average season. Even when a formula which is likely to suit most seasons is devised, experience, or "instinct," must play a great part in the decision as to how far the system should be rigidly adhered to, and what departures should be made to meet unexpected or extraordinary changes.

The construction of a formula suited to the average season is, however, the first step to be taken, and to this end experiments have been conducted for the last three seasons over areas of 9 feddans.

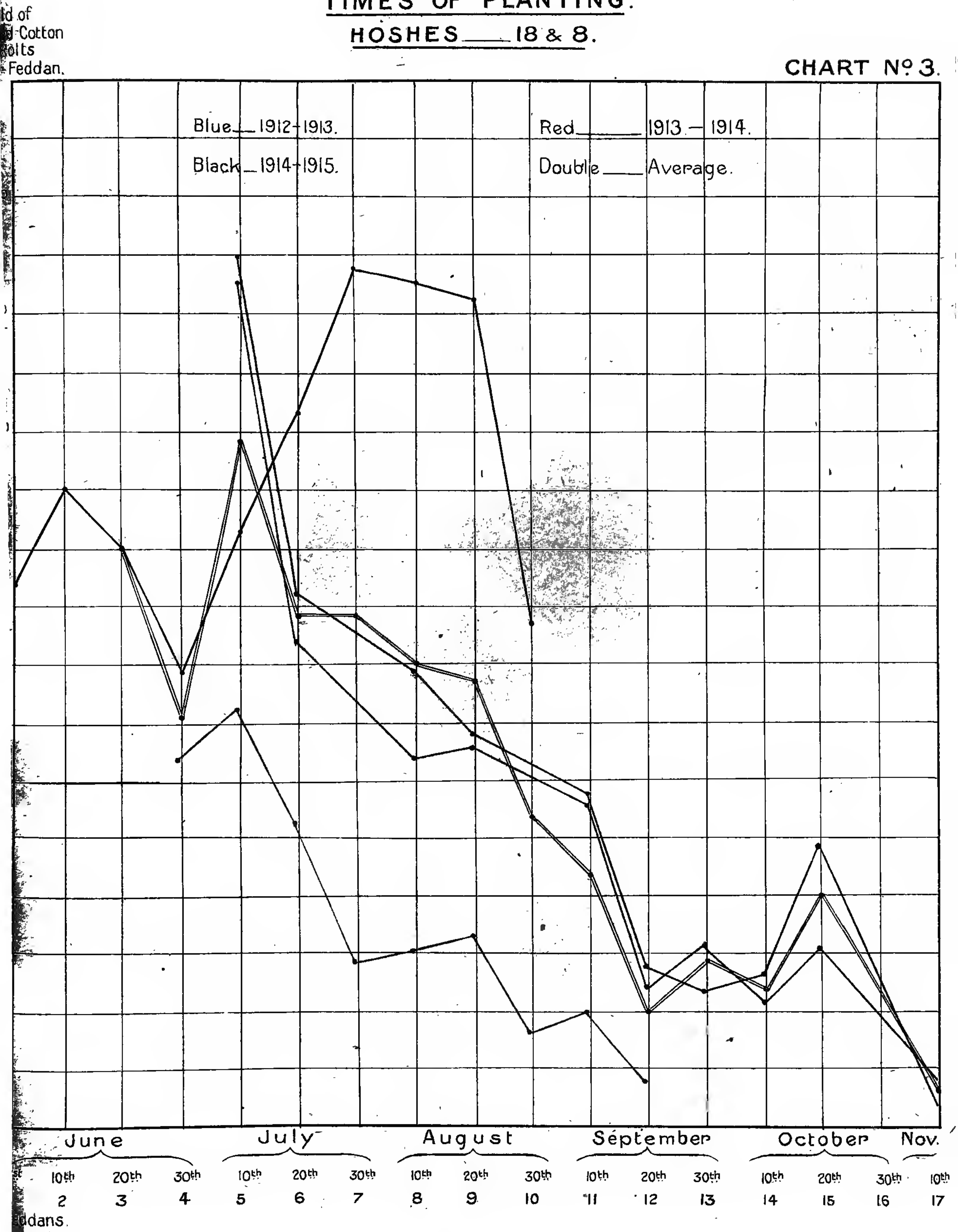
The following diagram illustrates the arrangement, amounts of water and intervals between waterings :—

	Fed. 9—300 cm^3 —20 days.
	Fed. 8—400 ,, —20 days.
	Fed. 7—500 ,, —20 days.
	Fed. 6—300 ,, —15 days.
	Fed. 5—400 ,, —15 days.
	Fed. 4—500 ,, —15 days.
	Fed. 3—300 ,, —10 days.
	Fed. 2—400 ,, —10 days.
	Fed. 1—500 ,, —10 days.

Times of Planting.

Hoshes — 18 & 8.

Chart No. 3.



Such an arrangement of plots conforms more nearly to popular field conditions than any other. Small plots arranged on the " scatter system " are bound to be influenced by neighbouring sections which receive a greater or less amount of water. The supply of water was regulated by a Gibb's Patent Module.

The yields to date have varied with the season, and it is still impossible to select any one feddan as an ideal. (*Vide* Chart No. 9.)

By a process of elimination, however, a provisional conclusion may be arrived at.

The " twenty-day " waterings are obviously inacceptable. The plants in Feddans 7, 8 and 9 were stunted and sparse ; few flowering branches developed and the yield was poor. The cotton matured very rapidly, however, only 141 days elapsing between planting and the first picking.

Of the " fifteen-day " waterings Feddans 5 and 6 seemed to suffer somewhat at times. The growth, though much better than in Feddans 7, 8, 9, was not continuous, and development was consequently spasmodic. Feddan 4 presented a much better appearance, growth being vigorous and sustained. The extra amount of water supplied seemed to carry the crop over to the next watering.

Maturity occurred at a later date than in the previous section, 174 days elapsing between planting and first picking.

The " ten-day " waterings present a difficult problem. Reference to Table A will show the comparative profits obtained from each feddan. The maximum yield was obtained from Feddan 1, and was obviously due to the enormous amount of water (12,500 cubic metres) which this plot received.

The low yield from Feddan 2 in the last season was due to the partial flooding of the soil, accentuated by a slight unevenness of surface probably attributable to the heavy leads of water.

The yield from Feddan 3 was very satisfactory and returned a profit not far short of that from Feddan 1. (Table A.)

TABLE A.

1914-1915 Crop.

Feddan.	Yield.	Gross Profit.	Cost of Production.	Nett Profit.
		£E. Mills.	£E. Mills.	£E. Mills.
1	1,377	13.770	7.200	6.570
2	886	8.860	6.300	2.560
3	1,154	11.540	6.000	5.540
4	816	8.160	5.500	2.660
5	892	8.920	5.200	3.720
6	703	7.030	4.700	2.330
7	770	7.700	4.600	3.100
8	588	5.880	4.150	1.730
9	491	4.910	3.800	1.110

TABLE B.

Average 1913-1914 and 1914-1915 Crops.

Feddan.	Yield.	Gross Profit.	Cost of Production.	Nett Profit.	Nett Loss.
		£E. Mills.	£E. Mills.	£E. Mills.	Mills.
1	1,007	10.070	5.950	4.120	—
2	754	7.540	5.325	2.215	—
3	910	9.100	5.000	4.100	—
4	718	7.180	4.675	2.505	—
5	693	6.930	4.425	2.505	—
6	569	5.690	4.075	1.615	—
7	515	5.150	4.000	1.150	—
8	369	3.690	3.575	0.115	—
9	281	2.810	3.275	—	0.465

NOTE.—Gross profit is reckoned at the rate of 10 millièmes per rotl of seed cotton, being somewhat less than the realised value of the crop. The cost of water for the purpose of this comparison was provisionally taken as 20 millièmes per 100 cubic metres. The actual cost over the entire season, 1914–15, was

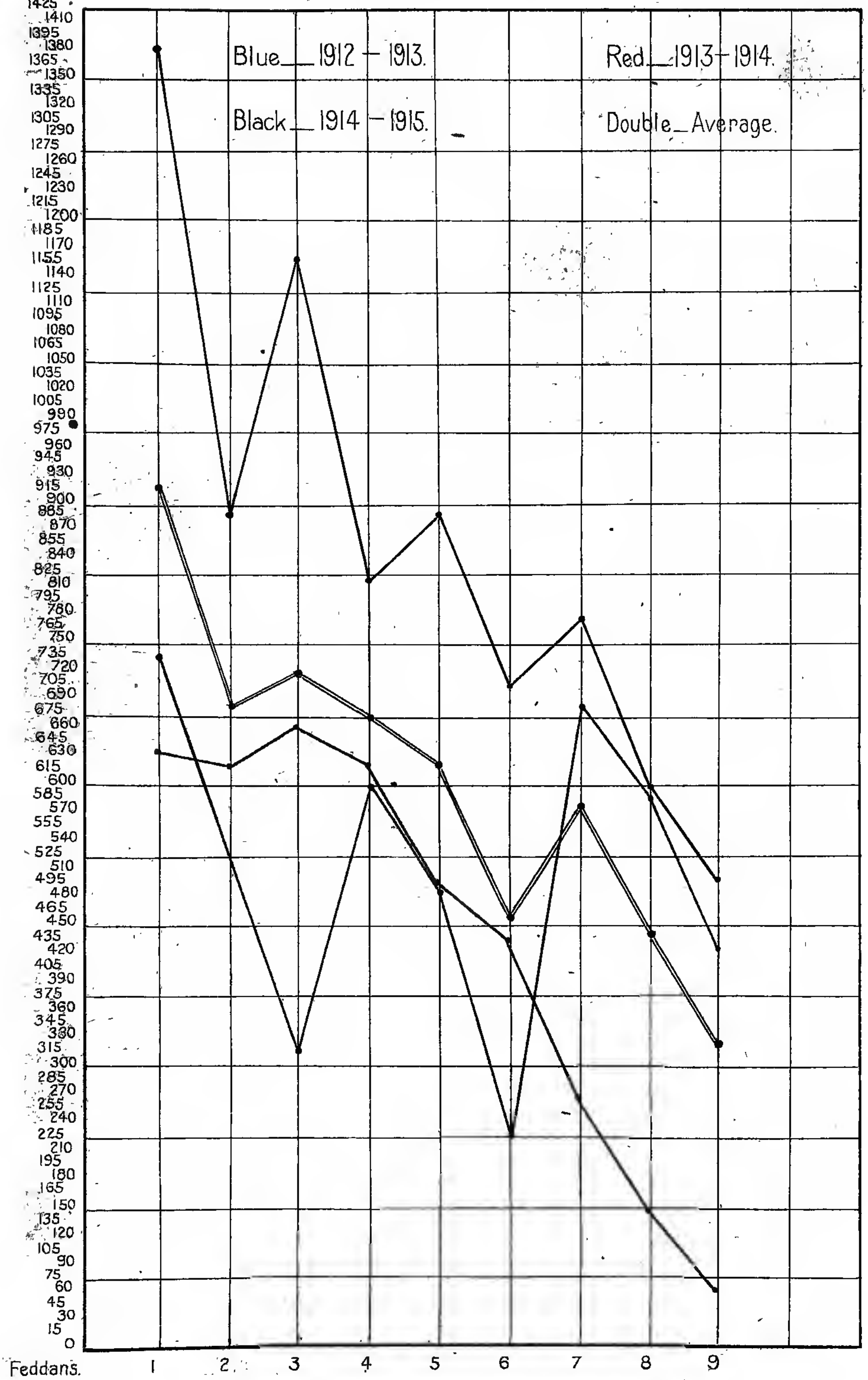
The Effect of Heavy Irrigation on the Cotton Plant.

DUTY OF WATER.

HOSHES 4.20.

CHART No. 4.

Yield of Seed Cotton in Rolts.



subsequently ascertained to be 26.6 millièmes, but recent developments would point to the possibility of establishing the former figure as a normal standard for the cotton crop.

If the mean of two seasons (Table B) be considered, the profit from Feddan 3 practically coincides with that from Feddan 1.

The appearance of the cotton in these three plots was much better than that of any other on the farm.

Feddan 3 produced well-grown, sturdy, vigorous plants with numerous lateral branches.

Feddan 2 was very patchy and uneven owing to the irregularities in the ground.

In Feddan 1 the growth was too luxuriant. The weight of bolls was more than the stems could sustain, and in many cases they snapped.

A study of the condition of the soil revealed the fact that the amount of water given to Feddan 1 was so excessive as to be a hindrance to both cultivation and the growth of the crop during the early stages. The surface actually never became dry between waterings, and thorough horse-hoeing and cleaning was impossible.

Picking was rendered very difficult by the muddy ground and the fact that the plants were interlaced and lodged in most cases.

Feddan 2 showed these features in less degree than No. 1, but for practical purposes may be classed with it.

Feddan 3, however, was always workable between waterings, except when rains coincided with a watering, and picking was not hampered by excessive growth. The cotton in this section took 189 days to mature.

It may thus be provisionally stated that the application of 300 cubic metres of water at intervals of ten days has proved the most suitable system of irrigation for cotton in this district.

Distance of Planting.—Areas of 10 feddans are set apart each season for this experiment, and the following spacings are employed :—

Fed. 1—120 cm.	× 45 cm.	= 7,600 hills		Fed. 6—100 cm.	× 45 cm.	= 9,300 hills.	
Fed. 2— 90 ,,	× 60 ,,	= 7.700	,,	Fed. 7— 80 ,,	× 45 ,,	=11,650	,,
Fed. 3— 90 ,,	× 45 ,,	=10,250	,,	Fed. 8— 90 ,,	× 60 ,,	= 7,700	,,
Fed. 4— 90 ,,	× 30 ,,	=15,400	,,	Fed. 9— 90 ,,	× 45 ,,	=10,250	,,
Fed. 5—120 ,,	× 45 ,,	= 7,600	,,	Fed. 10— 90 ,,	× 30 ,,	=15,400	,,

An average of the yields obtained during the last three seasons places Feddan 6 at the top of the list. (*Vide* Chart No. 5.) This is a fairly wide spacing—100 cm. between ridges and 45 cm. between plants. This gives approximately 9,300 hills to the feddan, or an area of ·45 square metres per hill. Each hill carries two plants. It has been found in Egypt that " two plants to the hill give about 10 per cent. higher yield than a single plant, since each one of the pair produces a little more than half the crop which a single plant would give and not one half exactly."*

A study of the averages returned by each spacing (*Vide* Chart No. 6) leads to the conclusion that when wider spacings than 100 by 45 are adopted, the yield depends upon the number of plants developing per feddan, while the yields from narrower spacings are reduced by root interference. In fact the influence of root interference on the yield is the chief problem which this experiment is designed to solve.

It seems most probable that in the Sudan the cotton plant requires a larger area from which to draw the water and plant food necessary to its growth than in Egypt, where the best return is obtained from a spacing giving 14,000 hills to the feddan.† This is probably due to the dearth of nitrogenous matter in Sudan soils, and the greater demand for water made by the plant.

The protection afforded by the extra shade and support of the closer-grown cotton does not influence the yield. During the earlier growth, when the plant is taking all its water from the first foot of the soil, the leaf area is not sufficient to extend any appreciable shade to the ground and consequently evaporation is high and the drying out of the soil is rapid. Later, when the plant is throwing an increased amount of shade, the root system has penetrated 3 or 4 feet below the surface of the soil and is drawing its water from a level practically unaffected by the sun and wind. "On the other hand, the free circulation of wind and the hot, dry surface soil around wide-sown plants increase their transpiration, but the self-regulation of the plant, as between the function of root and shoot, tends to minimise these differences. Thus wilting and stomatal closure on a hot afternoon appear to set in at nearly the same time in all spacings."‡

Arrangement as distinct from spacing, must also play a part in determining productiveness. Thus, cotton sown 80 by 60 did not yield as highly as that sown 90 by 30, although the area per hill afforded by the former method is greater. This result is probably due to interference with the roots by horse-hoes during the early stages. Eighty c.m. between ridges is the minimum distance which will permit employment of mechanical methods of cultivation with any degree of safety to the plant.

With the one-metre ridge not only is cultivation facilitated, but irrigation is carried out more rapidly and with less waste. The cotton soil of the Sudan cracks very badly as soon as it dries, and as small ridges dry up sooner and develop bigger cracks than large ones, they are much more liable to be washed away. The result of this is a waste of water and the loss of plants which fall down when the earth supporting them is carried away.

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* "Analysis of Agricultural Yields," Part I. Balls and Holton.

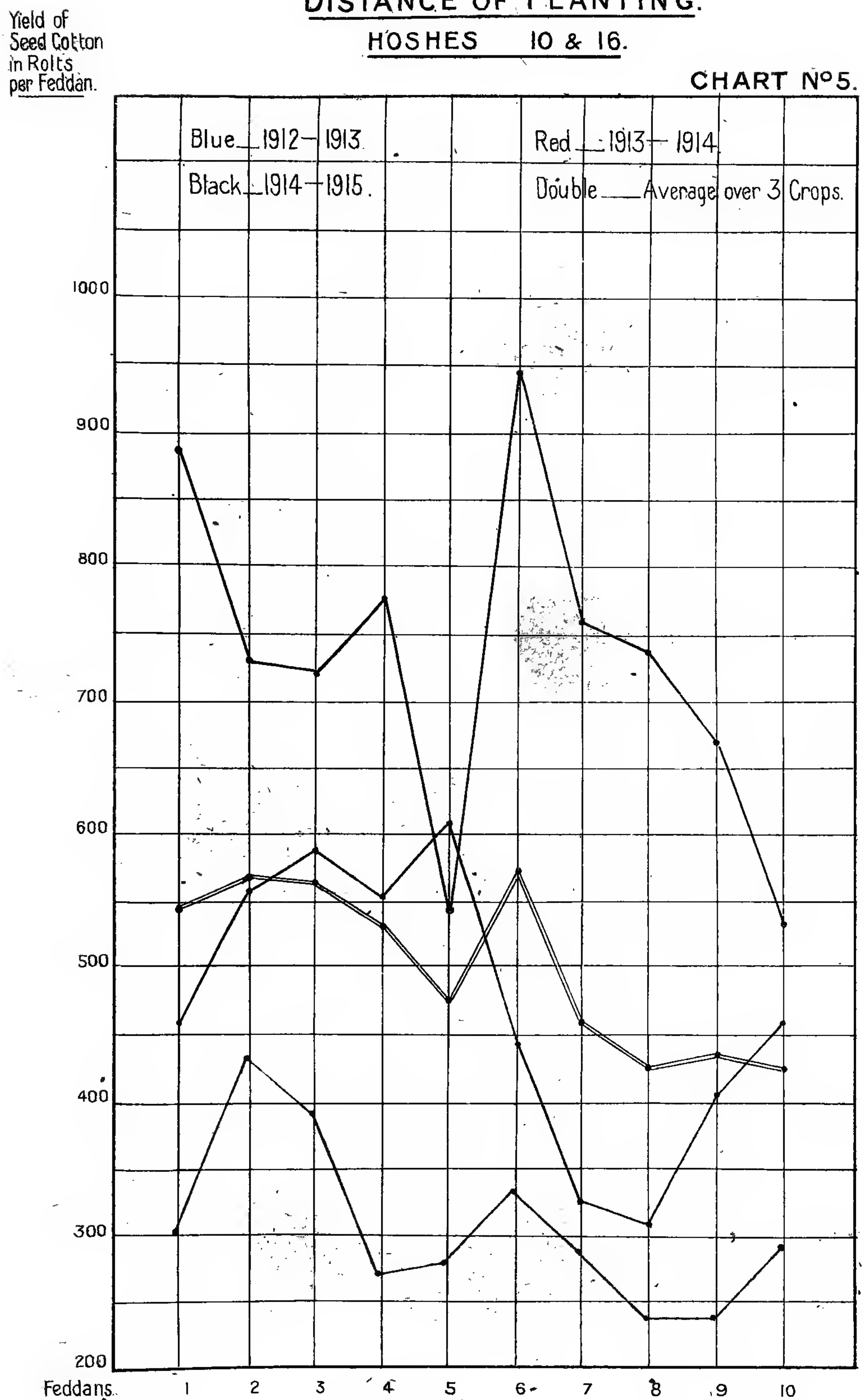
† *Ibid.*

‡ *Ibid.*

Distance of Planting.

Hoshes 10 & 16.

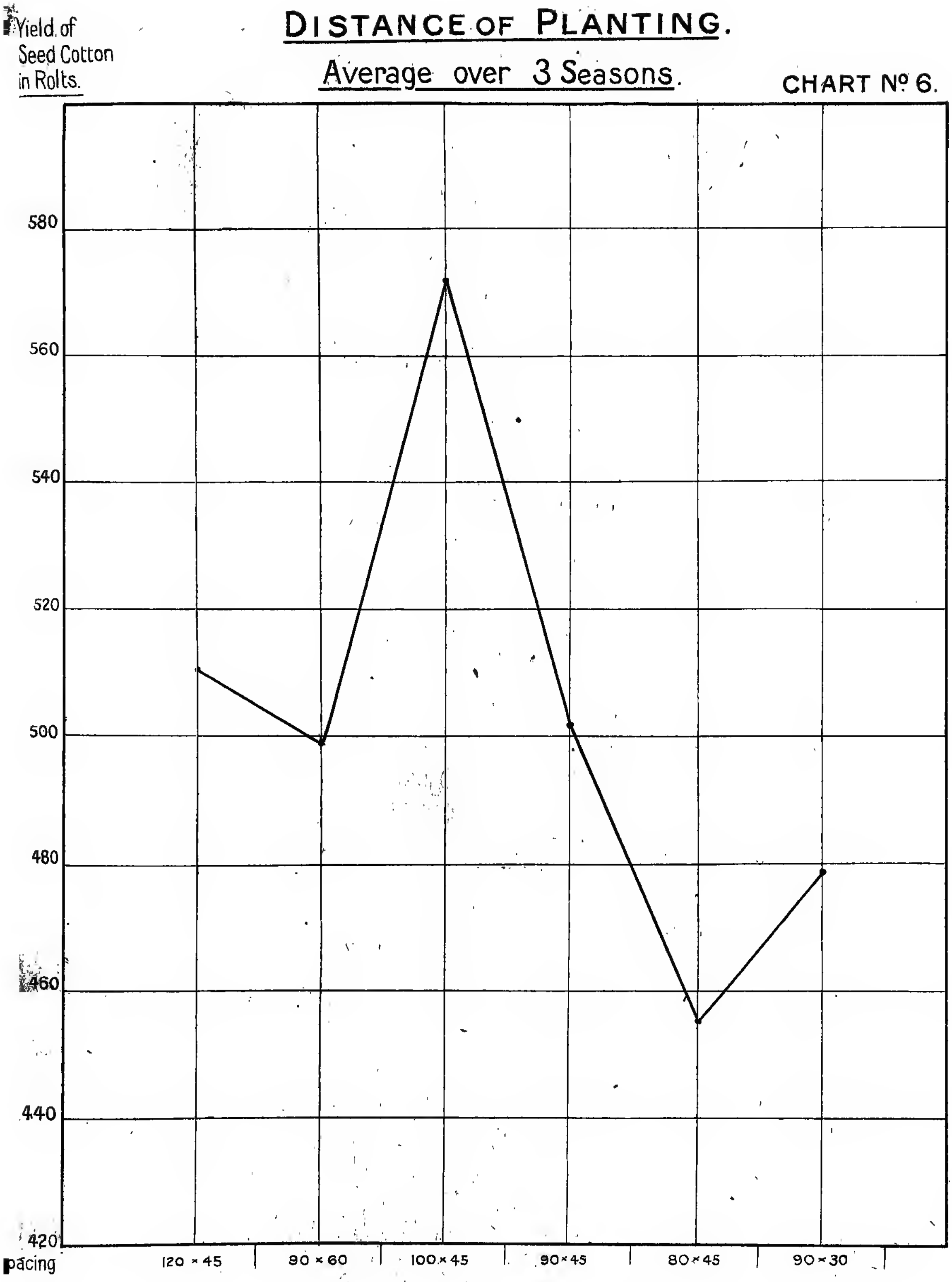
Chart N°5.



DISTANCE OF PLANTING.

Average over 3 Seasons.

CHART No. 6.



Picking also is considerably easier with a wide ridge ; fewer branches and bolls are broken off during the operation, and it is easier to keep the picked cotton clean.

It may, therefore, be provisionally stated that both from the point of yield and facility of cultivation a spacing of one metre between the rows, with 45 cm. between the hills of two plants, is the most suitable spacing and arrangement for cotton in this district.

Manuring.—Desert soils are remarkable for the high percentage of phosphates and potash which they contain and for the virtual absence of humus and nitrates in any form. The problem which confronts every agriculturist in the Sudan is consequently that of increasing the nitrogen content of the soil. Areas of 10 feddans are cultivated annually as a manure experiment. The feddans are bisected, half of each constituting a check plot while the other half is manured.

The following combinations of manures are applied :—

Plot 1A receives 10 tons farmyard manure, 300 lbs. superphosphate and 200 nitrate of soda.
Plot 1B check.
Plot 2A receives 10 tons farmyard manure.
Plot 2B check.
Plot 3A receives 100 lbs. nitrate of soda.
Plot 3B check.
Plot 4A receives 300 lbs. superphosphate and 200 lbs. nitrate of soda.
Plot 4B check.
Plot 5A receives 300 lbs. superphosphate.
Plot 5B check.
Plot 6A receives 200 lbs. nitrate of soda.
Plot 6B check.
Plot 7A receives 150 lbs. superphosphate and 100 lbs. nitrate of soda.
Plot 7B check.
Plot 8A receives 150 lbs. superphosphate.
Plot 8B check.
Plot 9A receives 100 lbs. nitrate of soda.
Plot 9B check.
Plot 10A receives 50 lbs. nitrate of soda.
Plot 10B check.

The results were remarkably similar in each year (*vide* Chart No. 7). They clearly indicate that the addition of superphosphate to the soil is not only unnecessary but has a limiting effect on the yield. In each case where superphosphate has been applied alone, the yield has fallen below that of the check plot.

Where superphosphate is applied in conjunction with farmyard manure or nitrate the yield has been proportionately reduced.

Where nitrate of soda is applied alone the yield shows an extraordinary advance on that of the check plot. The application of farmyard manure has a similar effect.

It will be readily admitted by all who have come into contact with Sudan cotton soil that an increase in the amount of humus is very necessary. This is most readily and economically provided in the shape of green manures.

The limited production of farmyard manure, and its extensive employment in the form of "zibla," for the plastering of mud-brick buildings, coupled with its speedy deterioration in so arid a climate, render this source of organic nitrogen little available for extensive agricultural operations.

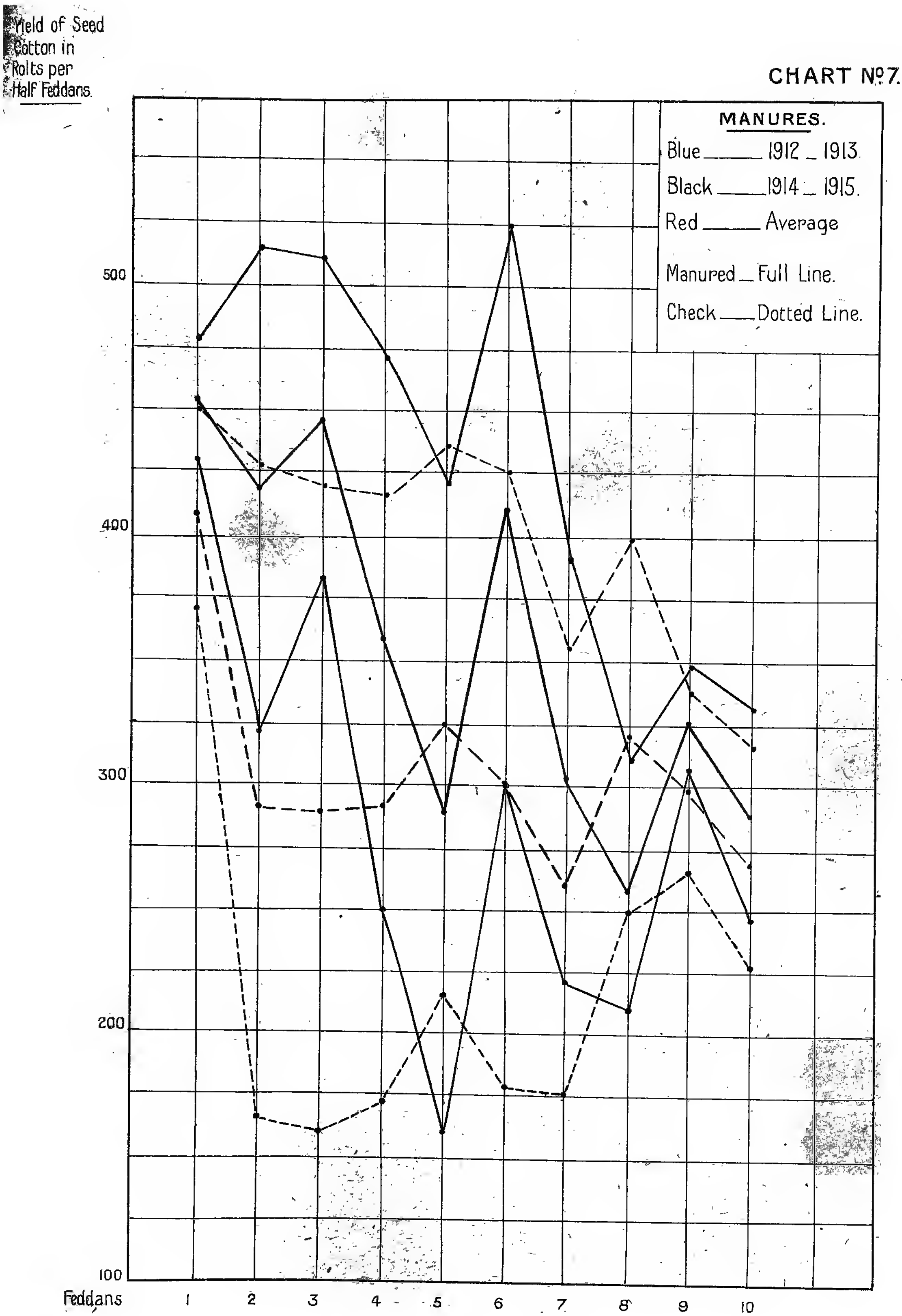
Lubia afin (*Dolichos lablab*) is without doubt the best green manure for this district. It is a legume, and thus increases the nitrogen content of the soil during growth; it is extremely hardy, grows luxuriantly, and requires little cultivation or attention. It is a profitable crop to grow either for fodder, *provided a contract for its disposal in a green form has been concluded*; or for the manufacture of hay, when a forage baler is necessary, as there is always a ready sale for the hay in Khartoum provided it is in a portable form; or as a seed crop, the grain constituting an article of native diet.

If it is to be used as a green manure it may be cut just as flowering starts and converted into hay or sold green. The stubble should then be watered immediately after cutting, when a new growth will develop. This may be watered twice and then ploughed under. Care should be taken not to cut the plant off too near with the ground, but to leave a 6-inch stubble to carry the second growth.

The improvement in the physical qualities of the soil due to the introduction of green manure is not so noticeable or so lasting in this country as in others, as all visible traces of roots, stalks, etc., disappear in a very short time.

As explained elsewhere, however, such destruction is in reality a process of nitrification, and if accompanied by crop growth and irrigation does not fail in its purpose. Periodic treatment of this nature is almost indispensable to successful cotton cultivation, and must ultimately result in a marked and permanent improvement in the soil.

Sheep-feeding Experiments.—Restorative crops are by nature feeding crops, and the necessity of their inclusion in any rotation opens the question of the place of livestock in any local system of agriculture. While a regular market exists for small quantities of green forage and lubia hay, profitable disposal of large acreages of the few leguminous crops which flourish on our heavy cotton soil must be based on the general introduction of dairy or butchers' stock.


Yield of Seed Cotton in Rolts per Half Feddans.
CHART No 7.
MANURES.
Blue 1912 _ 1913.
Black 1914 _ 1915.
Red Average
Manured _ Full Line.
Check Dotted Line.
500
400
300
200
100
Feddans
1
2
3
4
5
6
7
8
9
10

For the last three years experiments in the fattening and sale of sheep have been carried out.

Following are the results :—

Year.	Buying Price.	Time Kept.	Sale Price.	Profit.
				%
1913	276.8 m/ms.	4 months	548.5 m/ms.	271.7 or 94·2
1914	306.2 m/ms.	7 months	580.6 m/ms.	274.4 or 89·6
1915	298.4 m/ms.	8 months	650.0 m/ms.	351.6 or 117·8

Average Buying Price ... ... 293.8 m/ms.
Average Sale Price ... ... 593.0 m/ms.
Average Profit ... ... 299.2 m/ms.

Or 100·5 % on a turnover of 6·3 months.

N.B.—Cost of supervision is included in buying price.

No crops were fed at any time, as sheep were grazed over gadwels, stubbles and cotton stalks. It was determined that an average of 200 feddans, organised for perennial irrigation, could in this way regularly carry 100 head of sheep. Were lubia to be fed in addition, this number could probably be quadrupled.

A similar experiment with young steers has since been instituted, and it is much regretted that financial considerations prohibit any investigation of the potentialities of dairy farming as an adjunct to the cultivation of cotton.

Cost of Agricultural Operations.—Of no less importance than the determination of approved methods of cultivation and irrigation, is a clear understanding of the system advocated as a business proposition. Costs of production in local conditions are necessarily high, and such methods, involving the introduction of expensive machinery and more thorough tillage, necessarily involve considerable capital expenditure, and an enquiry will naturally arise as to the security of such investment.

The costs detailed below embrace all ordinary field operations, and are based on data carefully recorded over a period of three years :—

Ploughing—with mouldboard plough	432	m/ms. per feddan.
Cross-ploughing—with mouldboard plough	374	,, ,, ,,
Ploughing—with disc plough	550	,, ,, ,,
Harrowing—tine harrow	055	,, ,, ,,
Harrowing—disc harrow	070	,, ,, ,,
Clod Crushing—Cambridge Roller	109	,, ,, ,,
Levelling or Making Hods	117	,, ,, ,,
Ridging (first time)	133	,, ,, ,,
Hand Work	146	,, ,, ,,
Watering	049	,, ,, ,,

Planting	080	m/ms.	per feddan.	
Re-patching	025	,,	,,	
Thinning (cotton)	040	,,	,,	
Horse-hoeing	060	,,	,,	
Hand-hoeing	160	,,	,,	
Re-ridging	060	,,	,,	
Picking Cotton	000.85	m/ms.	per	roll.
Cutting Wheat	275	m/ms.	per feddan.	
Ginning	130	,,	,,	kantar.
Threshing	030	,,	,,	,,
Water	266	,,	,,	1,000 cu. m.

Cost of Production of Cotton per Feddan.

	m/ms.
Ploughing	132
Cross-ploughing	371
Rolling	109
Ridging	133
Hand Work	146
Planting	80
Re-patching	25
Thinning	40
Horse-hoe—3 times	180
Hand-hoe—3 times	480
Ridging—3 times	180
Watering—14 times	686
Water	1.792
Picking—3 kantars	803
TOTAL	£E.5.460

Cost of Production of Wheat per Feddan.

	m/ms.
Ploughing	132
Cross-ploughing	371
Rolling	109
Making Hods	117
Planting	80
Hand Work	146
Re-patching	25
Harrowing—twice	110
Watering—7 times	313
Water	896
Cutting	275
Threshing—10 kantars	300
TOTAL	£E.3.207

The latter statement does not, however, take into account the results of employing a modern threshing plant, which our financial resources are inadequate to purchase, and its absence affords a striking example of the losses involved by the primitive methods of harvesting in general vogue. Last season's wheat crop was cut by the end of March and stacked on one of the feddans in the field. A portion of the feddan was prepared as a threshing floor by coating it with zibla, the ordinary native method.

This operation cost £E 1.330 for labour alone.

Threshing was commenced at once. When this was finished, at the end of May, the feddan was watered before ploughing, and the quantity of wheat which germinated induced the writer to attempt a calculation of the loss sustained.

Ten squares, each 5 cm. by 5 cm., were marked out at random over the threshing floor and neighbourhood. The seedlings growing in each square were counted and the average found to be approximately seventy. The following figures speak for themselves :—Seventy seedlings per 25 square cm.=117,600,000 per feddan. As 800 grains weigh one ounce, the total loss from this threshing floor and neighbourhood was 9,187 lb. Reducing this figure to a half for safety's sake, and taking the normal price of wheat as five millièmes per rotl, the total loss from this one floor was at least £E.22.965.

Some ten or twelve similar floors were employed for threshing the native wheat crop on land supplied with water from the farm pumps, with an equivalent multiplication of this loss.

It is unfortunate that this is the only loss that can be estimated, as the crop was not weighed as it was cut. It remained stacked in the open for three months, and the amount eaten by birds, vermin and stray animals, to say nothing of the quantity of "tibn" (threshed straw) blown away during threshing, may be imagined.

If a threshing machine with a capacity of 35–50 bushels per hour had been available for dealing with the crop, the operation would have been completed in ten hours at a running cost of not more than £E.1, when the plant would have been available for the treatment of the native crop. As it was, it took three months at a cost of £E.7.500 for threshing on the one floor, in addition to £E.1.330 for laying the floor, and £E.2.700 wages of a watchman ; to which has still to be added wheat to the value of £E.22 left on the ground.

Cost of Production of Lubia Afin per Feddan.

	m/ms.
Ploughing ...	432
Disc harrowing ...	70
Ridging ...	133
Planting ...	80
Hand Work ...	146
Re-patching ...	25
Horse-hoeing—twice ...	120
Hand-hoeing—twice ...	320
Ridging—twice ...	120
Watering—6 times ...	294
Water ...	768
Cutting ...	200
TOTAL ...	£E.2.708

Cotton and Wheat Accounts.—To the above costs of production must be added in the case of the cotton crop for which no organised local market exists, expenses for ginning and baling, and transport charges to the European market. Local disposal of wheat and lubia has proved the more profitable.

The very fair average crop of three kantars of cotton and a barely satisfactory return of 984 rotls of wheat per feddan, taken from our revenue hoshes in 1914–15, may be used to illustrate the incidence of all costs of production and the resulting profits with normal charges and prices.

Cotton Account.

A three-kantar yield from 22 feddans ... ... =20,790 rotls.
or { 6,930 rotls lint. 13,860 rotls seed.

COSTS.	£E.m/ms.
Sixty-six large sacks @ 80 m/ms. each ...	5.280
Ginning, handling, weighing, @ 130 m/ms. per kantar ...	8.580
Seventy sacks for seed @ 30 m/ms. each ...	2.100
Transport from Khartoum to Port Sudan on lint, including handling at Port Sudan ...	9.753
Ditto ditto on seed ...	6.237
Transport on lint, Port Sudan–Liverpool ...	7.795
Transport on seed, Port Sudan—Liverpool ...	7.795
	£E.47.540

6,930 rotls cotton @ 9.5d. or 38 m/ms. ...	£E.263.340
Less brokerage and charges ...	6.048
	£E.257.292

A Cotton Crop on the Experimental Area, Central Research Farm.

A Groundnut Crop at Tuti Island.

Cotton Account—*continued.*

13,860 rotls cotton seed @ £E.7.500 per metric ton		£E.103.850
Less brokerage @ 2 m/ms. %...		2.596
		£E.101.254
Nett proceeds—Sale of lint		£E.257.292
Sale of seed		101.254
		£E.358.546
Cost of transport, sacks, ginning		£E.47.540
Cost of growing, 22 feddans @ £E.5.460		120.120
		£E.167.660
Result	£E.358.546	
	167.660	
Nett Profit	£E.190.886	or £E.8.677 per feddan.

Wheat Account.

The wheat crop, 1914–15, yielded 246 kantars (of 100 rotls) of grain and 300 kantars (of 100 rotls) of "tibn" from 25 feddans.

£E.2.000 may be regarded as a normal price for the large ardeb of 400 rotls of wheat :—

61.5 ardebs @ £E.2.000		£E.123.000
300 kantars tibn @ 100 m/ms.		30.000
		£E.153.000
Cost of Production.		
25 feddans @ £E.3.207		£E.80.175
Result	£E.153.000	
	80.175	
Nett Profit	£E. 72.825	or £E.2.913 per feddan.

Disposal of Lubia Crops.—Lubia afin is a very much underrated crop from a commercial point of view.

The fact that it is a legume and will grow all the year round should be sufficient argument for its inclusion in all rotations without question. It will be seen from the following figures that it is a profitable crop to grow, apart from the foregoing reason.

In 1912 a contract for the supply of green lubia fodder to the Municipal Dairy at Khartoum was obtained. The price agreed upon was 60 millièmes per kantar, and the supply was to continue uninterruptedly for twelve months.

The average yield per feddan, over three years, was 130 kantars. This shows a return of £E.7.800 per feddan, while the cost of production was only £E.2.708.

As the trade in export cattle and sheep grows, so will the demand for fodder of this description. It must be baled, however, as in any other form it is costly and wasteful to handle on trains, ships, etc.

The profits to be made from growing the crop for seed are uncertain, depending, as they do, on the fluctuations of local market prices. Another watering would have to be given, thus increasing the cost of production to £E.2.885. Cost of picking is about the same as for cutting. The market price for seed ranges between 100 millièmes and 750 millièmes per kantar. During 1913, 7,856 rotls were collected from an area of five feddans. This at 250 millièmes per kantar is equivalent to £E.19.640, or £E.3.930 per feddan.

That the fattening of sheep for sale is a profitable undertaking has been demonstrated earlier in this report. Whether or not it would pay at the present time to grow extra food for them remains to be proved.

Increased competition among sellers and greater discrimination among buyers of this type of stock will naturally cause more attention to be paid to the feed, and no better feeding crop than lubia afin is to be found in the Sudan.

REPORT III

THE INFLUENCE OF ENVIRONMENT AND AGRICULTURAL TREATMENT ON THE COTTON CROP.

R. E. MASSEY, *Economic Botanist.*

In the present report it is proposed to consider briefly the effect of the various environmental factors already described on the development of the cotton plant.

Owing to the impossibility of obtaining an artificial approximation to field conditions by laboratory methods, precise data on the physiology of the plant are lacking. Moreover, the operating factors influencing and limiting development are so interwoven that an attempt to isolate any one for comparative development has always resulted in failure. A scheme of observations has therefore been elaborated by which the most salient features of the life history of the plant may be correlated to some extent with the measurable factors of the environment.

Methods.—The general arrangement of the experimental plots has been described elsewhere, and it only remains to add that in each plot rows were marked off, from which all observations were taken throughout the season. In many instances the experimental area consisted of half a feddan, the other half being employed as a control or check plot. To ensure uniformity, an observation row was chosen in each half, so that every feddan contained two such rows. Weekly measurements and counts were made of the following features :—(*a*) height, (*b*) number of flowers, (*c*) the number of bolls per plant, (*d*) number of open bolls per plant. The minimum number of plants employed was a hundred, except in the case of the height, where the average of twenty-five was found sufficient.

It will be fairly obvious that when conducting a number of experiments each season with a limited supply of labour, uniformity of agricultural treatment could not be ensured if the laborious chessboard system of plots were adopted. It was felt that sufficient accuracy could be obtained and inequalities due to the soil eliminated, if observations were taken from a row extending the whole length of the plot.

A comparison was made of the two methods by dividing a plot into a number of equal areas and counting groups of thirty-five plants in each.

The following count of the number of bolls per plant is typical of the results obtained :—

Number of bolls per plant from two observation rows :—

Average of 200 plants ... ... 3·1

Averages of groups of thirty-five plants counted in different squares of plot : 3·1, 3·5, 3·0, 3·2, 3·0, 3·2, 3·0, 3·2, 3·1.

Furthermore, it is not intended to make any final statement until confirmation has been obtained by repeated observations extending over several years.

A few words are necessary in explanation of the methods used in the laboratory. The length of the fibres has been obtained by combing out the lint from the seed, and measuring to the extreme length of the halo by means of dividers. Strength has been estimated by a home-made machine similar to that invented by O'Neill.* This machine has never been standardised with any other, so that the figures obtained are purely comparative. It is believed, however, that they are approximately correct. "Ginning percentage" was obtained by ginning 500 grammes of seed cotton with a hand-roller gin and dividing the weight of lint obtained by five. "Weight of Seed" was calculated as the average of 250 seeds.

SECTION I.

The Influence of Climate and Soil on the Growth of the Cotton Plant.

Before discussing the effect of agricultural treatment on the crop, it will be well to review the scanty available data bearing on the influence of climate and soil on the growth of the plant.

Temperature and Growth.—During the period of most active growth, that is, from July to September, there are usually very few days when the daily maximum temperature does not exceed the optimum for healthy development. Daily measurements of the increase in height have shown that the maximum amount of growth takes place not in the daytime, but between sunset and the early hours of the morning.

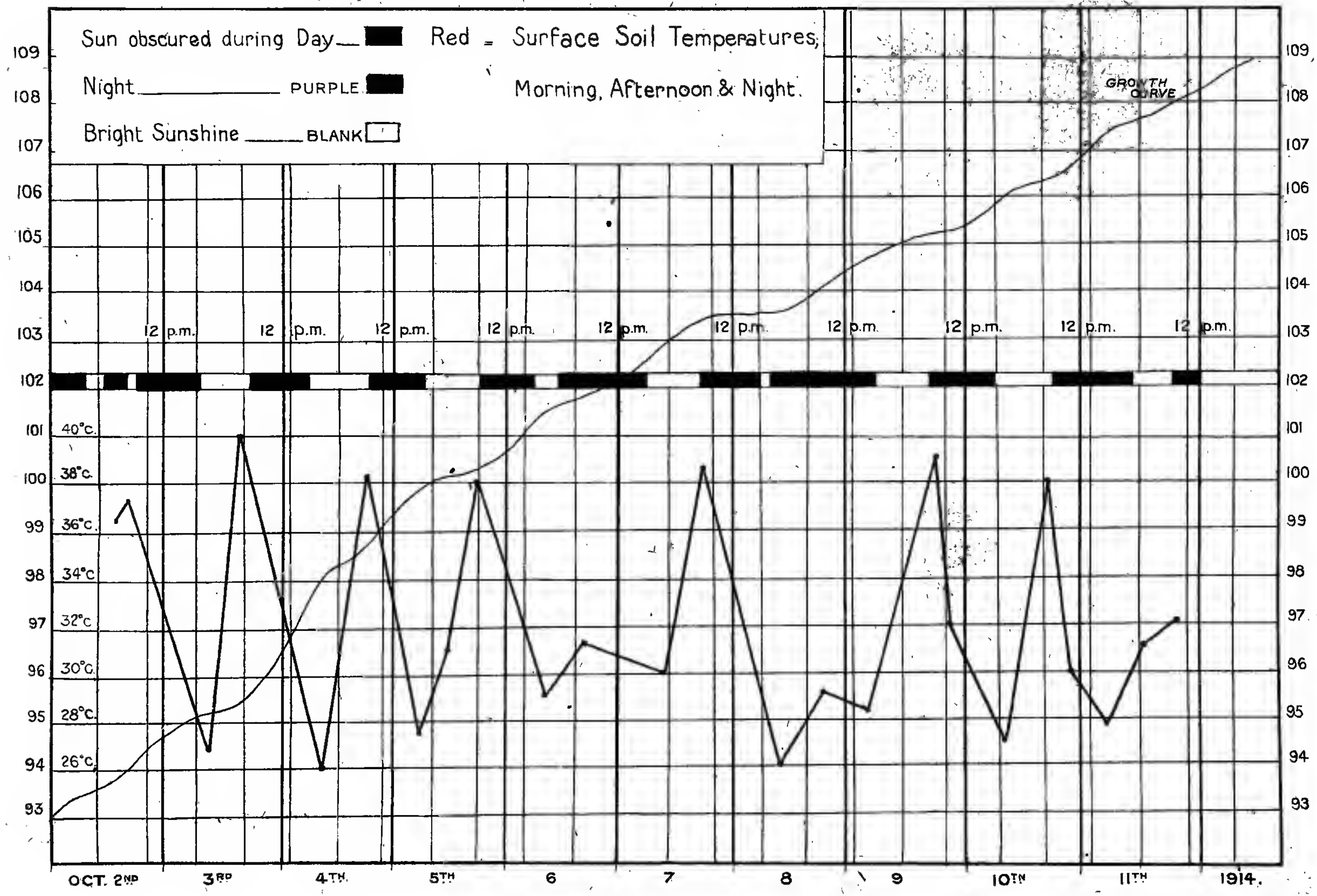
Should the night temperature remain high, growth is continuous until dawn, when inhibition soon occurs by reason of the increasing intensity of the sun's rays. This "sunshine effect" is very marked in the Sudan and is due to the excessive strain thrown on the transpiratory organs of the plant.†

The alternate rise and fall in the growth rate, and the effect of direct sunshine are well brought out in Fig. 1. The growth curve was obtained by

* Henry : "Détermination de la valeur commereiale des fibres de coton," p. 36.
The very ingenious method of mounting the fibres introduced by Hughes was used throughout the work.

† Balls : "The Cotton Plant in Egypt."

INFLUENCE OF SUNSHINE ON GROWTH.



means of an auxanometer, and the soil temperatures were recorded by a thermometer, the bulb of which was immersed in the soil.

While the plant is growing vigorously it is not unusual to observe the increase of 1 cm. in height in a single night, but as the season advances and the temperature after midnight decreases, the growth rate falls to 0·2 cm. or 0·1 c.m. each night, and at a temperature of about 58 deg.F. growth is inappreciable.

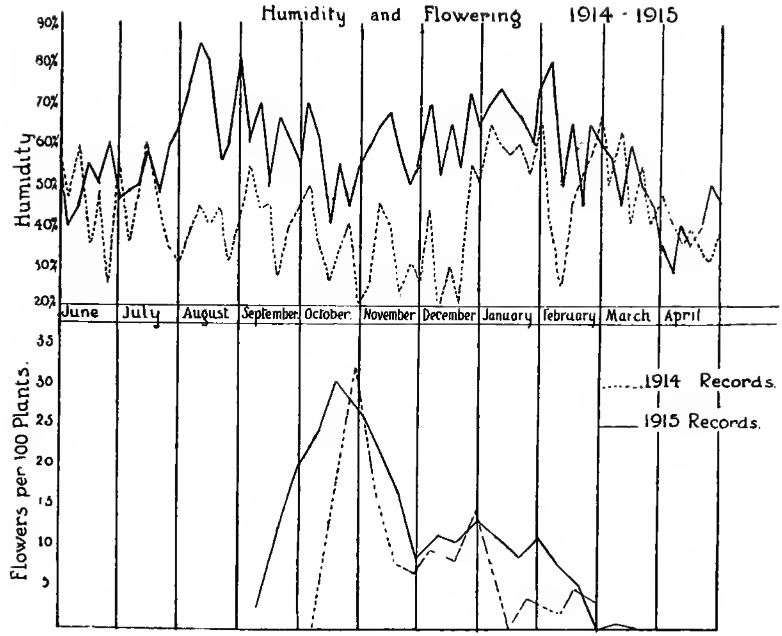
Soil Conditions and Growth.—The cessation of growth is not, however, only caused by a lowered temperature. On stiff clay soils, in which penetration is difficult and the movement of water slow, incomplete development and stunting are often caused by root limitation. The water requirements of a cotton plant are very great, and should the root system prove inadequate, owing to the mechanical difficulties imposed by the texture of the soil, the effect is at once observable in the stunted, straggly condition of the aërial portion.

Fortunately no trouble has as yet been experienced from water-logging of the soil, which might result either from a rising water-table or from excessive irrigation. As it has been shown, the natural water-table lies very low, and, even with heavy irrigation, the water content of the subsoil never approaches saturation point under the conditions stated. Water, however, tends to accumulate at a depth of about two metres and without an efficient drainage system, continued irrigation would finally result in the formation of an artificial water-table, which would not only give rise to root asphyxiation, but would be the cause of an increasing accumulation of alkali in the surface layers as a result of capillary action and evaporation.

Humidity and Growth.—While temperature is undoubtedly the limiting factor during early growth, the water supply becomes of increasing importance as the season advances and the humidity of the atmosphere becomes less. At the onset of the dry winter winds a considerable amount of foliage is always shed to maintain the equilibrium between absorption and transpiration of water. This loss of assimilatory surface must affect the productive power of the plant, and both the yield and the quality of the lint suffer in consequence.

By a fortunate chance the season 1914–15 was unusually humid, and a definite proof has been obtained of the above statements. Little change was noted in the height of the plants, but the vegetative development greatly exceeded that of previous years. It will be sufficient at the moment to present the flowering and the humidity curves of the last two seasons, leaving the evidence secured from the lint to be considered later.

Date of Planting



SECTION II.

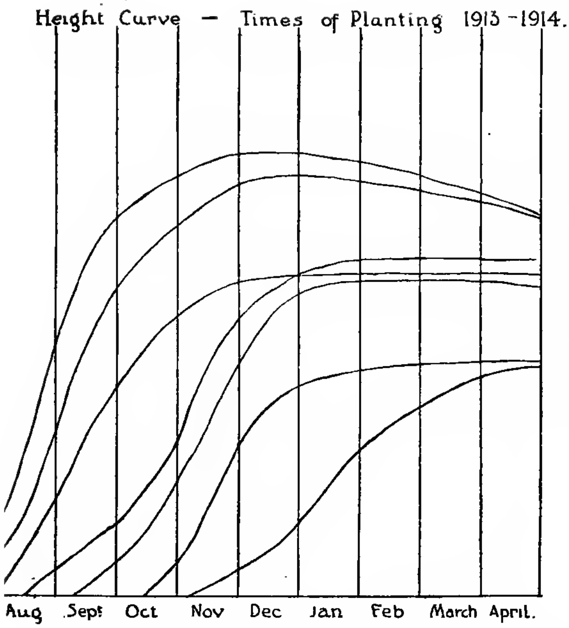
The Influence of Cultural Operations on the Growth of the Cotton Plant.

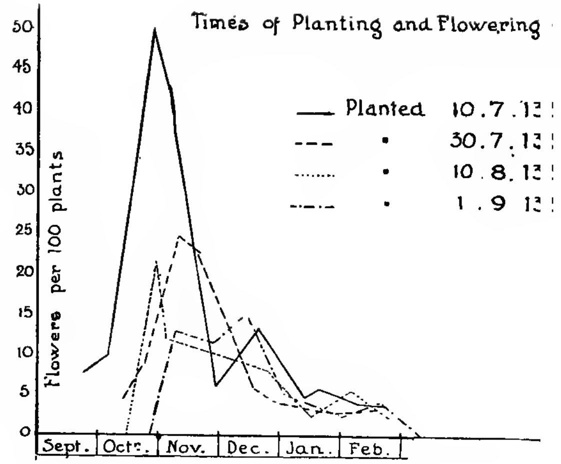
Turning to the environmental features over which definite control can be maintained, it is desirable to consider in detail the influence of various cultural operations on the development of the plant. These may be conveniently discussed under the following heads :—

(*a*) Time of sowing.
(*b*) Irrigation.
(*c*) Manuring.
(*d*) Distance of planting.
(*e*) Cultivation.

As space will not permit the inclusion of all the data obtained, representative figures only will be quoted, and graphs will be introduced where possible.

Times of Planting.—In view of the depressing effect of a decreasing temperature already established, it is only to be expected that all the records obtained over a period of three years would indicate the advisability of early planting. Unfortunately, no sowings earlier than June could be made on the farm, and the critical period for this locality has not yet been definitely established. The height curves of a series of plots sown at different dates are charted in the accompanying graph. When it is realised that the development of branches, and consequently of flowers, is directly connected with the development of the main axis, the commercial importance of early sowing becomes obvious. The flowering curves for the same series of plots are also appended.





The most interesting results have, however, been furnished by an examination of the seed cotton. Nothing could be more definite than the effect of the climatic environment on the quality of the lint. It seems probable that the whole explanation of the quality of the lint, whether length, strength or the ginning percentage be considered, lies in the climatic environment during the period of maturation in the boll, provided that the water supply is adequate and cultivation normal.

It has been stated that warm nights and a comparatively humid atmosphere are the most favourable conditions for development. An inspection of the meteorological data will show that these conditions obtain during the first half of the life-history of the crop rather than during the second portion. Therefore if our hypothesis is correct, the early-maturing cotton should be of better quality than that gathered later on, even though the latter be the first picking from the parent plants.

Effect of Time of Planting on Length of Cotton.—A tabular analysis of the records obtained during the season 1914–15 is given below :—

Length of Cotton Fibres in mm.

SAKEL, 1915.

Date of Sowing.	Length of First Picking.	Length of Last Picking.	Difference.
1–6–14	34·5	33·7	0·8
10–6–14	34·0	31·4	2·6
20–6–14	33·8	29·7	4·1
20–6–14	33·0	29·8	3·2
10–7–14	32·3	28·7	3·6
20–7–14	32·1	26·3	5·8

Length of Cotton Fibres in mm.—*continued.*

AFIFI, 1914.

Date of Sowing.	Length of First Picking.	Length of Last Picking.	Difference.
1–7–13	30·4	26·7	3·7
10–7–13	32·0	26·3	5·7
20–7–13	29·4	25·6	3·8
30–7–13	29·0	—	—
1–9–13	27·6	26·3	1·3

When the pickings from the whole of this particular experimental area are grouped together the decrease in the length is still noteworthy. Cultural treatment was precisely the same in each plot, the only variation introduced being the different times of sowing :—

SAKEL, 1915 SEASON.		AFIFI, 1914 SEASON.	
Date of Picking.	Length of Cotton.	Date of Picking.	Length of Cotton.
	mm.		mm.
11–10–14	33·4	(No pickings in October.)	
19–10–14	34·0	20–11–13	31·2
2–11–14	33·2	7–12–13	28
29–11–14	33·5	24–12–13	29·2
3– 1–15	33·0	8– 1–14	28
18– 1–15	32·0	24– 1–14	28·4
13– 2–15	32·7	12– 2–14	27·8
2– 3–15	32·4	2– 3–14	27·3
6– 3–15	30·5	14– 3–14	26·2

The apparent discrepancy between the two sets of figures is caused by the grouping of the first pickings of the later-sown cotton with the last pickings of the earlier-sown plots.

Typical Development of the Cotton Plant in the Northern Sudan.

Effect of Time of Planting on Strength of Cotton.—When we consider the strength of the fibres expressed as the breaking strain in grammes, we find a similar but less pronounced falling off in the values. It is not until the remnants, so to speak, of the cotton crop are examined that an appreciable loss of quality is evident. Moreover considerable variation in the strength of the fibres is found during the earlier part of the picking season :—

Variation in Strength of Fibres throughout Season.

Afifi, 1914.		Sakel, 1915.	
Date of Picking.	Strength in Grams.	Date of Picking.	Strength in Grams.
20–11–13	6·7	11–10–14	5·4
7–12–13	7·0	20–10–14	4·9
20–12–13	6·7	2–11–14	4·8
24– 1–14	6·4	29–11–14	5·0
12– 2–14	5·9	13– 1–15	4·8
2– 3–14	6·1	13– 2–15	5·1
14– 3–14	5·9	2– 3–15	5·0
		7– 3–15	5·2
		3– 5–15	4·6

Variation in Individual Plots, 1915.

	First Picking.	Last Picking.	Difference.
Early sowing ...	5·4	5·2	0·2
Medium „ ...	5·2	5·0	0·2
Late „ ...	5·2	4·6	0·6

The variations in the ginning percentage are remarkably definite, and the range has been very similar throughout the three years that observations have been made, in spite of the fact that a different kind of cotton, *i.e.*, Sakel, was grown in the year 1915 :—

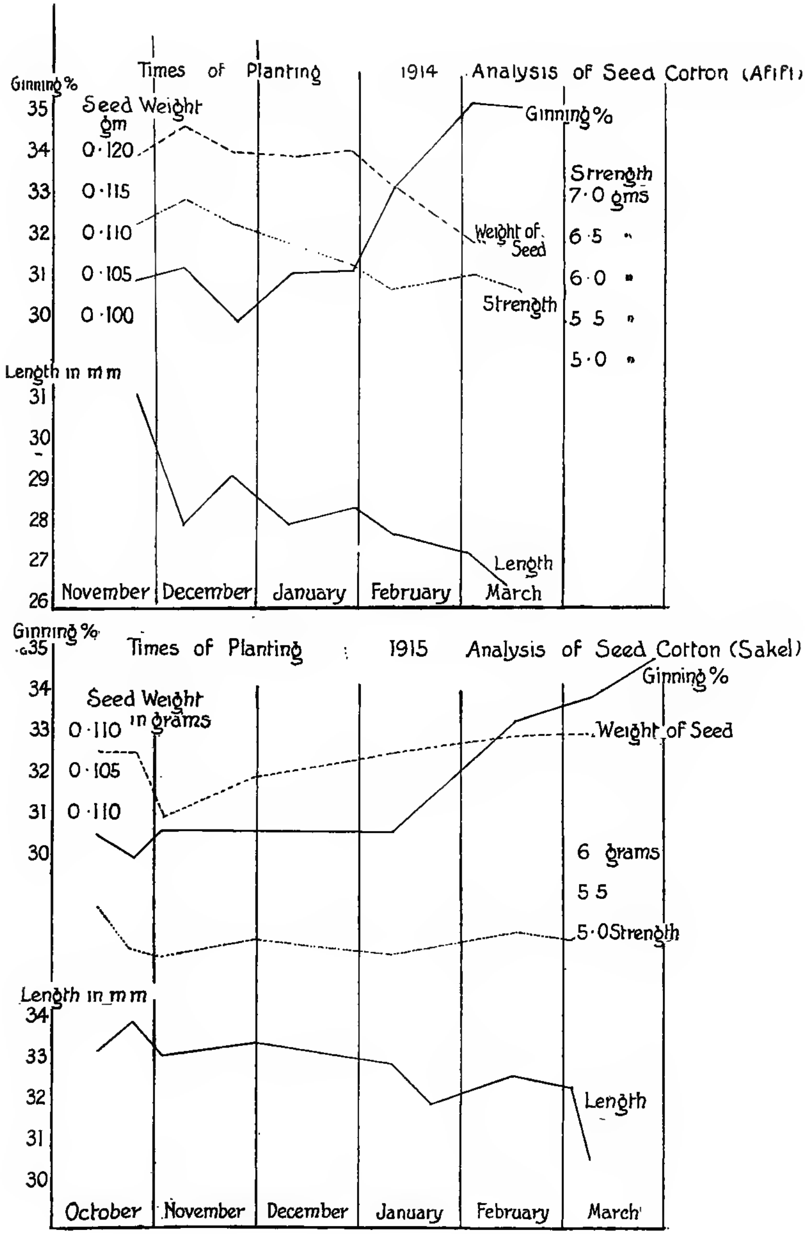
1913.		1914.		1915.	
Date of Picking.	Ginning Percentage.	Date of Picking.	Ginning Percentage.	Date of Picking.	Ginning Percentage.
		20–11–13	31	11–10–14	30·6
		7–12–13	31·25	19–10–14	30·1
		11–12–13	29·6	1–11–14	30·7
		27–12–13	30		
		8– 1–14	31·2		
1–2–13	30	24– 1–14	31·3	13– 1–15	31·7
4–2–13	31·6	12– 2–14	33·2	13– 2–15	33·4
13–2–13	33·4	2– 3–14	35·4	6– 3–15	34
25–3–13	33·6	14– 3–14	35·3	27– 3–15	35·5
29–4–13	34·8	9– 4–14	35·3		

Individual variations between the pickings of the different plots were greater in 1914 than in 1915, and this was undoubtedly due to the shortage of water which occurred that year :—

Variation in Individual Plots.
1914.

Date of Sowing.	G. P. of First Picking.	G. P. of Last Picking.	Difference.
1–7–13	30·5	33·2	2·7
20–7–13	30·0	33·0	3·0
30–7–13	30·0	35·7	5·7
	1915.		
1–6–14	30·5	31·25	0·75
20–6–14	30·5	32·0	1·5
8–8–14	33·5	35·0	1·5

The Seed Weight fluctuates also throughout the season. It is probable that the 1914 and 1913 records are more typical of a normal year than those of 1915, when exceptionally favourable conditions prevailed.



The variations in the mean weight of a single seed (average of 250) during the three years are given below :—

Variations in Seed-Weight throughout the Season.

Afifi.				Sakel.	
1913.		1914.		1915.	
Date of Picking.	Weight of one Seed.	Date of Picking.	Weight of one Seed.	Date of Picking.	Weight of one Seed.
	Grams.		Grams.		Grams.
		20–11–13	0·12	11–10–14	0·108
		11–12–13	0·124	19–10–14	0·108
		20–12–13	0·121	1–11–14	0·100
		8– 1–14	0·120	29–11–14	0·105
		24– 1–14	0·121	18– 1–15	0·108
4– 2–13	0·14	12– 2–14	0·117	13– 2–15	0·110
13– 2–13	0·135	2– 3–14	0·110	7– 3–15	0·110
25– 3–13	0·132	14– 3–14	0·112	4– 5–15	0·108
18– 4–13	0·125	9– 4–14	0·098		
29– 4–13	0·117				
1– 6–13	0·105				

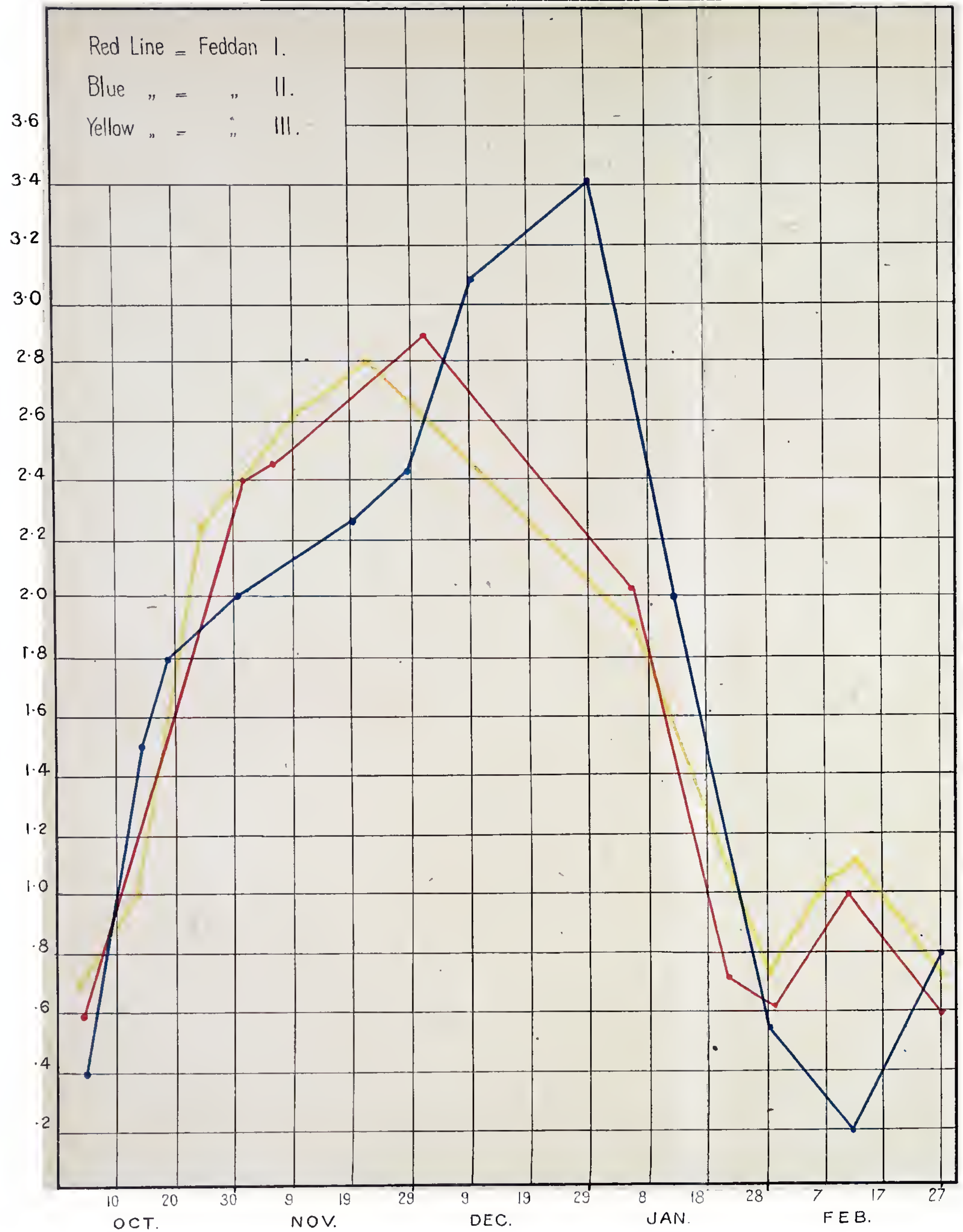
A representation of these figures is given in the accompanying graphs. When these curves are compared with the distribution curve of the yield for each sowing, the advantage of an early sowing with which the bulk of the cotton matures in optimum conditions, is at once apparent.

Duty of Water Experiment.—An understanding of the water requirements of the cotton plant is essential for the successful and profitable cultivation of the crop. The effects of a varying water supply on the soil have been dealt with in the preceding section, and it is now necessary to study the comparative effects on the plant, and the resulting crop of seed cotton.

Previous work undertaken in Egypt has shown that " where the level of the subsoil water was low, the yield of cotton increased as the amount of water

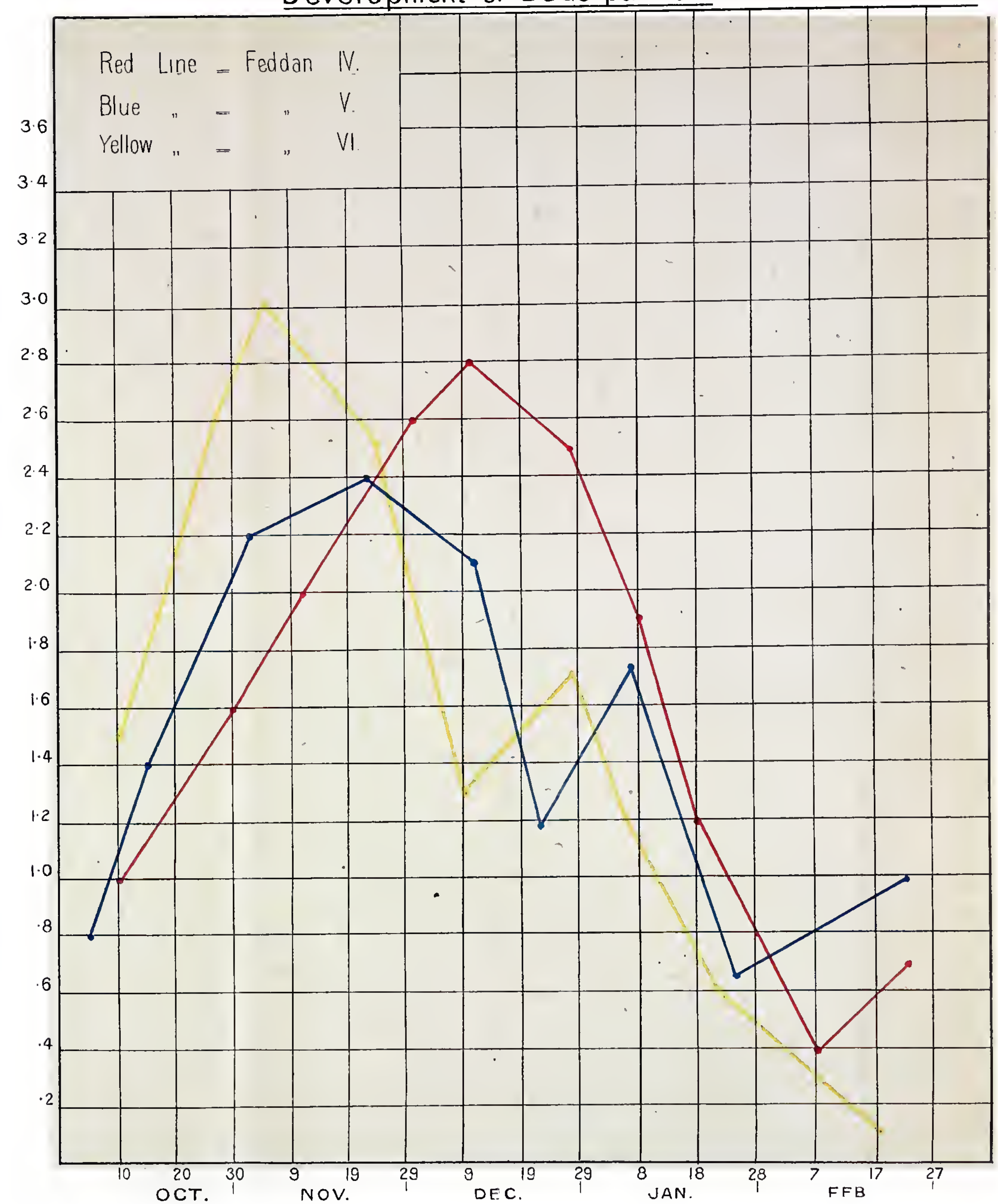
Duty of Water Experiment__1913-1914.

Development of Buds per Plant.



Duty of Water Experiment__1913-1914.

Development of Buds per Plant.



applied to the land increased, though there were signs of a maximum yield having been reached. On the other hand, the maturing of the cotton was delayed by increase of the water applied."*

The general arrangement of the experiment carried out at the Central Research Farm during the season 1914–15 was as follows :—A series of nine adjacent plots was divided into three sets watered every ten, fifteen and twenty days respectively. Individual plots were then given either 500, 400 or 300 cubic metres of water, so that each set comprised three feddans watered on the same date, but receiving a decreasing supply, *i.e.* :—

1st Set	Feddan I.	500	cubic metres every 10 days.
	„ II.	400	„ „ „
	„ III.	300	„ „ „
2nd Set	Feddan IV.	500	cubic metres every 15 days.
	„ V.	400	„ „ „
	„ VI.	300	„ „ „
3rd Set	Feddan VII.	500	cubic metres every 20 days.
	„ VIII.	400	„ „ „
	„ IX.	300	„ „ „

The amount of water was regulated by means of the Gibb's Module described elsewhere.

Effect of Irrigation on Flowering.—From the flowering curves for the season 1914–15 it is deduced that :—

(*a*) The amount of flowering decreases with an increasing amount of water.

(*b*) A distinct retardation in the formation of flowers occurs with an increasing supply of water even in the individual plots of the three sets.

(*c*) That the earliest formation of flowers occurs in the plots which have received the lightest watering.

An even more striking result was obtained in 1913–14 when the observations were carried a stage further back and the formation of buds was recorded.

The effect of this retardation and diminution in the formation of flowers was of course apparent when the bolls began to open. Details of the picking will be given later, but it may be mentioned here that the first picking was

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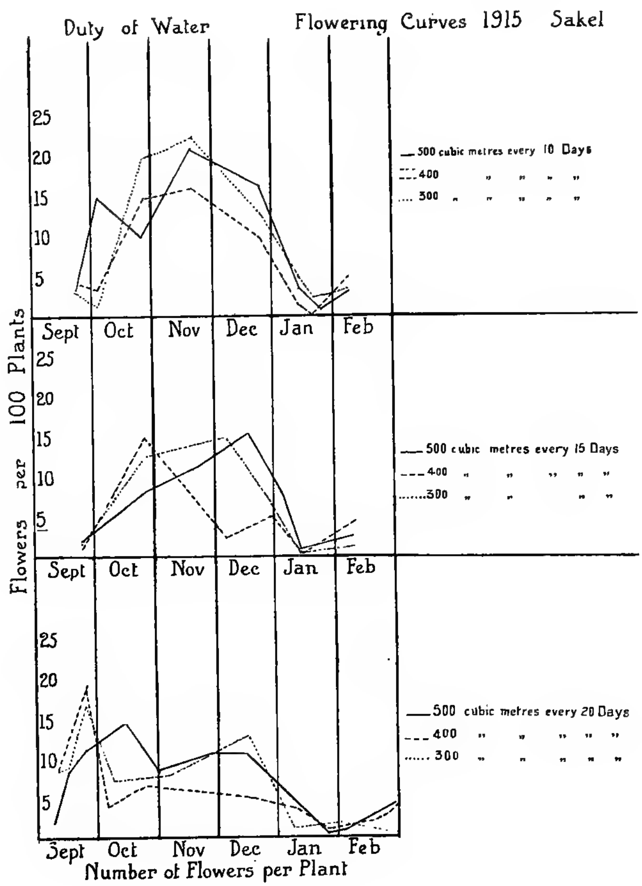
* "The Effect of Water on the Cultivation of Cotton." Survey Department Paper No. 31, Cairo, 1913.

obtained from the lightest watering in November, while no cotton was obtained from the heavier waterings until late in December.

The bolling curves are not included on account of lack of space, but they agree in detail with the curves given above.

The whole effect of the retardation seems to lie in the formation of buds, and not with the maturation period of the bolls. Whether this would be the case should a sudden cold spell intervene is not known at present. As has been repeatedly stated, the season 1914–15 was unusually warm and humid, and flowering proceeded without any definite check until late in the season.



Effect of Irrigation on Length of Cotton.—We must now turn to the effects produced on the seed cotton. In order to condense the records, the figures obtained from similar waterings and similar intervals of watering have been grouped :—

Effect of Varying Amounts of Water on the Length of the Cotton Fibre, 1915 (Sakel).

Heavy Watering. Feddans I., IV., VII.		Medium Watering. Feddans II., V. & VIII.		Light Watering. Feddans III., VI. & IX.	
Date of Picking.	Length.	Date of Picking.	Length.	Date of Picking.	Length.
	mm.		mm.		mm.
3–12–14	36·3	3–12–14	39·0	26–11–14	33·0
29–12–14	36·4	29–12–14	36·7	6–12–14	31·0
12– 1–15	37·2	12– 1–15	39·7	30–12–14	35·2
19– 1–15	35·1			14– 1–15	35·1
7– 2–15	36·3	11– 2–15	35·7	10– 2–15	33·7
3– 3–15	35·0	3– 3–15	34·2	3– 3–15	34·0
1– 4–15	35·0	14– 2–15	33·1		
10– 4–15	34·3	25– 3–15	32·0	25– 3–15	34 0
17– 4–15	32·0	10– 4–15	33·3	10– 4–15	34·4
		17– 4–15	32·8	17– 4–15	34·6

It must be remembered that the earlier dates are of relative importance, for the bulk of the cotton is picked then, while later the amounts gathered become insignificant.

The figures obtained in 1914 were similar but less pronounced. The average length of the fibre up to the same date in February, when unfortunately the water supply failed, was as follows :—

Length of Fibres, 1914 (Afifi).

Heavy Watering.	Medium Watering.	Light Watering.
mm. 29·1	mm. 29·9	mm. 29·4

It will be seen that a medium watering favours length, although in 1915 the cotton from the heavily-watered plots was on the whole more even.

It remains to consider the effect of a varying interval of time between the individual waterings. If the evaporation and temperature figures given in Report I are compared with those recorded for Cairo, the comparative frequency of the watering in the Sudan will not appear strange. A full set of figures is given for 1915, and the means of the first picking for 1914.

Effect of Varying Intervals in Watering on the Length of the Cotton Fibre.

SAKEL, 1915.

10 Days' Interval.		15 Days' Interval.		20 Days' Interval.	
Date of Picking.	Length.	Date of Picking.	Length.	Date of Picking.	Length.
	mm.		mm.		mm.
No Picking		No Picking		26–11–14	33·0
,,		,,		3–12–14	34·0
,,		29–12–14	36·8	30–12–14	34·2
14– 1–15	36·3	14– 1–15	36·6	14– 1–15	35·7
8– 2–15	35·8	11– 2–15	35·4	11– 2–15	34·6
3– 3–15	34·5			14– 3–15	33·1
1– 4–15	34·3	11– 4–15	34·3	11– 4–15	33·4
17– 4–15	33·1				

AFIFI, 1914.

10 Days' Interval.	15 Days' Interval.	20 Days' Interval.
29·0 mm.	29·5 mm.	29·3 mm.

It does not seem improbable that the greater differences existing in the case of the Sakel were due to a much superior vegetative development, and hence greater water requirements, for whereas most of the Sakel plants were well branched, leafy bushes, the Afifi strain always remained straggly with very little branching and small leaf surface. Any insufficiency in the water supply would therefore be more keenly felt by the Sakel crop. On the whole, a medium interval of fifteen days would apparently favour length of cotton.

Effect of Irrigation on the Strength of Cotton.—It would not appear that there was any definite connection between the length and strength of the fibre beyond the fact that both are affected by changes in the environment. The variations noted in the laboratory are small in amount, but that they are definite and significant is proved by the fact that in spite of the different climatic conditions obtaining during the two seasons 1914 and 1915, the results of the experiment are qualitatively the same, although they differ quantitatively. It has been most encouraging to find that in general the brokers' valuation of samples from the different experimental plots agrees with the laboratory results :—

Effect of Varying Amounts of Water on the Breaking Strain of the Cotton Fibre.

SAKEL, 1915.

HEAVY WATERING.		MEDIUM WATERING.		LIGHT WATERING.	
Date of Picking.	Strength.	Date of Picking.	Strength.	Date of Picking.	Strength.
3–12–14	5·5	30–12–14	5·5	6–12–14	5·5
30–12–14	5·7	14– 1–15	5·6	29–12–14	5·3
13– 1–15	5·9			13– 1–15	5·3
11– 2–15	5·3	19– 1–15	5·3	19– 1–15	5·4
3– 3–15	5·0	4– 3–15	5·3	10– 2–15	5·8
1– 4–15	5·2				
10– 4–15	5·3	7– 4–15	5·4	4– 3–15	5·0
17– 4–15	4·7				

AFIFI, 1914.

HEAVY WATERING.		MEDIUM WATERING.		LIGHT WATERING.	
11–12–13	7·0	11–12–13	6·4	11–12–13	6·2
12– 1–14	6·4	12– 1–14	6·1	12– 1–14	6·3
24– 1–14	6·0	22– 1–14	6·0	18– 1–14	6·6
23– 2–14	5·0	24– 2–14	6·3	23– 2–14	6·9
4– 3–14	4·8	17– 3–14	5·0	4– 3–14	5·9

Effect of Varying Intervals between Waterings on the Breaking Strain of the Cotton Fibre.

SAKEL, 1915.

10 DAYS.		15 DAYS.		20 DAYS.	
Date of Picking.	Strength.	Date of Picking.	Strength.	Date of Picking.	Strength.
—	—	7–12–14	5·5	3–12–14	5·5
—	—	28–12–14	5·5	30–12–14	5·4
13– 1–15	5·5	14– 1–15	5·4	13– 1–15	5·7
7– 2–15	5·5	—	—	19– 1–15	5·4
3– 3–15	5·1	11– 2–15	5·5	11– 2–15	5·2
1– 4–15	5·2	10– 4–15	5·5	11– 4–15	5·0
7– 4–15	5·5				
17– 4–15	4·7				

AFIFI, 1914.

20–12–13	6·0	11–12–13	6·4	11–12–13	6·7
1– 1–14	6·2	13– 1–14	6·3	—	—
24– 1–14	5·6	22– 1–14	6·2	20– 1–14	6·4
1– 2–14	6·2	—	—	—	—
23– 2–14	5·8	24– 2–14	5·2	24– 2–14	5·4
4– 3–15	5·8	4– 3–15	5·1	7– 3–14	5·1

Each figure in the above tables represents the mean of a number of samples gathered from different parts of the plots, and the minimum number of fibres individually examined from each sample is fifty. The variation between the individual fibres of a sample has shown that the most regular lint is obtained from the medium watering at a medium interval.

Variation between Individual Fibres.

	No. of Fibres Examined.	Means.	P.E. of one Result.	Standard Deviation.
Heavy watering ...	50	12·9 + 0·41	2·9	4·4
Medium ,, ...	50	15 + 0·34	2·4	3·6
Light ,, ...	50	11·5 + 0·39	2·8	4·1

The above figures are calculated from the direct readings given by the breaking strain apparatus, and therefore refer to the number of c.c.'s of water. For obvious reasons only the means of the determinations were reduced to the equivalent in grammes. With the home-made machine in use at the present time, each 5 c.c.'s equals 2·05 grammes, so that the actual variation in grammes is smaller than that given in the above figures.

Effect of Irrigation on Ginning Percentage.—The ginning percentage has remained remarkably constant throughout this experiment, the only variations occurring in the early maturing cotton receiving light waterings, so that while the water supply is an essential factor, the climatic conditions prevailing during the maturation period of the boll have been directly responsible for the change in ginning percentage. (See Times of Planting Experiment.)

If cotton picked at the same date from different plots be compared, the ginning percentage is found to be practically constant.

GINNING PERCENTAGE.

Duty of Water Experiment.

SAKEL, 1915.

Varying Intervals between Watering.

Date.	10 Days.	15 Days.	20 Days.
26–11–14	No picking	No picking	29·0
30–12–14	No picking	29·8	29·8
12– 1–15	31·2	31·3	31·4
10– 2–15	32·5	32·5	32·6
10– 4–15	—	34·6	34·5

Varying Amounts of Water.

Date.	Heavy.	Medium.	Light.
26–11–14	No picking	No picking	29·0
29–12–14	29·7	29·5	29·8
12– 1–15	31·0	31·5	31·3
10– 2–15	32·6	32·4	32·8
10– 4–15	34·5	34·5	34·3

The figures obtained from the Afifi crop in 1914 were similar in every respect. All observations go to show that the curve of the ginning percentage of any one strain is very constant throughout the season, whatever the treatment afforded. The main differences exist between individual strains.

Effect of Irrigation on Seed Weight.—Turning to the seed weight, the variations are again slight, but there is a distinct tendency for the heavier watering to increase the weight of the seeds. This fact is more apparent in 1914 than in 1915 when greater humidity obscured the effect of irrigation.

Mean Weight of Single Seeds.

1914 : Afifi.

Date.	Heavy Watering.	Medium Watering.	Light Watering.
11–12–13	Nil	Nil	0·130
31–12–13	0·127	0·120	0·130
13– 1–14	0·128	0·120	0·120
24– 2–14	0·113	0·111	0·112
12– 4–14	0·09	0·09	0·09
	1915 : Sakel.		
26–11–14	—	—	0·104
3–12–14	—	—	0·105
29–12–14	—	0·108	0·108
12– 1–15	0·105	0·107	0·104
10– 2–15	0·101	0·105	0·104
10– 4–15	0·109	0·109	0·109

It is not advocated that watering should be given with such regularity as has been maintained through this experiment, for the amount of water required obviously varies with climatic conditions. Actually, 400 cubic metres every fifteen days is rather in excess of the water supplied to the main crop in general practice.

Conclusions.—(*a*) The seasons 1914 and 1915 afford effective contrasts, for in 1914 a pronounced water shortage was experienced, while in 1915 climatic conditions were exceptionally favourable.

(*b*) Heavy watering retards the development of buds, but increases vegetative growth, *i.e.*, cotton tends to become weedy. The actual yield is as a rule high.

This retardation of the crop is not due to any increase in the maturation period of the bolls in suitable climatic conditions but entirely to an actual delay in the formation of the bolls.

(*c*) Water shortage hastens maturity, but causes a depreciation in the quality and quantity of the lint which becomes more pronounced as the season advances. The quantities of water necessary in the Sudan to obviate an early senescence are relatively large.

(*d*) Fine quality lint was produced by the plots receiving a medium quantity of water, *i.e.*, 400 cubic metres every fifteen days.

(*e*) Length and strength are greatly influenced by the water supply, and it is possible to maintain them at a maximum by suitable waterings.

(*f*) Seed weight is increased by heavier waterings, but ginning percentage is less influenced than the other three features. The ginning percentage seems to be determined by the date of the maturation of the boll.

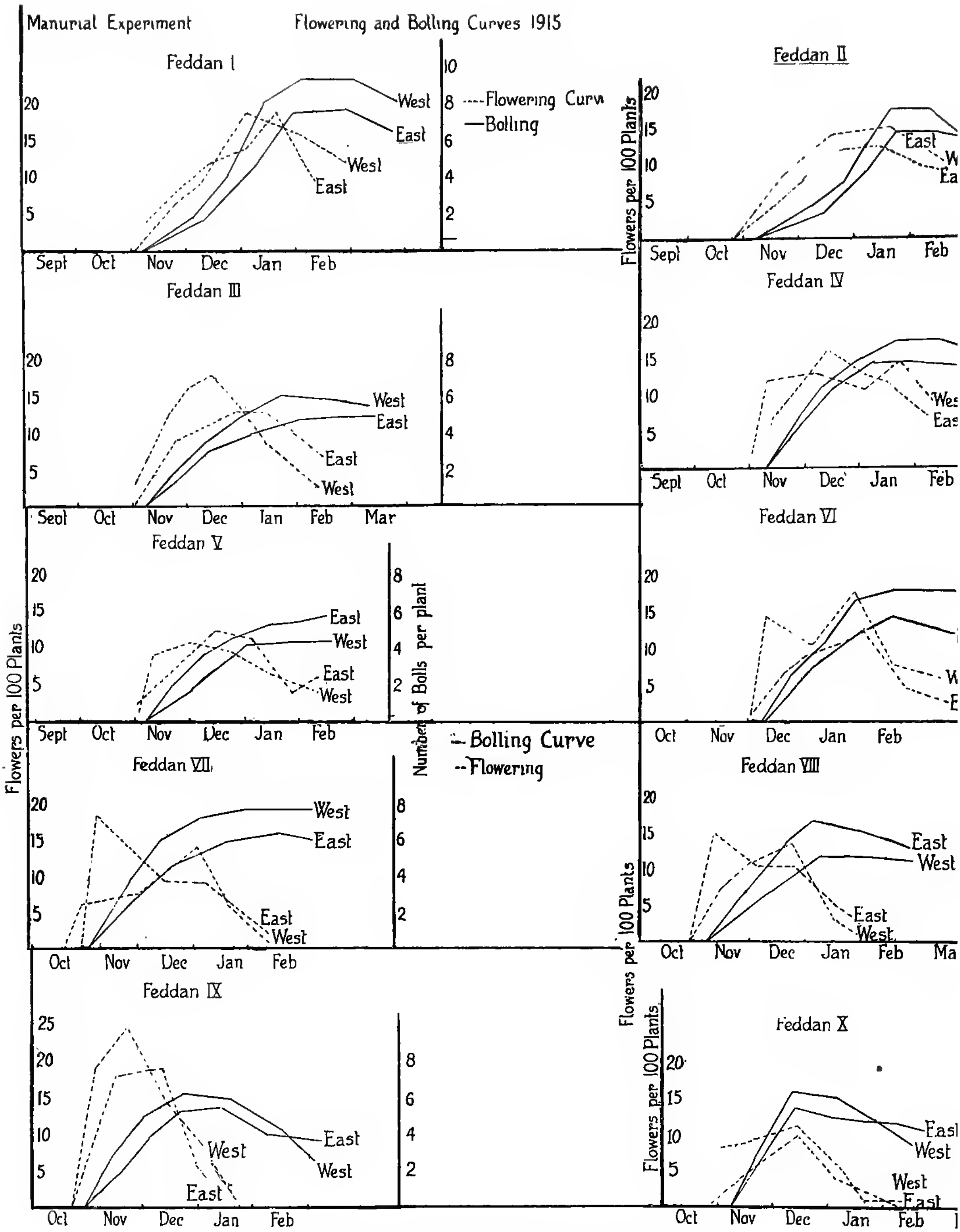
(*g*) These fluctuations, though small in range, are appreciable in the mass and recognised by spinners.

The Influence of Manures on the Cotton Crop.—The soil analyses, earlier tabulated, would seem to indicate an urgent need for an increased nitrogen supply, while other food materials would seem to be present in abundance.

The principal manures employed in the experimental work on the farm have been :—

(*a*) Stable manure.
(*b*) Nitrate of soda.
(*c*) Superphosphate of lime.

Combinations of these have been made in varying proportions and applied to the west half of feddan plots, the second east half of the feddan being employed as a control in every case. Uniformity in conditions other than manuring has been maintained as far as possible. The same system of observations has been used as in the experiments previously described, by which a weekly record has been obtained of all measurable factors.



The following are the details of treatment :—

Feddan I.—10 tons of stable manure, 200 lb. nitrate of soda and 300 lb superphosphate.

II.—10 tons stable manures.

III.—100 lb. nitrate of soda.

IV.—200 lb. nitrate of soda and 300 lb. superphosphate.

V. 300 lb. superphosphate.

VI. 200 lb. nitrate of soda.

VII. 150 lb. superphosphate and 100 lb. nitrate of soda.

VIII. 150 lb. superphosphate.

IX. 100 lb. nitrate of soda.

X. 50 lb. nitrate of soda.

The superphosphate was incorporated before ridging, the stable manure before ploughing, while the nitrate was added mixed with sand after the crop was well established, and worked in with the first inter-row cultivation.

The curves for 1915 are given alone on account of lack of space ; but it may be said that greater agreement was obtained with the records of previous years than in the case of any other experiment. The results set out above may therefore be taken as fairly representative.

The flowering curve is not so useful as the bolling curve when comparison of the yields is desired, but two points are brought out strongly. The first is the increase in the rate of flowering caused by manuring with nitrate of soda, and the second the depressing effect of superphosphate even when applied with nitrate. The antagonism between superphosphate and nitrate is more apparent than real, for only when superphosphate is applied alone is any reduction in yield obtained.

The bolling curve is more illustrative of final results than the flowering curve. With the exception of the superphosphate plots, the addition of manure has always resulted in a heavier yield. The contrast between the manured plots and the controls was most marked in the fields. The more luxuriant growth and the deeper green of the manured portion spoke eloquently to the need for nitrogen.

Turning to effects produced on the cotton itself, the records obtained in the laboratory during the past three years will be found on the accompanying table.

The uniformity of the cotton derived from the check plots permitted a pooling of the figures, which thus furnished a standard for the effect of the manures.

PLOT.	1915 Sakel.				1914 Afifi.				1913 Afifi.			
	Length.	Strength	Ginning.	Weight of Seed.	Length.	Strength	Ginning.	Weight of Seed.	Length.	Strength	Ginning.	Weight of Seed.
1. Complete manure ...	32·8	5·0	33·25	0·120	29·7	7·0	33	0·114	32·2	6·0	34	0·114
2. 10 tons stable manure	31	5·0	33·1	0·110	28·1	6·3	32·6	0·112	30·1	5·2	33·2	0·114
3. 100 lb. nitrate of soda	32·8	4·8	33·0	0·118	27·8	6·0	32	0·112	31·4	5·8	33·1	0·113
4. 300 lb. superphosphate and 200 lb. nitrate ..	31	5·0	32·5	0·110	28·4	5·0	33·0	0·110	31·2	5·1	33·8	0·112
5. 300 lb. superphosphate	35	5·0	34	0·106	29·3	6·6	34	0·110	34	5·0	35	0·112
6. 200 lb. nitrate of soda	31	4·4	32·8	0·118	26·8	7·0	32·6	0·113	31·4	6·3	33·5	0·113
7. 150 lb. superphosphate and 100 lb. nitrate ...	33	4·6	33·5	0·110	28·2	6·0	33·5	0·112	32·4	5·3	33·3	0·112
8. 150 lb. superphosphate	33·8	5·0	33·8	0·107	28·8	6·1	33·8	0·110	33	5·7	34	0·111
9. 100 lb. nitrate ...	32·1	4·9	32·8	0·112	28·1	6·5	32·7	0·113	31·9	6·2	33·3	0·114
10. 50 lb. nitrate... ...	31·2	5·4	33·3	0·109	28·3	—	—	0·112	32	—	33·3	0·113
Control Plots (mean) ...	33·2	4·6	33·2	0·108	28·5	6·0	32·5	0·110	32	5·5	33·	—

It will already have been reoognised that the effect of cultural operations on the quality of cotton is very limited. Indeed, it is far easier to affect the character of the lint adversely than to improve it. A given strain afforded optimum conditions, will become more regular, and possibly a little longer, but otherwise, unless affected by adverse environic conditions, such as bad cultivation, or by crossing with an inferior type, will remain fairly constant from year to year. In short, it is impossible to change a short coarse cotton into long fine one by such cultural operations as manuring.

There are a few points which seem fairly definitely established by this experiment :—

(*a*) Length seems to be improved by superphosphate and depressed by nitrogenous manures.

(*b*) Strength varies little, but is on the whole improved by manures.

(*c*) Ginning percentage also fluctuates very slightly, but tends to be depressed by nitrate and raised by superphosphate.

(*d*) The weight of the seed is increased by nitrogenous manures, and is probably the factor most affected by manures.

In general the action of manures is mainly exercised on the plant itself, and is reflected principally by increased vegetative development, followed by a larger yield of cotton, the inherent good qualities of which become accentuated by reason of the improved environment.

Distance of Planting Experiment.—The necessity for an unusually large root development to meet the water requirements of the cotton plant in local conditions has been emphasized. In many ways the " Distance of Planting " experiment is a study in root limitation, for it seems probable that the effect on the aërial portion is of less importance in determining the yield per feddan.

The spacings adopted in the experiment were as follow :—

Spaces between Ridges.		Spaces between Plants.	Approximate Number of Plants per Feddan.
120	×	45	15,378
90	×	60	15,400
90	×	45	20,504
90	×	30	30,800
100	×	45	18,440
80	×	45	23,300

Two plants were left to each " hole."

The results of the records taken from the observation rows may be summarised as follow :—

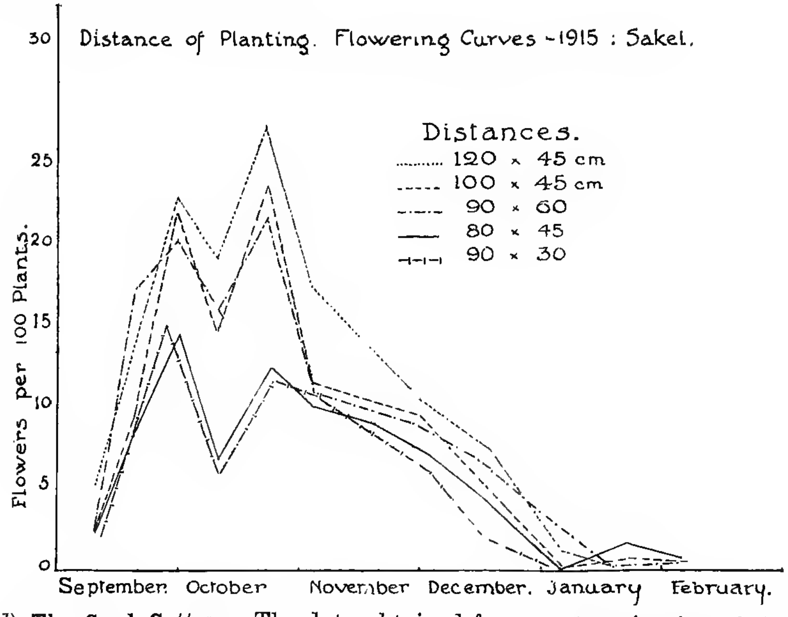
(*a*) **Height.** Practically uniform throughout. If anything, the plants of the closer sowings were smaller than those of the wider sowings.

(*b*) **Flowering Curve.**- The flowering curve is probably the best method of expressing the amount of vegetative development shown by the plant, since it is directly dependent on the branching system. The curves for 1915 are depicted on the accompanying graph.

It will be seen that root limitation did not exert any definite depressing effect except in the closest sowings, *i.e.*, 80 by 45 and 90 by 30. Very little difference existed between the medium sowings, *i.e.*, 90 by 60 and 100 by 45, but, if anything, 100 by 45 was the better.

The largest number of flowers per plant was obtained from the widest sowing, *i.e.*, 120 by 45.

(*c*) **The Bolling Curve.**—The bolling curve is obviously the flowering curve minus the amount lost by shedding. As it proved practically uniform for all plots except the widest sowing (120 by 45), it may be taken that the amount of shedding was constant, with the one exception named. It has been found repeatedly in pedigree work that, although the number of bolls per plant is immensely increased by wide sowing, the amount of shedding is also greater. This is largely due to the lack of shelter, and the increased evaporation induced by the cold, dry winds of winter.



(*d*) **The Seed Cotton.**—The data obtained from an examination of the seed cotton in the laboratory are given below. It will be seen that there are no marked effects to be recorded from the various spacings. In 1915 the length of the fibre from the widest sowing was certainly slightly greater than that of the closer sowings, but other features seem to have been uninfluenced.

Distance.	1915, Sakel.			1914, Afifi.			1913, Afifi.		
	Length.	Ginning.	Weight of Seed.	Length.	Ginning.	Weight of Seed.	Length.	Ginning.	Weight of Seed.
	mm.	%	Grams.	mm.	%	Grams.	mm.	%	Grams.
120 × 45	34·0	29·0	·108	28·5	29·0	·128	32·3	31	·135
	34·5	32·0	·104	21·3	29·0	·127	28·2	36	·120
	35·0	32·5	·104	28·1	32·5	·122	29·1	37·5	·110
	33·7	33·5	·118	28·0	35·5	·110	—	—	—
90 × 60	35·0	29·5	·110	29·7	29·3	·133	36·2	32	·120
	33·0	31·7	·106	29·2	29·0	·133	29·9	34	·122
	32·5	32·5	·105	29·0	32·0	·125	28·6	36·5	·110
	32·5	33·7	·112	25·0	35·0	·110	—	—	—
90 × 45	32·0	29·7	·110	27·7	29·7	·130	32·0	30	·133
	34·0	31·2	·109	28·8	29·3	·135	28·4	34	·120
	34·5	32·3	·109	28·1	31·7	·125	27·9	35	·110
	33·0	33·0	·110	27·0	35·6	·115	—	—	—
90 × 30	33·0	30·0	·108	28·1	28·2	·120	32·2	32	·132
	33·0	32·0	·108	27·6	28·4	·127	28·5	35	·116
	33·5	32·7	·108	27·3	32·0	·130	28·1	36	·100
	33·5	33·2	·108	28·6	33·5	·110	—	—	—
100 × 45	30·0	30·0	·108	27·5	27·5	·135	—	—	—
	33·2	31·5	·104	28·0	31·0	·125	—	—	—
	33·2	32·0	·108	27·3	33·7	·115	—	—	—
	33·0	33·7	·120	25·6	35·2	·110	—	—	—
80 × 45	35·0	30·0	·100	28·8	28·5	·135	—	—	—
	32·0	31·0	·108	28·6	28·5	·130	—	—	—
	34·0	32·0	·108	29·0	32·2	·120	—	—	—
	33·0	32·7	·126	25·6	35·0	·110	—	—	—
	Dates of Picking :— 9–12–14, 12– 1–15, 4– 2–15, 11– 3–15			Dates of Picking :—22–12–13, 3– 1–14, 14– 2–14, 28– 2–14			Dates of Picking :—18–2–13, 24–3–13, 24–4–13		

The crux of the experiment then lies in the number of bolls developed per plant, or still further back, the number of flowers borne by each plant. If, within certain limits, the number is not influenced by spacing, obviously the yield per unit area will depend on the number of plants present. This has been found to be the case in practice. With spacing above 100 cm. by 45 cm. the yield per feddan is affected only by the number of plants, but with closer sowings root limitation plays an all important part, and the yield is depressed.

The Influence of Improved Cultivation.—No work has been more encouraging or given more confidence in the accuracy of laboratory and field observations than the results of the cultivation experiment. As with the manurial experiment, the check plots showed so little variation that all the records were grouped together and a representative mean obtained. Full details of the cultural treatment allotted to the various plots will be found elsewhere, but for the sake of clearness the main points are briefly summarised below.

The check plots, being Feddans 2, 4, 6, 8 and 10, represent normal cultivation in that they were ploughed, harrowed, ridged and planted similarly to the main crop.

FEDDAN I.—Flooded, ploughed, harrowed with disc and zigzag harrow, levelled, cross-ploughed with disc plough, subsoiled, harrowed, ridged and planted. Subsequent treatment included horse-hoeing and ridging as occasion required.

FEDDAN III.—Flooded, ploughed, harrowed, graded, disc ploughed, tooth harrowed, ridged and planted.

FEDDAN V.—As Feddan I, but not flooded before ploughing.

FEDDAN VII.—As Feddan I, but the ground was not levelled.

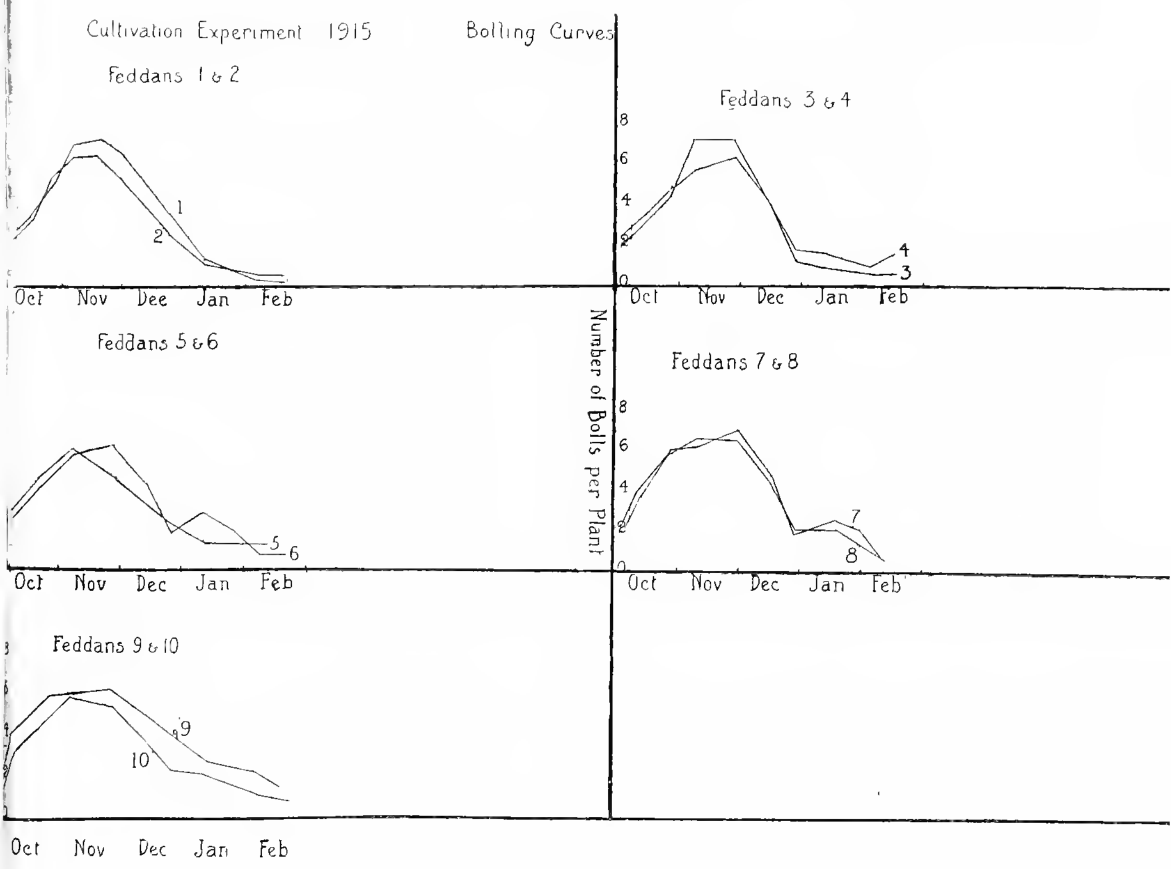
FEDDAN IX.—As Feddan I, but no subsequent cultivation was accorded to the growing plants.

It will readily be conceded that any improvement in the tilth will be most beneficial in the initial stages of the plants' development. All the evidence accumulated during the past three years goes to show that, generally speaking, the whole future of the crop, both as regards quality and quantity, is determined by the environmental influences operating long before the opening of the first bolls.

In the Sudan the life history of the cotton plant may be divided into two sections. First, a period of active growth during which the formation of branches bearing flowers proceeds smoothly, and a nightly increase in the height of the stem is recorded. Second, and the turning point is determined by the onset of the cold winter winds, a period in which growth is checked and very little further formation of branches or flowers occurs. The bolls already formed proceed to maturity, the quality of their contents depending on the climatic conditions during the initial stages of their development.

The influence of increased cultivation is clearly seen in the accompanying graph, on which the bolling curves of the different plots are depicted. In every case an improved tilth has resulted in an increased yield per plant, and consequently a larger return per feddan.

The effects on the seed cotton are tabulated below. Only the results from the last season are available, but there is no reason to suppose that they are in any way abnormal.



Effect of Improved Cultivation on the Character of Seed Cotton.

Cultivation.	1915, Sakel.		
	Length.	Ginning.	Weight of Seed
	mm.	%	Grams.
Check Plots	34·4	30·0	·098
	34·9	29·5	·111
	33·3	31·5	·106
	32·6	34·5	·106
	29·6	33·6	·112
Feddan III.	—	—	—
	34·4	29·5	·104
	36·7	31·5	·108
	36·0	34·25	·104
	—	34·5	·108
Feddan V.	35·4	30·0	·112
	38·7	30·0	·112
	36·3	31·25	·112
	34·4	34·0	·112
	—	35·0	·116
Feddan VII.	35·2	31·0	·096
	35·0	29·8	·112
	34·6	31·2	·108
	—	—	—
	30·0	32·5	·116
Feddan XI.	35·0	28·5	·108
	36·0	30·0	·112
	36·5	—	—
	—	—	—
	32·2	34	·104

Dates of Picking :—26–11–14
23–12–14
14– 1–15
16– 2–15
26– 3–15

SECTION III.

The Improvement of the Cotton Crop.

With the increase in knowledge of the laws of heredity has come a recognition of the fact that a permanent improvement in the quality of a crop can never be obtained by selection alone.

When dealing with a crop such as cotton, in which vicinism plays so great a part, mass selection either by seeds or plants would only increase the tendency towards irregularity, since any apparent superiority is usually due to cross fertilisation. If contamination from outside sources were excluded, and pure parents were employed, improvement of a temporary nature might be expected by the selection of the most desirable plants and the sowing of the seed resulting therefrom.

The commercial cotton crop is, however, a heterogeneous collection of hybrids derived from various sources, the individual characteristics of which segregate in accordance with the simple laws of heredity.

In order that the futility of mass selection in the presence of cross fertilisation may be appreciated, a brief statement will be made of Mendel's law.

The fundamental fact on which this law is based is the conception of individuals as composed of unit characters which are transmitted intact. Whenever mating occurs between a pair of individuals, each separate unit character blends with a corresponding character, producing a hybrid which resembles either parent according as one is dominant over the other.

The hybrid on being propagated, splits, and the characters of the resulting progeny segregate in the definite ratio 1 : 2 : 1, or judging from the external appearance only, in the ratio 3 : 1.

A simple illustration will render this clear, and also illustrate the necessity for dealing with unit characters separately.

If a white-flowered is crossed with a yellow-flowered cotton the resulting hybrid is yellow, owing to the fact that yellow is "dominant" and white "recessive."

Y W

YW (hybrid yellow in appearance)

When this hybrid reproduces, segregation occurs as follows :—

YW

(Yellow) YY — YW — YW — WW (White)

$\underbrace{\text{YW} \quad \text{YW}}_{\text{Yellow}}$

YY — YY — 2 YW — WW — WW

The pure forms YY and WW will breed pure, but the impure YW will continue to split as long as it is propagated. It is assumed, of course, that vicinism or natural crossing is excluded.

Crossing between unlike individuals has proceeded unchecked and uncontrolled for years in the commercial crop, so that the hopelessness of ever obtaining a uniform seed supply from such a source is apparent.

Methods Employed.—The first step to be taken when attempting the improvement of the crop, is the purification of existing strains until individuals are obtained which breed true in every character. This result is only to be secured by constant self-fertilisation extending over a number of years, and by excluding all possible sources of contamination.

Work was begun on the farm in 1912, when a large number of apparently desirable types were isolated from the field crop, and self-fertilised by the simple expedient of covering the flowers before opening with gauze bags. The seed from these plants was sown in 1913 and the progeny compared with the detailed records which had been made of the parents during the previous year. Purity in all the characters was of course out of the question, so that particular stress was laid on such features as determine the commercial value of the crop. Plants which approximated most closely to the parent types were selfed, and the resulting seed sown next year.

It is obvious that the number of individuals dealt with each successive year must increase very largely, as does the labour of selfing and comparing characters. In 1914, during which year the operations described above were repeated in detail, over 2,000 bags were in use every morning.

Sufficient seed was accumulated to sow this year 1 feddan of each of the most desirable and uniform types isolated in 1912.

Further selections were constantly made throughout the three years, and the purification of these will be continued separately. A supply of pure seed for field purposes will be maintained by selfing a sufficient number of plants. It is hoped that cages will be available in order to render this work more certain and to lessen the ever-increasing labour of hand-bagging.

The combination of desirable characters will be attempted by crossing, but as some years must necessarily elapse before the resulting hybrid is definitely fixed, this work will continue as a branch of the main task of furnishing a supply of seed which may be relied on to produce a uniform crop.

Practical Application of Methods.—To demonstrate the practical effects of the methods described above, it will be well to disregard the question of Inter-Egyptian crosses and consider the case of a hybrid which furnished an interesting example of the laws of heredity.

In 1912 a small plot was sown with Makhsous cotton, this being a strain which had shown promise in the Northern Sudan. One hundred plants were selected for examination, but owing to the irregularity of the lint, only one plant was finally chosen to propagate the strain. Of all the external features recorded in the ledger, only those will be considered here which can be readily distinguished.

1912 Records.

Flower	Pale yellow.
Spot	Pale red.
Style	Short.
Seed	Copious green fuzz, covering seed with a dense felt.
Lint	Average length, 32 mm.

The seed of this plant was sown in 1913 and the resulting plants selfed. Segregation of characters appeared, giving rise to an extremely varied crop, in which all gradations between the original parent plants could be recognised. In some instances an analysis of the crop revealed an almost perfect segregation in Mendelian proportions.

Colour of Flower ...	It is difficult to distinguish the intensity of the intermediate shades, so that all flowers not distinctly white were classed as yellow. The proportion of yellow to white in a hundred flowers chosen at random was 77 : 33.
Colour of Spot ...	Intermediate shades were ignored here also, two classes only being recognised, *i.e.*, red and colourless. The proportion, red to colourless, was 71 : 24.
Length of Style ...	Projecting, 70; not projecting, 23.
Seed	All possible gradations were found between dense fuzz and complete nakedness; no counts were made on account of the difficulty of satisfactorily distinguishing between the intermediate forms.
Lint Length & Ginning	Percentage will be found graphically represented on the accompanying diagrams.

In 1914 the sowing of this strain was discontinued, as the quality of the lint did not warrant the expenditure of the time and labour necessary to secure a strain which would breed pure, but a few plants were obtained for the sake of interest. It was found that the white-flowered plants produced a typical upland type, the seeds of which varied between full fuzz and nakedness. Fully yellow-flowered plants bred true to yellowness, but again the seed was mixed. Pronounced intermediates split up, but the number of plants was too small to obtain definite ratios.

The crux of the whole matter lies in the fact that if the 1912 seed had been sown on a larger scale, all the types described above would have appeared, and from a commercial standpoint the crop would have proved of little value. Of course this is a pronounced case. Specific differences between Egyptian crosses are hard to recognise, but they do exist very largely in the commercial crop, and tend to produce a general deterioration in the most valuable characteristics of the crop.

It can thus be realised that an extensive depreciation in the quality and quantity of a crop may be brought about by the introduction of a single Hindi plant into a cotton area, and how that once the damage is done, years of labour must ensue before elimination of the undesirable factors is complete.

Considerable use has been made of the target diagrams devised by Mr. W. L. Balls * on which the length of the fibre is plotted against the ginning percentage, the closeness of the pattern indicating the uniformity of the strain.

The selections made in 1913 were largely based on such diagrams, and the marked improvement in the uniformity of the strains may be clearly seen in the 1915 results.

In conclusion, it may be claimed that a definite start has been made towards the creation of a pure seed supply, for from the hundred plants chosen in 1912, sufficient seed has been obtained to sow eighteen feddans in 1915, the parental characters of each individual plant in the area being known in detail for the three intervening seasons.

Concurrently with the above, new types are constantly being isolated, so that it should be possible to obtain pure strains and meet any change that may occur in the requirements of the market.

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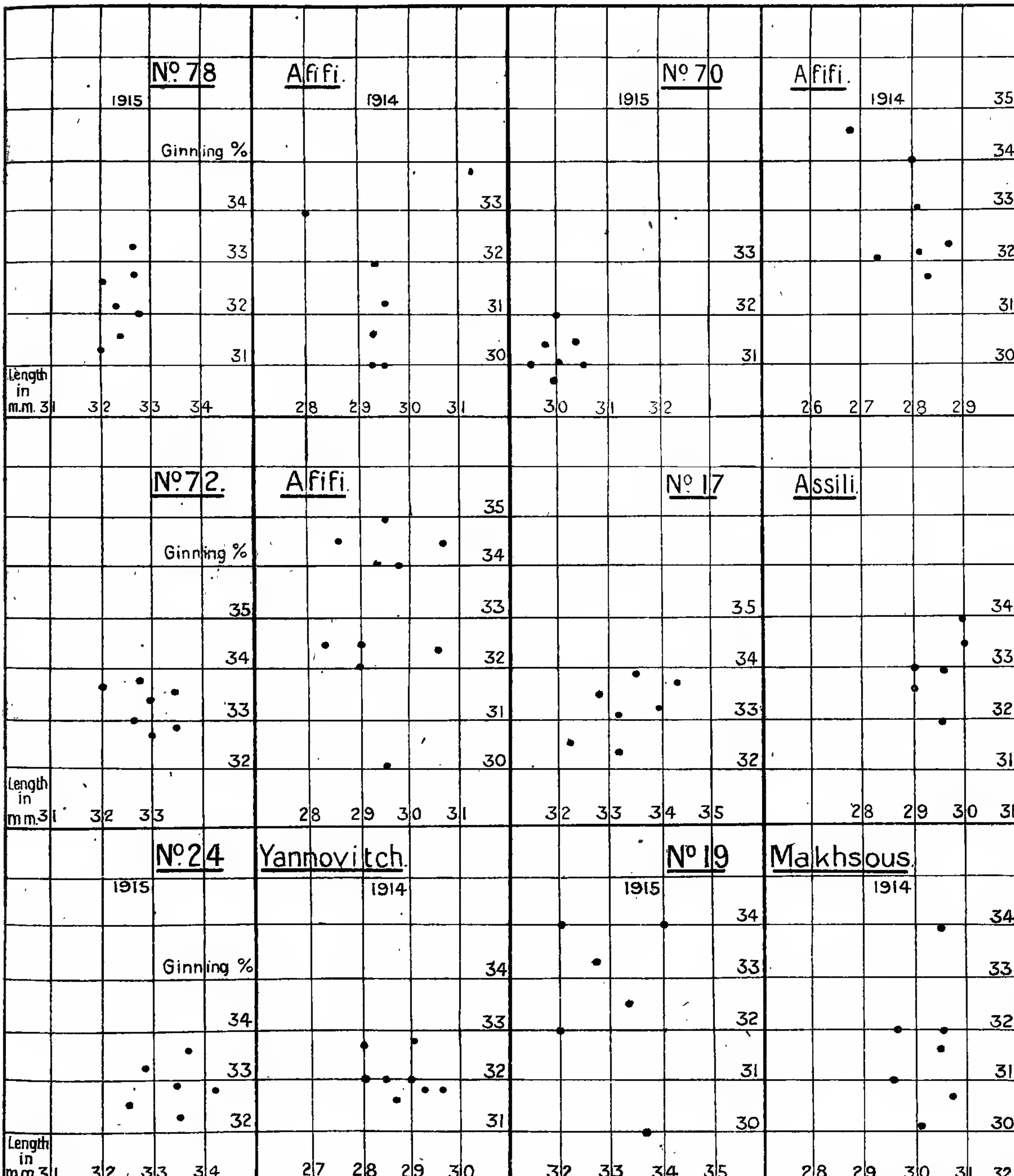
* "The Cotton Plant in Egypt."

Target Diagrams of Cotton Strains.



REPORT IV.

PUMPING MACHINERY AND ENGINE TESTS.

G. E. PENNINGTON, *Superintendent Engineer.*

The primary object of this report will be to show the working and test performances of each pumping unit employed in connection with the work of the Central Research Farm and its relative suitability for general adoption. Boiler, engine and pump tests have been made with each plant, and the results obtained will be found in tabulated form.

The early history of the farm was one of unceasing effort to maintain connection with the river and ensure continuity of the water supply, which was repeatedly threatened by shifting sand banks. Reliability rather than economy was consequently sought in the machinery selected.

The transfer of the farm to the Education Department in 1912 coincided with the final isolation of the central pumping station from the river by a large and permanent sand bank, when a new site was selected 1,400 metres to the north and floating pumps adopted as a solution of the sand-bank problem.

At the earliest opportunity engines of a more modern and efficient type superseded those originally installed, and a marked reduction in running costs was effected.

The benefits subsequently obtained were, however, lost for a season by the sinking in transit of a new 18-inch pumping plant with its pontoon by a hurricane. Recovered some seven months later, the unit was ultimately erected, and its performance is described in the body of the report. Happily it suffered little or nothing from submersion.

The decision to irrigate native-owned lands in the vicinity of the farm and on Tuti Island, involved the purchase of additional plant and a strengthening of the staff for the supervision of pumping stations and the distribution of water.

Wood being the only available local fuel, has been used in all steam boilers at a cost of 500 millièmes (10s. 3d.) per ton, and a saving of 46 per cent. has been effected on earlier running costs with imported coal purchased at £E.3 per ton.

This reduction might have been further extended by the employment of fire-boxes specially designed for wood fuel, but use had to be made of boilers already on hand.

Description of Units and Results of Tests.

In general, the tabulated results are self-explanatory.

By water horse-power is meant :—

Gallons per minute × weight per gallon × head in feet ÷ 33,000.

The costs are given in local currency :—

1,000 millièmes =£E.1 Egyptian = £1 0s. 6d. sterling.

The areas irrigated are given in feddans :—

1 feddan = 1·06 acres.

Plant No. 1. Central Research Farm.

This pumping unit was one of the earliest used for irrigating the farm lands, the total area served being about 250 feddans. It was situated on the banks of the main Nile, about $4\frac{1}{2}$ miles below Khartoum.

The plant contained one vertical Cochran boiler, furnishing steam to a tandem compound vertical engine fitted with enclosed forced lubrication.

The pump was directly coupled to the engine shaft by flange couplings, and was of the centrifugal type, having suction and delivery pipes of 12-inch diameter.

The rise and fall of the river at flood season is very considerable, the variation in the lift being as much as 20 feet, and to obviate the necessity of lifting and lowering the engine and pump with the rise and fall of the river, they were placed in a watertight building and erected at low river level. By the adoption of this method the pump was submerged at high flood, while a short suction was permanently ensured when the river had fallen to its lowest level. The boiler was installed in a separate building above flood level, and was supplied with feed water by an injector and a duplex pump, both delivering from a feed heater. This engine was originally fitted with a jet condenser, but serious defects finally necessitated the scrapping of the condensing gear.

The first trial was run on August 25th, 1912, to determine the fuel consumption, and unfortunately did not permit the separate determination of engine and pump efficiencies. The lift was low, being only 8·3 feet, consequently the plant was running much below full speed, which resulted in considerable loss of efficiency.

The figure 269 (feed water per W.H.P. per hour) shows the combined performance of engine and pump, and is abnormally high, a result due partly to the inclusion of steam used by the feed pump which was by no means economical, and partly to loss of efficiency caused by the low speed.

The conclusion arrived at for this excessive consumption of steam was that it was due either to badly-fitting piston valves or to leaky pistons. As the indicator was not used during the trial, it was not possible to speak very definitely of engine defects.

The boiler performance on wood fuel may be considered quite satisfactory, the evaporation being equivalent to a a coal fuel performance of $6\frac{1}{2}$ lb. of water per lb. of coal (from and at 212 deg.), the makers' figures for this type of boiler being 7 lb.

Test of Plant No. 1.

Date ...		August 25th, 1912.
Duration of test		2 hours 25 min.
Kind of fuel used		Wood.
Total fuel fired	lb.	1,377
Fuel fired per hour	lb.	570
Total feed water	lb.	3,854
Feed water evaporated per hour	lb.	1,595
Feed water temperature	°F.	80
Water evaporated per lb. fuel as fired	lb.	2·80
Water evaporated per lb. fuel from and at 212° F.		3·28
Steam pressure by gauge	lb. per square inch	78
Revolutions of engine and pump	per minute	336
Discharge of pump	cub. ft. per second	6·3
Discharge of pump	gallons per minute	2,360
Discharge of pump	cubic metres per hour	642
Total lift of pump	feet	8·3
Water horse-power		5·9
Fuel per W.H.P. per hour	lb.	96
Feed water per W.H.P. per hour	lb.	269
Cost per W.H.P. per hour	millièmes	29·8
Cost per cubic metre discharge	millièmes	0·276
Cost per 1,000 m^3 discharge	millièmes	276

A thorough examination of the engine was made after the test, and on removing the pistons for inspection it was found that piston rings had not been fitted by the manufacturers.

The latter were communicated with, and stated in reply that it was not their practice to fit rings to that type of engine.

The point was pressed, and rings were supplied, the result being a considerable economy, the actual working cost being reduced from 29·8 to 23 millièmes per W.H.P. hour.

This engine continued to run for two seasons, during which time various breakages occurred, and it was finally superseded by a plant of a larger and more efficient type.

Plant No. 2. Central Research Farm.

The irrigation of native-owned lands at Shambat, adjoining the farm, necessitated the purchase of a new pumping plant capable of providing the large amount of water demanded, which the old farm plant was entirely unable to supply.

It was thought advisable to instal a pump capable of irrigating both the farm and native lands, their combined areas being about 1,000 feddans.

In view of previous incessant trouble caused by the formation of sand banks, a permanently-fixed plant was thought inadvisable, and it was decided to float the engine and pump on a barge.

This system obviously possesses many advantages, the lifting and lowering of heavy pumps and pipes is obviated and, greatest recommendation of all, its mobility allows of rapid transfer to any section of the irrigated area.

As an instance of this, the plant after erection was uncoupled from its position and towed up the river a distance of two miles to save a valuable wheat crop which was jeopardised by engine failure.

The whole time taken in the operation did not exceed fifteen hours, and this fact, as a recommendation for the system of flotation, speaks for itself.

This plant contains three locomotive-type boilers, furnishing steam to a compound, high-speed, vertical, condensing engine of the open type.

The pump is of the centrifugal pattern, coupled directly to the face of the engine disc fly-wheel, and carries suction and delivery pipes of 18 inches diameter.

The condenser is of the jet type, fixed vertically behind the H.P. crosshead.

The engine cylinders are of $11\frac{1}{2}$ inches and $18\frac{1}{4}$ inches diameter, the pistons having a stroke of 11 inches.

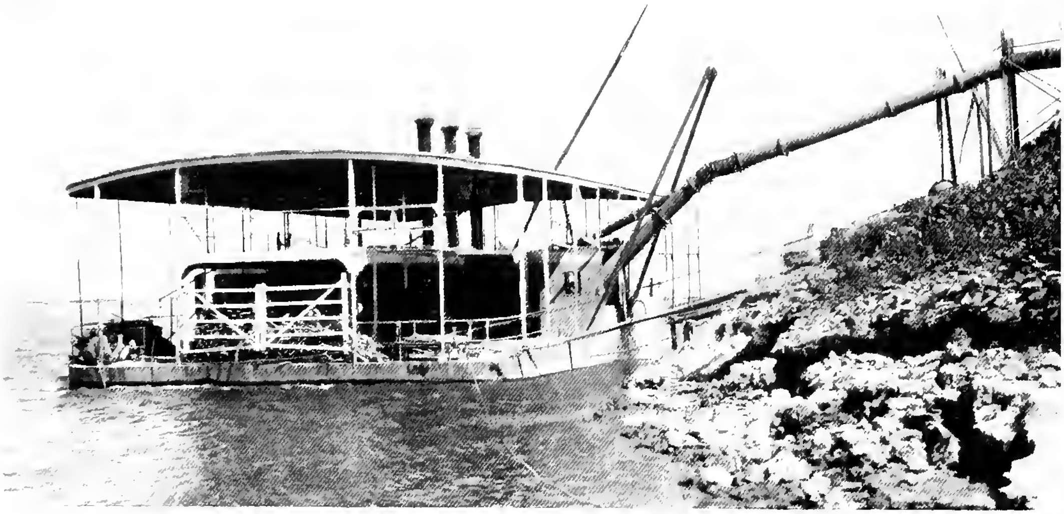
The jet condenser air-pump bucket is 12 inches diameter, and has a stroke of 4 inches.

Two boilers are fired, the third one being cleaned out and made ready for firing in rotation. Little trouble is experienced with scale, the river water being practically free from injurious scaling salts.

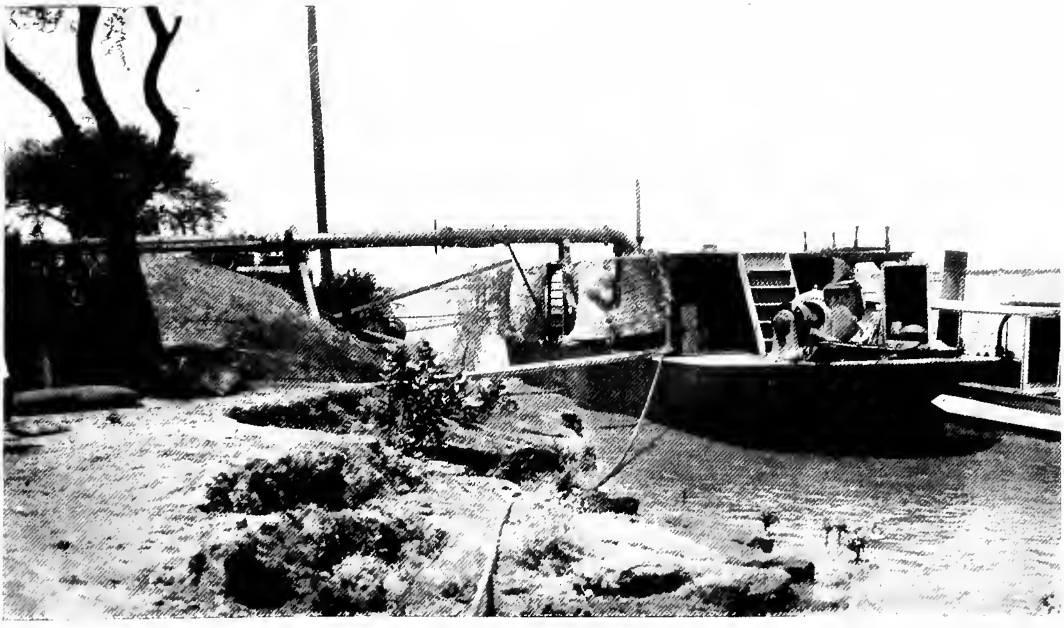
A feed-water heater is fitted for use when running non-condensing, though this is seldom done.

The movement of the floating barge necessitates the insertion of two short lengths of flexible leather pipe in the delivery pipe line, and the arrangement adopted may be readily seen from the illustration.

The flume runs for 400 metres in length before delivering water into the main canals, and has a maximum capacity of 20 cubic feet per second, sufficing for the irrigation of 1,000 feddans. The presence of a shallow khor between canals and river necessitated the flume being carried over the depression as a



The Floating Pump at Shambat for the Irrigation of a Thousand Feddans.



Semi-Diesel Pumping Plant at Tuti Island for the Irrigation of Five Hundred Feddans.

50 metres steel trough slung from girders on brick piers. An illustration of this is given.

The measuring weir situated in close proximity to the main canal is two metres in width, and delivery records are accurately made by a self-recording gauge. This is found to be a great improvement on the old type of hook gauge, as any variation of delivery can be immediately detected and corrected, and the times of starting and stopping the pump can be checked.

The first trial of this unit was held on October 3rd, 1914, and was limited to the determination of fuel consumption only. The river being in flood, the lift was small, and the W.H.P. developed correspondingly low. It was also discovered during the trial that the suction inlet area was restricted, thus allowing the pump to draw in air.

First Trial of Plant No. 2, Shambat.

Date		Oct. 3rd, 1914
Duration of trial		4 hours
Kind of fuel used		Wood
Total fuel fired	lb.	3,283
Fuel fired per hour	lb.	821
Steam pressure at boilers	lb. per square inch	78
Steam pressure at engine	lb. per square inch	60
Revolutions per minute		223
Average vacuum	inches	15
Average weir reading	inches	9·8
Average discharge of pump	gallons per minute	6,000
Average discharge of pump	cubic metres per hour	1,635
Lift of pump	feet	9·5
Water Horse-power		17·3
Fuel per W.H.P. per hour	lb.	47·5
Cost per W.H.P. per hour	millièmes	12
Cost per 1,000 m³. water delivered	millièmes	·127

A second trial was made seven days after to determine the plant's performance when using coal fuel, and results clearly demonstrated the economy effected by the use of wood fuel, the actual saving being 46 per cent.

As before stated, the relative costs of coal and wood delivered at site are £E.3, and 500 millièmes respectively.

Second Trial of Plant No. 2, Shambat.

Date		Oct. 10th, 1914
Duration of trial		4 hours
Kind of fuel		Coal
Total fuel fired	lb.	1,188
Fuel fired per hour	lb.	297

Steam pressure at boilers*	lb. per square inch	78
Steam pressure at engine*	lb. per square inch	56
Revolutions per minute		211
Average weir reading	inches	10·0
Discharge of pump in gallons per minute		6,180
Discharge of pump in cubic metres per hour		1,685
Total lift of water	feet	9·5
Water Horse-power		17·8
Fuel fired per W.H.P. per hour	lb.	16·7
Cost per W.H.P. per hour	millièmes	22·4
Cost per 1,000 m^3 water delivered	millièmes	236

A third trial was held on October 24th, 1914, to determine the steam consumption together with efficiencies of engine and pump.

The total efficiency of pump and engine was only 35 per cent., accountable for by the comparatively low speed of engine which was only at about half load.

The pump, too, was running much below speed, and working at about one-third the lift for which it was designed.

An improvement in the figure was expected with the fall of the river, though it was not thought that under the most favourable circumstances the efficiency would exceed 60 per cent.

The engine performance as represented by the figure 45·8 is, of course, high, partly for reasons enumerated above, and partly because it included all condensation, steam jacketing and other losses between engine and boiler, which, strictly speaking, ought not to be laid to the account of the engine, but which were included owing to difficulty of measurement.

The performance of the boilers may be regarded as fairly satisfactory, but could be considerably improved, though skilful firing by native stokers is almost unobtainable.

Third Trial of Plant No. 2. Shambat.

Date		October 24th, 1914.
Duration of trial		4 hours.
Kind of fuel used		Wood.
Steam pressure at boilers	lb. per sq. inch	79
Steam pressure at boilers	lb. per sq. inch	57
Vacuum	inches	14
Indicated Horse-power :—		
High-pressure cylinder	33·7	
Low-pressure cylinder	29·7	
Total	63·4	

* With regard to the large discrepancy of steam pressure at boilers and engine, it was afterwards found on testing the new gauges that both were unreliable.

Third Trial of Plant No. 2. Shambat—*continued.*

Weir reading	inches	9·75
Discharge from pump	gallons per minute	5,960
Discharge from pump	cubic metres per hour	1,625
Total lift of water	feet	12·3
Water Horse-power		22·2
Combined efficiency of engine and pump	per cent.	35
Total fuel fired	lb.	4,412
Fuel fired per hour	lb.	1,103
Fuel fired per W.H.P. per hour	lb.	49·7
Total feed water	lb.	11,871
Steam used per hour by feed pumps	lb.	63
Steam used per hour by engine	lb.	2,905
Steam used per I.H.P. per hour	lb.	45·8
Temperature of feed water	°F.	100
Water evaporated per lb. fuel as fired	lb.	2·63
Equivalent evaporation from and at 212° F.		3·03
Cost per W.H.P. hour	millièmes	12·5
Cost per 1,000 m^3. water delivered	millièmes	169

It was thought advisable to make a further test with this plant when working at its maximum lift, and this was arranged when the river had fallen to its lowest level.

The lift was 30 feet, and although all circumstances were favourable to a successful test, the results were rather disappointing, the combined efficiency of engine and pump only reaching the figure of 39·2 per cent. Assuming a mechanical efficiency of engine of 90 per cent., the efficiency of pumping would be 49·2 per cent., which is not a very high value.

This test was carried out in the same manner as the previous one, and it was intended to run for the same length of time, but a joint of the condenser gave way, and the engine had to be stopped a short time before the desired completion of period of test.

The engine performance was distinctly better than the previous one, the amount of steam per I.H.P. hour being 30·8 lb. This included all losses other than steam used by feed pump.

The performance of boilers was not very good, due to their being heavily steamed, and also to the unskilful firing of the native stokers.

The reduction in cost per W.H.P. hour is noteworthy, though the cost per 1,000 m^3 water delivered has increased considerably.

As this unit has been continuously running for a longer period than any other on the farm, a diagram showing its pumping costs at varying lifts is appended.

This plant has proved a great improvement on the old units used, and although its economy would be increased by the installation of a more efficient pump, it has nevertheless widened the margin of profit in a very satisfactory manner.

A further economy would be effected by superheating, for with the existing arrangement of steam pipes there occur considerable condensation losses.

4th Trial of Plant No. 2. Shambat.

Date		May 3rd, 1915.
Duration of trial		3 hours 50 minutes.
Kind of fuel used		Wood.
Steam pressure at boilers	lb. per square inch	105
Steam pressure at engine	lb. per square inch	100
Vacuum	inches	15
Indicated Horse-power :—		
High-pressure cylinder	62·7	
Low-pressure cylinder	68·0	
Total		130·7
Weir reading	inches	$9\frac{3}{8}$
Discharge from pump	gallons per minute	5,630
Discharge from pump	cubic metres per hour	1,522
Total lift of water	feet	30
Water Horse-power		51·2
Combined efficiency of engine and pump	per cent.	39·2
Total fuel fired	lb.	6,200
Fuel fired per hour	lb.	1,617
Fuel fired per W.H.P. per hour	lb.	31·5
Total feed water	lb.	15,900
Steam used per hour by feed pump	lb.	117
Steam used per hour by engine	lb.	4,030
Steam used per I.H.P. per hour	lb.	30·8
Temperature of feed water	°F.	108°
Water evaporated per lb. fuel as fired	lb.	2·56
Equivalent evaporation from and at 212° F.	lb.	2·94
Cost per W.H.P. hour	millièmes	7·9
Cost per 1,000 m³ water delivered	millièmes	260

Plant No. 3. Tuti Island.

The decision of the Government to irrigate native-owned lands on Tuti Island afforded an opportunity for the trial of an internal combustion engine adapted to the use of crude oil. Such an experiment was demanded by recent improvements in this type of engine, and demonstrated economies in running costs as compared with those of steam plant, which gave promise of solving the problem of cheap pumping in the Sudan.

Egyptian crude oil is offered in Suez at less than £E.3 per ton, and it was thought that the projected establishment of oil-tanks at Port Sudan and a system of bulk carriage on the railways would encourage general employment of the crude-oil engine, if its applicability could be shown. A trial shipment of 25 tons of crude oil was consequently procured at Suez, but, pending completion of arrangements for bulk carriage, the economic value of the fuel was practically killed by freight and handling charges of nearly £E.5 per ton.

The oil on analysis compared very favourably with American and Russian oils, its viscosity being slightly greater—a matter of little moment in the high temperatures obtaining in the Sudan.

The abilities of the native engine-driver being very limited, it was considered inadvisable to instal a full Diesel engine, with its complicated construction and abnormal pressures, and an order was placed with a well-known maker for a machine of the semi-Diesel type.

As in the case of Plant No. 2, the engine and pump were floated in a barge, this method possessing such great advantages that its ultimate adoption throughout the Sudan will doubtless be effected.

The pump was of the centrifugal type with suction and delivery pipes of 12 inches diameter, and was belt-driven from engine shaft. The delivery pipe line was arranged similarly to that of Plant No. 2, having two short lengths of flexible leather piping to take up the movement of the barge. The flume is brick-lined and runs a length of 100 metres before delivering over the measuring weir into the main canals, and had a capacity of 10 cubic feet per second, sufficing for the irrigation of 500 feddans.

The engine was of the semi-Diesel, two-cycle, vertical type, with double cylinders, and cranks at 180 ; and at 330 revolutions per minute was capable of developing 55 H.P. Compressed air was employed in starting, but was immediately cut off when the engine received the first impulse from the ignition of vapour.

Trouble was experienced at first as a result of the crude oil carbonising and clogging up the vaporiser bulbs, and the makers on being referred to, recommended running on a mixture of 10 per cent. paraffin, 90 per cent. crude oil. This was done, and the carbonising trouble disappeared ; but with paraffin at £E.16 per ton, the cost of running was necessarily enhanced.

The shop-test figures of this engine before delivery from the makers were extremely good, the consumption of fuel per W.H.P. hour being ·44 lb. paraffin and ·57 lb. crude oil. It at once became apparent, however, that in actual working conditions these consumption figures could not be touched, and a test was arranged to determine the actual result.

After a three months' working period, the engine cylinders showed signs of excessive wear, and, this being unequally distributed, the insertion of new piston rings did not eliminate the escape of gases into the crank chamber, which caused a gradual loss of engine efficiency and rise in running cost.

A fracture of the right-hand crank web closed the career of this interesting plant, the whole of one cylinder, details and bed plate being wrecked.

The failure of this engine is regrettable, for its purchase was made with a view to determining its suitability for general adoption in this country, and its performances with ultimate breakdown has probably created a prejudice against the system.

In fairness it should be pointed out that, when first installed, the plant provided water at a cheaper cost than any other employed, and its failure does not in any way affect the desirability of adopting the type, provided that better material be used in construction.

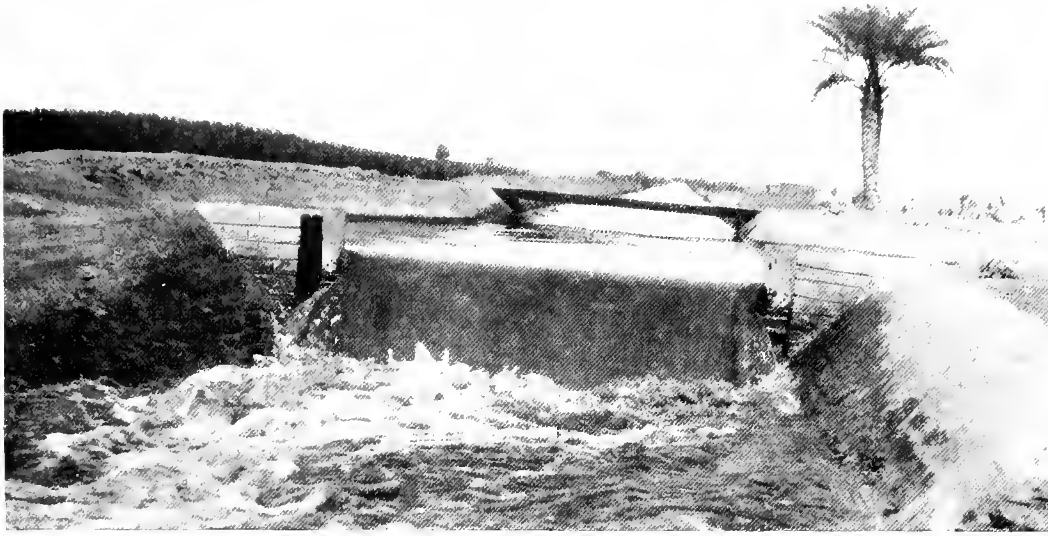
Thoroughly skilled labour is so scarce in the country, and wages are at such an excessive rate, that the wages bill on a complex, full Diesel engine would in all probability narrow the margin of pumping profits to vanishing point.

A semi-Diesel engine is comparatively simple in operation and construction, and if the prevailing local conditions were considered during its manufacture, this type of pumping plant would meet all requirements.

First Trial of Plant No. 3. Tuti Island.

Date ...		April 18th, 1914.
Duration of trial ...		6 hours.
Kind of fuel used ...		Crude petroleum.
Total fuel consumed ...	lb.	177·6
Fuel consumed per hour ...	lb.	29·6
Revolutions of engine ...	per minute	278
Revolutions of pump ...	per minute	556
Average weir reading ...	inches	4·29
Discharge of pump ...	gallons per minute	1,760
Discharge of pump ...	cubic metres per hour	474·7
Total lift of water ...	feet	27
Water Horse-power ...		14·4
Fuel consumed per W.H.P. hour ...	lb.	2·05
Cost per W.H.P. hour ...	millièmes	7·32
Cost per 1,000 m^3 water delivered ...	millièmes	222

It is noticeable that the fuel consumed per W.H.P. per hour is far in excess of the makers' figure on shop test, these being ·57 lb. crude oil, or, with allowances for efficiency losses in pump and belt transmission, ·8 lb.



Measuring Weir with Automatic Recorder at Shambat.

Measuring Weir at the Tuti Island Pumping Station

The price of crude oil delivered at the pumping station being £E.8 per ton, or 3·57 millièmes per lb., the cost per W.H.P. per hour noted on the makers' test figures would be 2·85 millièmes, or a reduction of 61 per cent. on the actual working figures.

On May 14th, 1914, a further trial was made to determine the consumption when paraffin fuel was used. The test was held under the same conditions as the previous case, with the exception of the lift which was slightly less.

Second Trial of Plant No. 3. Tuti Island.

Date	...	May 14th, 1914
Duration of trial	...	6 hours
Kind of fuel used	...	Refined Russian Petroleum
Total fuel consumed	lb.	258·72
Fuel consumed per hour	lb.	43·12
Revolutions of engine	per minute	300·8
Revolutions of pump	per minute	601·6
Average weir reading	inches	5·03
Discharge of pump	gallons per minute	2,220
Discharge of pump	cubic metres per hour	599·2
Total lift of water	feet	26·5
Water Horse-power	...	17·8
Fuel consumed per W.H.P. per hour	lb.	2·42
Cost per W.H.P. per hour	millièmes	16·1
Cost per 1,000 m^3 water delivered	millièmes	479

As was to be expected, the cost of pumping on paraffin was greatly in excess of that when using crude oil, the relative costs of the fuels delivered on site being £E.16 and £E.8 per ton respectively.

The saving effected by the use of crude oil should have been 50 per cent., but was in reality 54 per cent. This discrepancy was due to the decrease in engine efficiency since the earlier test, caused by reasons which have previously been stated.

The makers' test figure for paraffin fuel was ·617 lb. per W.H.P. per hour as against the actual working test performance of 2·42 lb., or four times their estimate.

Plant No. 4. Tuti Island.

The wrecking of the semi-Diesel engine necessitated its replacement by a new plant, and the makers of the wrecked engine offered a first-class steam plant on very generous terms. Time was an important consideration, and the new engine being offered from stock decided its purchase.

It was found impossible to float this unit, there being unfortunately no barge capable of holding it, so it was temporarily housed on the river bank, the pump being belt driven by a countershaft at low-water level and directly from the engine shaft during flood season. The pump supplied with the Semi-Diesel engine is utilised, and proves to be very efficient.

This unit is of the compound, composite, undertype pattern, the boiler being fixed directly over the engine, all being carried on a girder-frame bed. The locomotive-type boiler is arranged to burn either liquid fuel or wood, and tests have been made to determine comparative consumptions.

The engine cylinders are of 7½ inches and 13 inches diameter, the pistons having a stroke of 16 inches. A horizontal jet condenser is fitted and actuated by a tail rod from the L.P. piston. A feed heater is provided for use when running non-condensing, the boiler feed being supplied by a pump driven by an eccentric on the engine shaft, and provision is also made for an auxiliary horizontal duplex pump.

The tests were made immediately on erection of the unit for inclusion in this report, and furnish interesting comparative figures.

First Trial of Plant No. 4. Tuti Island.

Date		July 20th, 1915
Duration of trial		4 hours
Kind of fuel used		wood
Total fuel fired	lb.	1,400
Fuel fired per hour	lb.	350
Steam pressure at boiler	lb. per square inch	149
Steam pressure at engine	lb. per square inch	148
Revolutions per minute		149
Average vacuum	inches	21·5
Average weir reading	inches	5
Discharge of pump	gallons per minute	2,450
Discharge of pump	cubic metres per hour	661
Total lift	feet	21
Water Horse-power		15·5
Fuel per W.H.P. per hour	lb.	22·5
Cost per W.H.P. per hour	millièmes	5·6
Cost per 1,000 m³. water delivered	millièmes	132

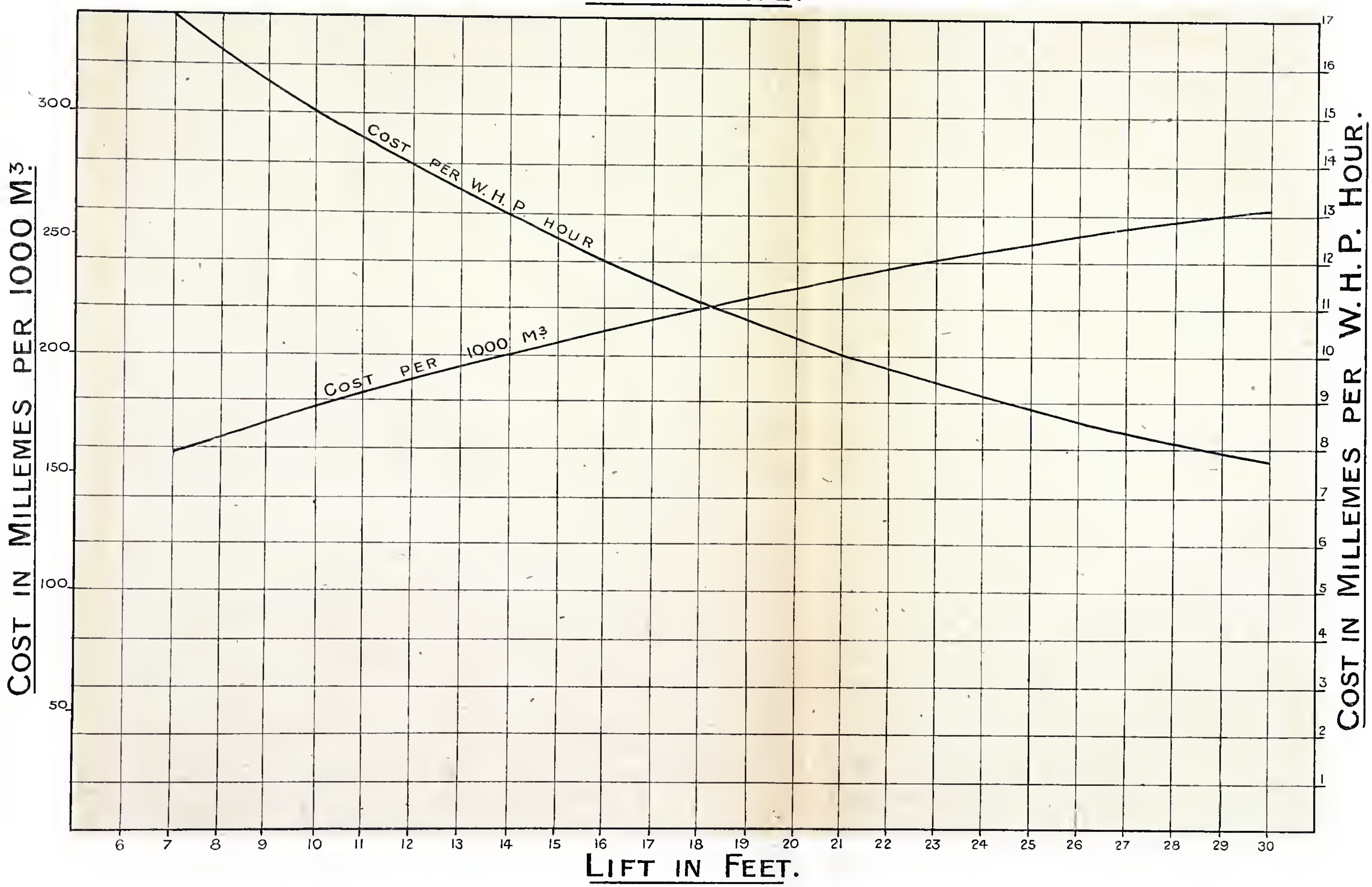
The test may be regarded as very satisfactory, particularly the cost per W.H.P. per hour, this figure being the lowest yet reached.

Slight slipping of the new countershaft belt took place during the test, and consequently the pump was not running quite up to its maximum speed.

Under-type Pumping Engine at Tuti Island—an Approved Pattern, adapted to Wood or Liquid Fuel.

Diagram showing Cost of Pumping at varying Lifts.

Plant No. 2.



Cost of Irrigation.

The final comparison of pumping units must be made on a financial basis, and in the choice of a type of plant for certain conditions not only must the costs of available fuels be considered, but also wages, repairs, depreciation, and interest on capital outlay.

Local variations in the cost of fuel, lubricating oils, transport and wages may materially influence costs of irrigation, and findings in one district will only have a limited application. In this country, where repairs are an expensive item, a plant must possess the essential quality of reliability, and particularly so if there is only a single pumping unit, as serious engine trouble may jeopardise the whole of the crops under irrigation.

The maximum financial economy in running costs is a *sine qua non* of profitable pumping. The margin of profit may be seriously influenced by variations in lift and reduction in the area irrigated. To secure the greatest economy the pumping unit must be run at its full capacity, and the largest possible area must be irrigated. In this way alone fixed charges, such as wages and interest, have the widest incidence obtainable.

Descriptions of the units, together with their test performances, have already been furnished, and it is now intended to consider in detail their actual working performances and the costs of irrigation. For simplicity and facility of comparison these have been shown in tabular form. It is regrettable that it has not been possible to include Plant No. 4, as, owing to its short period of service, any figures given would be practically valueless for comparative purposes. It may be said, however, that its performances during the few days since its installation give promise of its being the most economical plant yet erected.

PLANT.	Irrigation Period.	Total Hours run.	Average Delivery of Water M³ per hour.	Total Water delivered in Cubic Metres.	Average Lift in Feet.	Average Water Horse-power.	Total Feddans Irrigated.	Duty of Water per Feddan in Cubic Metres	Average Feddans Irrigated per Hour.
No. 1	December, 1913, to May, 1914.	1,631	381	621,411	Ft. in. 22 0	9·33	1,320	470	·809
No. 2	July, 1914, to March, 1915.	2,280	1,379	3,144,120	18 3	28·0	6,520	482	2·860
No. 3	April, 1914, to August, 1915.	1,048	503	527,144	26 6	14·2	640	823	·610

The Duty of Water is calculated from the discharge over weir sill. With reference to Plant No. 3, installed at Tuti Island, an explanation of the low duty of water is afforded in a following report. A great reduction has since been effected.

TABLE No. 2.—**Comparative Costs of Irrigation.**

PLANT.	Cost of Plant.	Cost of Fuel Consumed.	Cost of Lubricating Oil used.	Cost of Labour and Sundries.	Average Cost per W.H.P. per Hour.	Average Cost per 1000 M³. Water.	Cost per Feddan Irrigated.	Cost per 1000 M³ Wtr. plus 10% Depreciation and Interest.	Cost per Feddan Irrigated plus 10% Depreciation and Interest
	£E.	£E.	£E.	£E.	Millièmes.	Millièmes.	Millièmes.	Millièmes.	Millièmes.
No. 1	—	293.700	31.920	132.480	30·1	737	347	—	—
No. 2	1,645	576.875	19.017	223.837	12·8	260	125·7	299	144
No. 3	—	205.565	31.709	150.000	26·0	734	293	—	—

The item "Cost of Labour and Sundries" includes wages of engineers, sheikh of cultivation, water watchmen, boatmen, stokers, greasers, wood cutters, ghaffirs, minor repairs to plant, and extra labour employed for repairs to main canals

REPORT V.

THE IRRIGATION OF LANDS IN NATIVE OWNERSHIP.

A. F. NATHAN, *Inspector of Irrigation.*

THE rainless areas of the Northern Sudan afford an agricultural problem which centres round the provision of water for the crops at the smallest possible cost. Following the lines of least resistance, the native cultivator exploited from time immemorial the advantages attaching to the seasonal rise and fall of the Nile, and a large proportion of the cultivated area has always derived its irrigation directly or indirectly from the annual flood. Sand banks and mud flats, basins of low-lying land and the lower shelves of the river bank itself, exposed by the receding river, have been planted with quickly maturing crops and have furnished a livelihood to a considerable population.

Pressure of numbers, however, from time to time, drove the riverain tribes to irrigate lands lying above the flood level by means of primitive water-lifts, until a continuous belt of cultivation fringed both banks of the river, with a width determined by the radius of the elementary devices employed. Further progress could then only lie by way of improved methods and implements, and it is a noteworthy fact that local agricultural practice at the time of our recent occupation differed in hardly any detail from that depicted in the tombs of the Theban kings. A stationary population had been controlled by such positive checks as periodic famine, while isolation, internecine warfare and maladministration postponed the era of economic development.

To the benumbing influence of slavery may be attributed the retention of such anachronisms as the "shadoof" and the "sakia," and in the recent manumission of slaves may be found the stimulus necessary to the introduction of improved agricultural methods and labour-saving devices. The country's urgent need is for a large increase in the supply of free and skilled labour to develop the lands which will be rendered available for cultivation by modern engineering skill, and, in view of a general pacification, the control of epidemic disease and a system of famine relief, increase in the rural population will be determined directly by crop returns. The present report consequently reflects an effort to apply the results of local research to the dual object of increased production and the simultaneous education of agricultural labour.

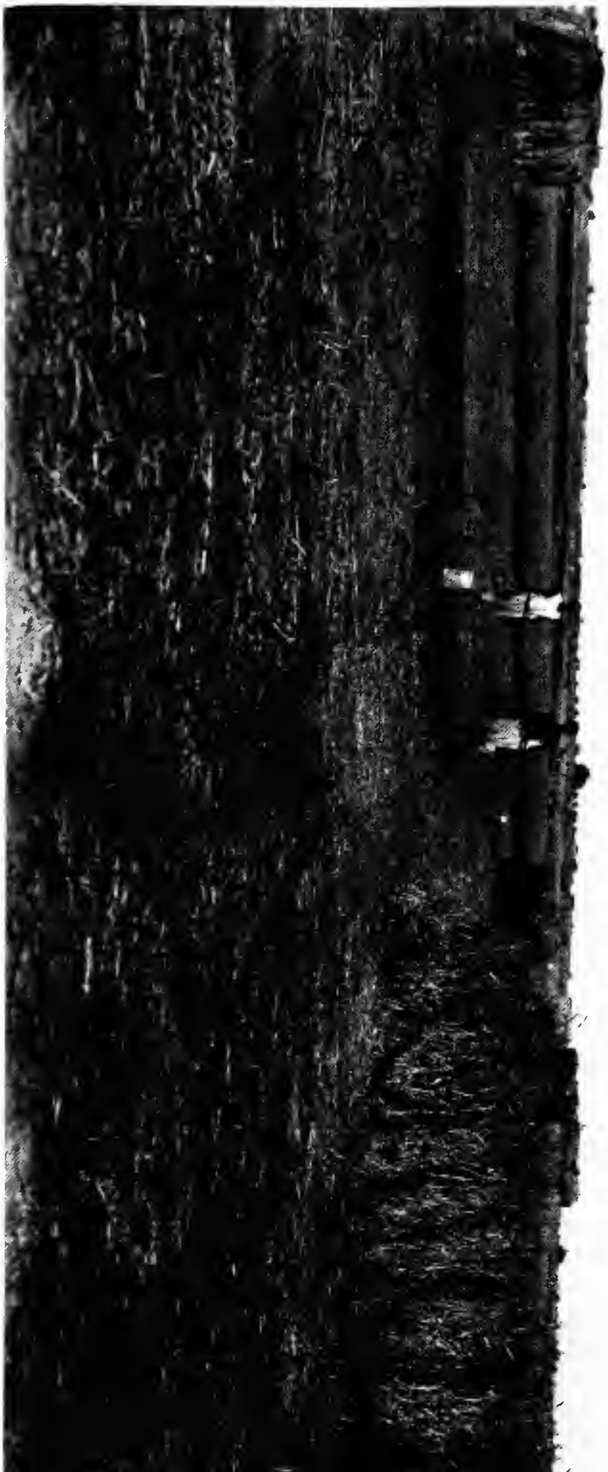
A majority of the problems encountered originate in customs and tradition upon which any modern superstructure must necessarily be founded. Innovations must stand the test of the experience of centuries, and a thorough understanding of the reasons underlying existing practice is essential to a sympathetic handling of an intensely conservative and suspicious population. The situation is further complicated by varying standards of agricultural skill and education, each class of land, if not every district, calling for individual examination and treatment. A brief examination of the principal local systems of cultivation will consequently serve to define the limits of the present undertaking.

Classification of Agricultural Areas.—Cultivated areas in the Northern Sudan have been classified with relation to the river flood, which determines the method of irrigation and incidentally the choice of crops and their treatment.

" *Gezireh* " land embraces alluvial areas which are entirely submerged at high Nile, and includes mud flats, sand banks and the lower shelves of the bank proper. In consistency they vary from sands to clay loam, and annually receive a deposit of silt and sand in varying proportions. Sowing takes place after the river falls and as soon as the surface is firm enough to bear the weight of the cultivator. A considerable variety of crops are cultivated, and particularly wheat, bulrush millet, pigeon-pea, cowpea, safflower, cucumbers, gourds, pumpkins, melons, tomatoes, lentils, lupines and roselle. The most primitive methods are followed; ploughing is unpractical, as the crop is dependent upon a rapidly-falling water-table for its moisture requirements, while the deposit of alluvium discounts the value of manuring or any regular rotation of crops.

" *Garf* " land lies just above the average flood level in the neighbourhood of the river bank. It is completely covered by the Nile in years of exceptionally high flood only. As a general rule the water necessary to garf cultivation is derived from lateral seepage. The breadth of the strip of garf depends upon the conformation of the river bank and the consistency of the soil. Garf land is invariably a light and friable alluvial deposit of recent development, and absorbs and retains a large amount of moisture. The crops generally grown and the methods employed are very similar to those found on gezireh lands, though cotton of the native type, and in the last few years American varieties in certain districts, have been also successfully cultivated.

" *Maya*," or basin, lands are periodically flooded at high Nile. They are connected with the river by natural or artificial channels, through which the flood reaches the basin and later drains back into the river as the water-level falls. The value of the flood depends upon the amount of water reaching the basin, the quantity of silt deposited, the period during which the water remains on the land and the rapidity with which it drains off when the river falls. If the land is not thoroughly flooded the crop will suffer from or succumb to drought before harvesting. Should the water remain for too long a period water-logging



will ensue, and the land will be sour and unsuitable for cropping. In a natural basin all these circumstances are beyond control and depend solely on the height and duration of the flood. By the construction, however, of suitable sluice-gates, canals and drains, an efficient system of flood irrigation can generally be evolved. As in the previous cases, the cultivator follows the receding water and generally dibbles in his seed with the " seluka " or the " melut." The favourite crops are wheat, barley, millet, maize, lupines and cowpea in the order named.

Flood Cultivation.—While successful basin irrigation is largely a question of engineering and flood control, certain disadvantages are common to all the above types of flood cultivation. The uncertainty of the flood-level, its incidence and duration, the rapid lowering of the water-table and a diminution in the water supply during the period of the crop's maximum demand, the short growing period afforded by this circumstance, and the prevalence of insect pests and plant diseases in all flooded areas discount the advantage of a practically gratuitous water supply. The value of preliminary and subsequent cultivation as a means of conserving moisture and limiting the damage normally sustained from such pests as the cutworm, has been clearly recognised by the authorities, and sustained development will be determined by the possibility of securing a general adoption of the practice by the cultivators themselves.

Artificial Irrigation.—" *Sakia* " lands generally lie well above the highest flood level, and their irrigation is entirely artificial. The indigenous means employed are the " *shadoof* " and the " *sakia* " or Persian Water Wheel.

Shadoofs are worked by manual labour, and are used where small quantities of water are required and the lift does not exceed from 2 to 3 metres. It consists of two posts with a cross piece on which a long lever is pivoted. On the short arm of this lever a weight is fixed, generally consisting of a large ball of mud wrapped in sacking or bound with fibre. This weight acts as a counterpoise to a rod and dipper hanging from the long arm. The dipper is usually a skin bag with wooden rim and a capacity of about 20 litres. With a lift of 2 to $2\frac{1}{2}$ metres a man working continuously for one hour can raise about $8{\cdot}4\ m^3$ of water.* In view of the exacting nature of the task a total lift of $50\ m^3$ per diem could not probably be exceeded, for which a normal wage of 35 millièmes would be paid. Such water would consequently cost the cultivator approximately 0·7 millièmes per m^3. In 1913, shadoofs to the number of 2,670 were working in the Sudan.

The sakia consists of an endless rope, generally made of palm-leaf fibre, carrying a series of earthenware pots (" qadus ") at intervals of from 2 to 3 feet. This rope passes over a vertical wheel actuated by a second horizontal wheel by means of engaging wooden pegs or cogs. To the axle of the second wheel a pole

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* Lang Anderson : " Implements of Irrigation."

is fixed, and motive power is supplied thereto by bulls. The entire structure is made of local timber by the village carpenter, who is also responsible for the frequent repairs required. The rope hangs freely in the water, and as the wheels revolve the pots are filled in succession, carried up and emptied as they pass over the top into a receiving trough, which in turn empties into the irrigation channel. The sakia is suitable for raising water to heights of from 3 to 8 metres, and is worked by one or two animals according to the lift, the number and size of the pots, and the number of teeth in the cog-wheel.

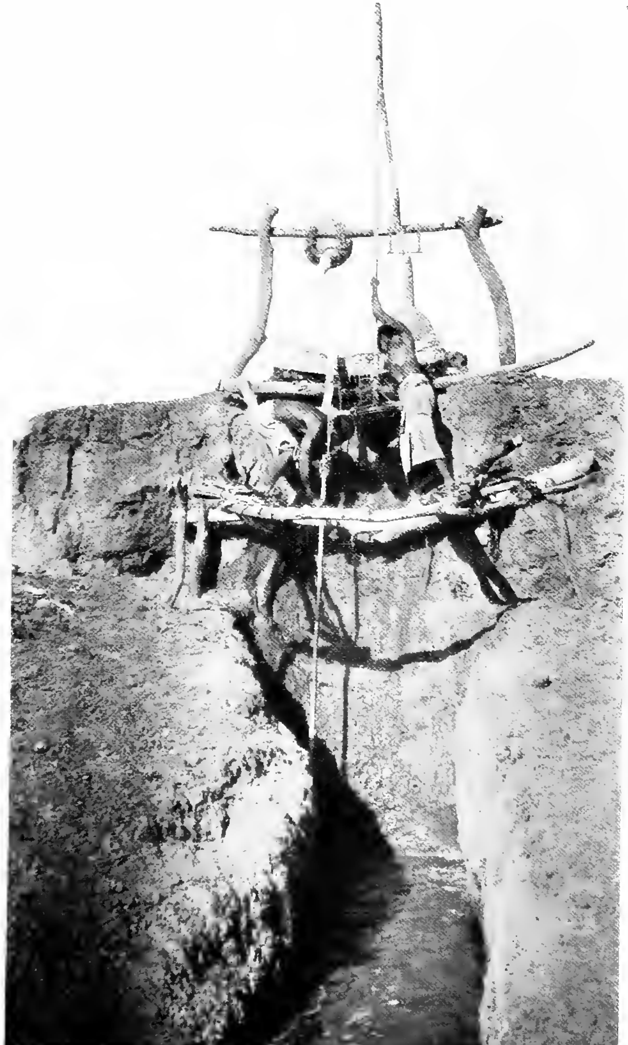
Costs of Sakia Irrigation.—With an average lift of 5 metres, the usual capacity of the sakia is some 30 m^3 of water per hour, or, say, 240 m^3 per diem with a single pair of bulls. According to local custom the hire of a pair of bulls with driver costs 200 millièmes per diem. The cost of water raised by sakia may consequently be stated as almost equivalent to that obtained by the use of the shadoof, but a greater lift is secured and a larger body of water is delivered. The latter feature reduces losses from evaporation and seepage and a larger proportion of the water raised actually reaches the cultivated area. In 1913, 10,075 sakias were working in the Sudan.

Direct experiment has determined the duty of water in local circumstances to be about 470 m^3 per watering per feddan for the clay loams constituting the majority of sakia lands on the river bank. This figure is based upon a discharge of from 5,000 to 6,000 gallons per minute as delivered by a modern pump through carefully-constructed canals, and if allowance be made for excessive losses where small streams of water are led through ill-constructed channels, it is certain that at least 500 m^3 will be required from sakia or shadoof. In either case, the duty is roughly equivalent to the output of two working days with the sakia, and the cost, according to local custom, is 400 millièmes.

A means of controlling this estimate is found in the payments made by tenants of sakia lands for water supplied by the owner. By local customs such a tenant would pay half his crop for the hire of the land and the water received from the sakia, and in addition would be responsible for half the land-tax. On this basis, if we take the yields per feddan on a 3-feddan holding, as follows :—

Cotton	... 3½ kantars @ £E.3 =	£E.10.500,	the tenant would pay		£E.5.250
Wheat	... 4 ardebs @ £E.1 =	£E.4.000	,,	,,	2.000
Dura	... 5 ardebs @ £E.0.600 =	3.000	,,	,,	1.500
		£E.17.500			£E.8.750

If this cotton requires twelve waterings, the wheat six, and the dura four, the average number of waterings per feddan would be seven and a third. For rent and watering of one feddan the tenant pays £E.2.917 exclusive of land-tax. By common convention the rent alone amounts to a tithe of the crop, so the cost of



The 'Shadoof,' or Hand Water Lift.

Planting with the 'Seluka' on Flood Lands,

water is almost exactly 397 millièmes per feddan per watering,* or again 400 millièmes in round figures.

Finally, mention may be made of the eagerness with which sakia owners accepted a suggested water rate of 250 millièmes per feddan for pumped water.

Comparative Costs of Pump Irrigation.—As compared with this figure of 400 millièmes, careful records maintained over an entire season of nine months furnish a cost for pumped water of 130 millièmes per $500m^3$ (*vide* Report IV; Table 2), the actual duty of water working out at $482m^3$ per feddan, including all losses in distribution, at a cost of 125.7 millièmes.

The average capacity of the sakia is the irrigation of ten feddans, and the total area served by this means amounts to approximately 100,000 feddans. If eight waterings are afforded annually, which is a very conservative estimate, at a cost, on the above basis, of £E.320,000, the general substitution of modern pumping plant would reduce this figure to £E.104,000 and effect a direct saving on costs of production amounting to £E.216,000 per annum.

Such economy represents, however, only one of the advantages which would attach to such a system. As already indicated, the radius of the sakia is strictly limited, and much land lying within half a mile of the river bank in demarcated ownership, now lying fallow and carrying no population, can be included in any scheme of pump irrigation.

In the case of the experiment now reported, the area of cultivation on a river frontage of 1,500 metres has been extended from about 60 feddans previously under sakia irrigation to approximately 500 feddans under the pump. On a conservative estimate it should thus be possible to quadruple the area of irrigation and reduce the cost of production by at least a fifth.

Agricultural Development and Education.—Pending the completion of projected schemes for the irrigation of extensive areas of land by means of gravity water, involving the construction of barrages and the organisation of comprehensive canal systems, no more promising opportunity would appear to offer for agricultural development and education than is found in the demand for a cheaper water supply to the riverain sakia lands, and steps have been taken by practical experiment to determine how the substitution of the modern pumping station for the water-wheel can be most satisfactorily effected. Happily the work has been facilitated by the fact that the sakia cultivator represents the most skilful class of agriculturists found in the country. He has learnt by experience the value, or necessity, of preliminary cultivation, whether with hoe or primitive wooden plough; he has appreciated the advantages

* Davie: Report on the Gezira Agricultural Experiment Station.

attending the use of farmyard manure and wood ashes, and has even evolved an indefinite rotation of crops as a means of obviating soil-exhaustion. His life, moreover, has in the past been one of excessive toil and hard living, and the prospect of a lightening of the customary burden is fully appreciated and serves as a stimulus to immediate effort. By dint of sustained effort he has previously raised a bare livelihood for himself and family and food for the sakia bulls. The realisation of a first profit under the new system has been followed by an enquiry for local schools, better implements and the possibility of a further extension of the irrigation area.

Organisation.—Regarded as a system of co-operation between the Government and the freeholder of sakia land, the general aspects of organisation have been discussed in an introductory Report. For various reasons a unit area of 1,000 feddans has been determined as offering possibilities of the greatest economy, when associated with others of a series under common supervision and management. A capital charge not exceeding £E.2.400 per feddan has been sustained in connection with the purchase and installation of the pumping plant, headworks, preliminary survey, bridges, modules, weir-gauges and other incidental expenses, while an irrigation contract, based on the security of the freehold title to the sakia, covers the payment of a water rate of 250 millièmes for a minimum of twelve waterings per annum.

It remains to describe in some detail the actual organisation of the work, irrigation practice and the preliminary results obtained.

Canalisation.—While the Government has, in the case of the experiment under discussion, accepted responsibility for the provision of plant and headworks, it has been decided that the cost of main and subsidiary canals shall be borne by the cultivators. Main canals have been constructed by the farm staff with loan funds constituting a charge on the first crops, and particulars of their cost and efficiency are of interest. The topography of the river banks affords an irrigable area sloping back from the flood bank with an average width of about half a mile. The main canal consequently parallels the bank and delivers water to distributory canals at right angles to the former.

For the irrigation of an initial area of 500 feddans a main canal has been constructed with a length of 2,650 metres, a fall of 1 : 2,500, a bottom section of 45 c.m., and a top section of 205 c.m. An economy in section has been effected by placing the pumping station in a central site and employing a double-ended canal. The costs of construction have varied with the relative amounts of "cut" and "fill"; thus, 2,000 metres following a fairly uniform natural slope were excavated as "cut and fill" at a total cost of £E.56.645, or at a cost of 28.3 millièmes per running metre, including labour, implements and hire of ploughs and cattle. A second section necessitating a raised canal for a considerable

The 'Sakia,' or Persian Water Wheel.

Trough Flume across Khor at Shambat.

length involved an expenditure of £E.88.985 for 650 metres, or a cost of 136.9 millièmes per metre. The proportionate charge per feddan of irrigated land amounted to 291 millièmes.

Distributory canals to serve the individual " hoshes " of 100 feddans into which the unit has been demarcated, were constructed under supervision by the cultivators themselves, who are similarly responsible for their cleaning and maintenance, as also for the upkeep of the main canal.

Distribution of Water.—A prime object of management should be the reduction of avoidable losses of water between headworks and land. In larger systems it has been estimated that not less than a third of the headworks' supply is lost before reaching the outlet, and it is affirmed by competent authorities that such loss is capable of reduction by about 40 per cent., which is equivalent to a saving of about 14 per cent. of the headwork discharge. The greatest losses in such cases are incurred by the use of too numerous small watercourses, and the amalgamation of such channels into canals carrying between 2,500 and 5,000 m^3 per diem largely increases efficiency. Such canals are capable of irrigating between 83 and 166 feddans in the Sudan, and have been universally adopted in laying out the experimental area. In the interests of malaria prevention and to facilitate regular cleaning, two such canals have, however, been provided on each " hosh," and are brought into use alternately for periods of four or five days. The intervals of disuse permit thorough drying, the destruction of mosquito larvæ, and the limitation of weed-growth. This arrangement is depicted in the attached plan.

The Gibb's Module.—Distribution to these smaller canals is effected through modules of the Gibb's pattern, as a great improvement on pipe-outlets. With the latter the water supply necessarily varies largely with fluctuations in the head of water in the main canal, whereas the module ensures a practically constant discharge.

In the Gibb's Module the water flows in a semi-circular path through a steel chamber, across which are fixed a number of vertical steel diaphragm plates. The lower edges of these plates are of such a shape, and they are fixed at such a height from the bottom of the chamber, as to allow a stream of just the correct required discharge of water to flow under them without interference. If, owing to an increase of head caused by a rise in the upstream water-level, the water tends to rise higher at the circumference of the chamber, then the water of the surface of the stream strikes against the diaphragm plates, and its centrifugal force being absorbed, it will fall in towards the centre. In this way the excess head that caused the additional rise of water at the circumference is used up by the fall back towards the centre.

It is hard to over-estimate the value of this contrivance as a means of facilitating control of the water supply in the interests of economy. With a determined duty of water and a known acreage of land to be irrigated, it suffices for all practical purposes to open a given module for a specified time and to advise cultivators that watering must be completed within such period. Water thefts, interference with supply pipes, and the banking up of streams to increase the head to a particular outlet are alike obviated, and the work of supervision is immeasurably lightened.

Evaporation and Seepage.—In an open canal evaporation can only be controlled by a suitably devised section, the regular cleaning of the channel and the expeditious emptying of the canal when pumping ceases. In certain classes of soil, however, measures for the limitations of seepage are of urgent importance. In such cases, experiment has determined that absorption can be profitably reduced by the use of suitable linings in the watercourses. In local conditions it has been found that a single brick lining set in lime mortar is both cheap and efficacious, an experimental section remaining in excellent condition after three years without repair.

The cost, which has certainly been more than recovered by the reduction of infiltration losses, worked out as follows :—

145 bricks per metre length	130	millièmes.
1/50 m^3 sand per metre length	4	„
1/100 m^3 lime per metre length	9	„
Labour	18	„
Porterage on materials and water	19	„
Total cost per running metre	180	„

Labour employed included one bricklayer at 80 millièmes per diem, six boys at 30 millièmes, one donkey at 50 millièmes, transport of bricks at 90 millièmes per thousand, and on lime and sand at 90 millièmes per cubic metre. Work proceeded at the rate of 15 running metres per diem with this staff.

Duty of Water.—It remains to examine the efficiency of irrigation practice as determined by the measures described above. As a preliminary step, careful measurement was made through the module of the water actually applied in ordinary practice to areas on the Research Farm, which was found to average 470 m^3 per watering per feddan, exclusive of the initial watering when absorption is abnormal. Comparison was then effected with a season's records obtained from gauge readings and irrigation returns of the adjoining area of native cultivation, when it was found that an initial supply of 833 m^3 was afforded on the occasion of the first watering, and an average supply of 482 m^3 throughout the season. The difference of 12 m^3 per feddan represents losses between headworks and module discharges, but does not include losses in the subsidiary channels. It is, however, an eminently satisfactory result when compared with similar returns from other centres when unduly extended canals without lining exhibit extraordinary losses of water in transit.

It is, however, to be noted that the soils through which this particular system has been carried are exceptionally retentive, and that a very different result

Earth Canal without Lining at Shambat.

A Canal with Single Brick Lining after Three Years' Service, Shambat.

was at first obtained in the sandy, alluvial soils of Tuti Island. At the latter centre and prior to the introduction of brick linings to the main canals, seepage losses were very high, particularly during the earlier waterings. During a first season the duty of water fell to the figure of 738 m^3 per feddan, while the initial watering applied to virgin soil actually absorbed 1,027 m^3. Such a result was attributed in part to the larger capacity of sandy loams for water absorption, offset in part by a longer period of retention, and by the excessive seepage from new canals constructed in these light soils. Large cracks in the underlying clay sub-soil, faulty levelling by unskilled cultivators, the use of too many small channels owing to inability to deal at first with reasonably large quantities of water, were additional causes contributing to this result. In such circumstances, brick-lined main canals are regarded as essential to profitable working and have since been inserted ; and the remaining causes of avoidable loss will disappear with the education of the cultivator in water control.

Methods of Cultivation.—A capital charge not exceeding £E.3 per feddan for pumping station and canal system should leave the land-owner with a mortgageable balance sufficient for the adequate equipment of his holding with draught cattle and implements. In the absence, however, of any adequate loan fund or the machinery for its administration, the greatest obstacle to development and education remains the want of improved devices and labour-saving machinery. The difficulty is exaggerated by the excessive cost of all imported supplies, which render futile suggestions for better methods of cultivation. Primitive native ploughs are borrowed and lent with their draught cattle as the exigencies of the moment permit, with the inevitable result that planting over the larger part of the area is delayed beyond an approved date, the simultaneous irrigation of a given unit is almost impossible, and the benefit of proper cultivation which would be willingly afforded, are denied to the land-owner. The few ploughs, harrows and cultivators which could be purchased with the funds at disposal have been greedily acquired, even at existing prices, but have been totally inadequate to the demand. The treading of the grain crop on primitive mud threshing floors monopolises draught cattle at a time when their services are urgently required to prepare land for cotton, and thus enhances the direct loss sustained from this faulty method of harvesting. To carry the education of the field worker beyond a training in actual irrigation practice is to create a demand for improved facilities which can only be provided at a reasonable cost when loan funds are readily available at a commercial rate of interest, and charges on imported requisites are reduced to less excessive proportions.

Crop Returns.—Finally, a brief examination may be made of the results secured from the experiment in its initial stages while subject to the handicap of under-capitalisation, lack of experience on the part of cultivators, and the vicissitudes attendant on the introduction of new and untried machinery.

The irrigation of native lands was inaugurated during the season 1912–13 with a test crop of 150 feddans of wheat grown on an area adjoining the Research Farm, and watered by the farm pumps. The average yield of grain amounted to 5·2 ardebs of 400 rotls worth at prices then ruling almost exactly £E.10. In addition, the " tibn," or chopped straw, rather more than covered the water rate of £E.1.500, selling at 80 to 90 millièmes per kantar of 100 rotls. All liabilities were promptly met by cultivators, including advances made to cover cost of canalisation. This result led to an immediate demand for an extension of the irrigated area, and provided encouragement for the purchase of additional pumping plant.

The following season saw some 350 feddans of native-owned land prepared for wheat and arrangements completed for the installation of the new pumps. Unfortunately, the entire plant was sunk in transit by a gale in deep water, and could not be recovered until the river had fallen to its lowest level. To obviate loss of time and labour expended on the preparation of the land, an effort was made to irrigate the crop with a collection of condemned engines and pumps, whose inefficiency was reflected both by crop returns and running costs.

By the summer of 1914, however, the recovered plant—100 H.P. Robey engine and 18-inch centrifugal pump—was running, and the irrigation of 390 feddans of native land, as well as the Research Farm, was satisfactorily effected. Of the native area, 115 feddans were planted with Afifi cotton, and the balance with Sorghum millet (dura) and Cowpea (lubia). To furnish the cultivators with an early food supply, permission was given to intersow the cotton with maize. The results of the latter operation were highly satisfactory, the grain crop giving a return worth from £E.3 to £E.4 a feddan after seven weeks, and during its growth acting as shade and wind-break to the young cotton plants throughout the most trying period of their development. The dura harvest, unfortunately, coincided with exceptionally heavy rain crops in the south and a resulting slump in prices. No pressure was consequently brought to bear on cultivators to realise on the crop, and they were rather encouraged to retain the grain as an additional food supply for the following seasons. Elsewhere, the economic position of this millet as an irrigation staple has been fully discussed, and its elimination from the local system has been determined. The actual yield was very satisfactory, ranging between five and six ardebs per feddan, but at a value of not more than 450 to 500 millièmes per ardeb, it should obviously give place to the more profitable wheat crop as the grain course in the rotation. Considerable quantities of the " gasab " (dried dura stalks) were sold in connection with the export trade in cattle at from 60 to 70 millièmes

(Quotations : " Good," Upper 7·15d.)

with the above, native crops were irrigated on T
the Sakel type, and ground nuts (ful suda
otton amounted to 45,593 rotls, equivalent to a
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of this crop, a circumstance which is reflected in a

he latter spells immediate cessation of work. In
ts have been limited to a proportion of the ac
rable with his requirements for working expense
of such proportion of his grain and ground nu
ued as domestic supplies. The following stateme
rigation account on 1st June, 1915 :—

ure the fulfilment of the terms of the irrigatior
recalcitrancy having been referred to the Inspe
discussion.

LONDON:

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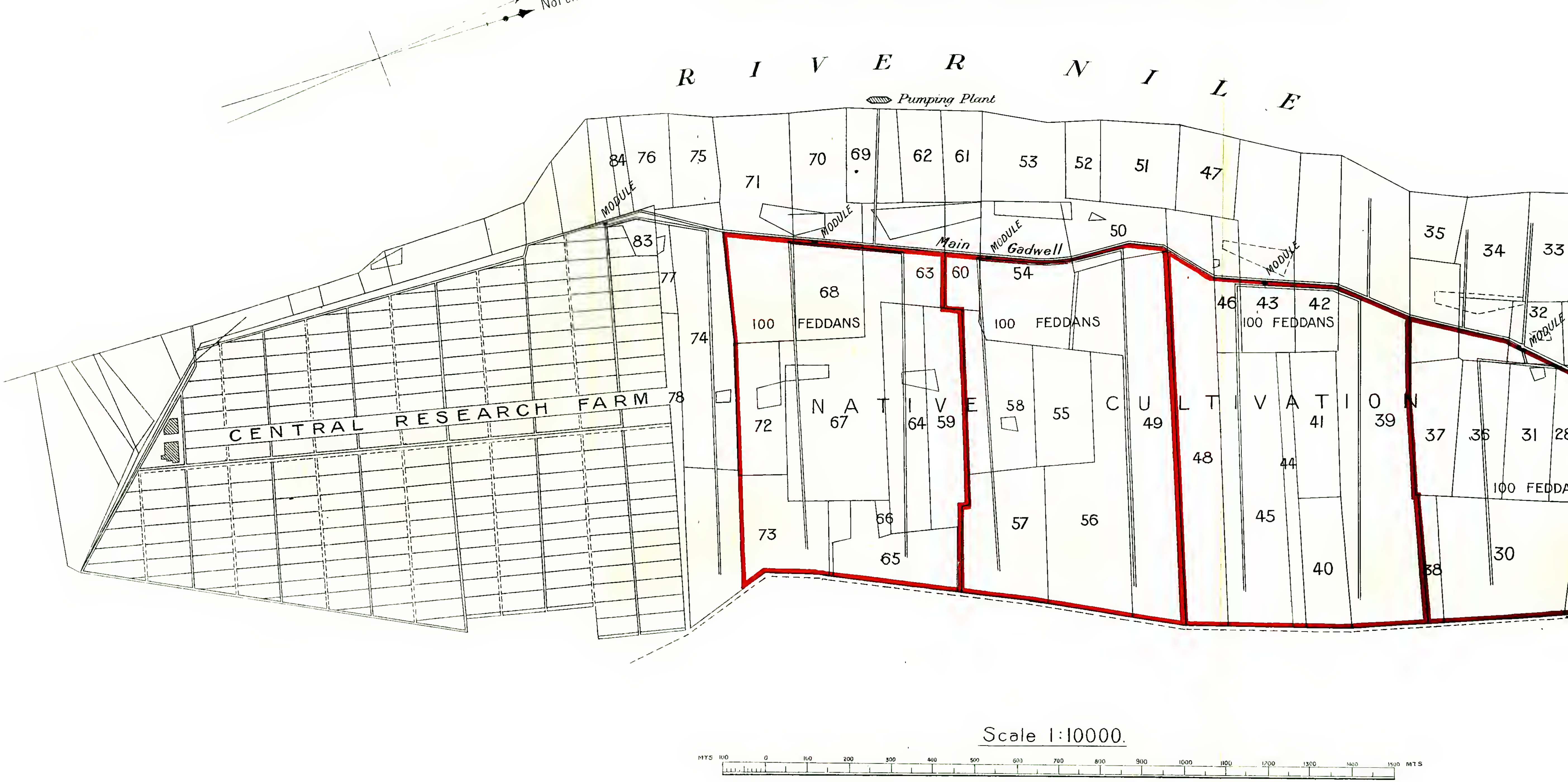
PLAN OF CENTRAL RESEARCH FARM
AND OTHER LAND IRRIGATED AT SHAMBAT.



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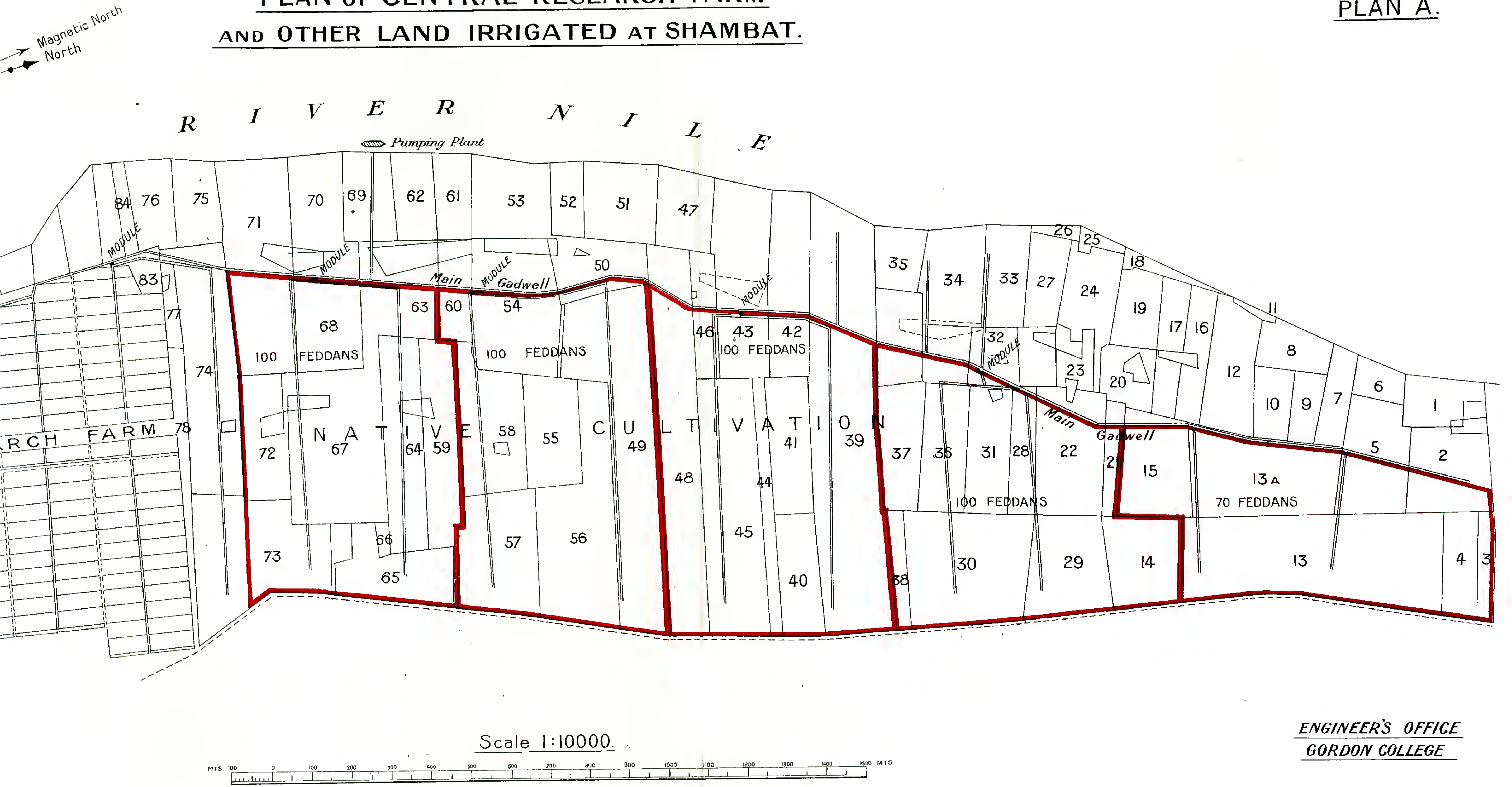
PLAN OF CENTRAL RESEARCH FARM AND OTHER LAND IRRIGATED AT SHAMBAT.

PLAN A.



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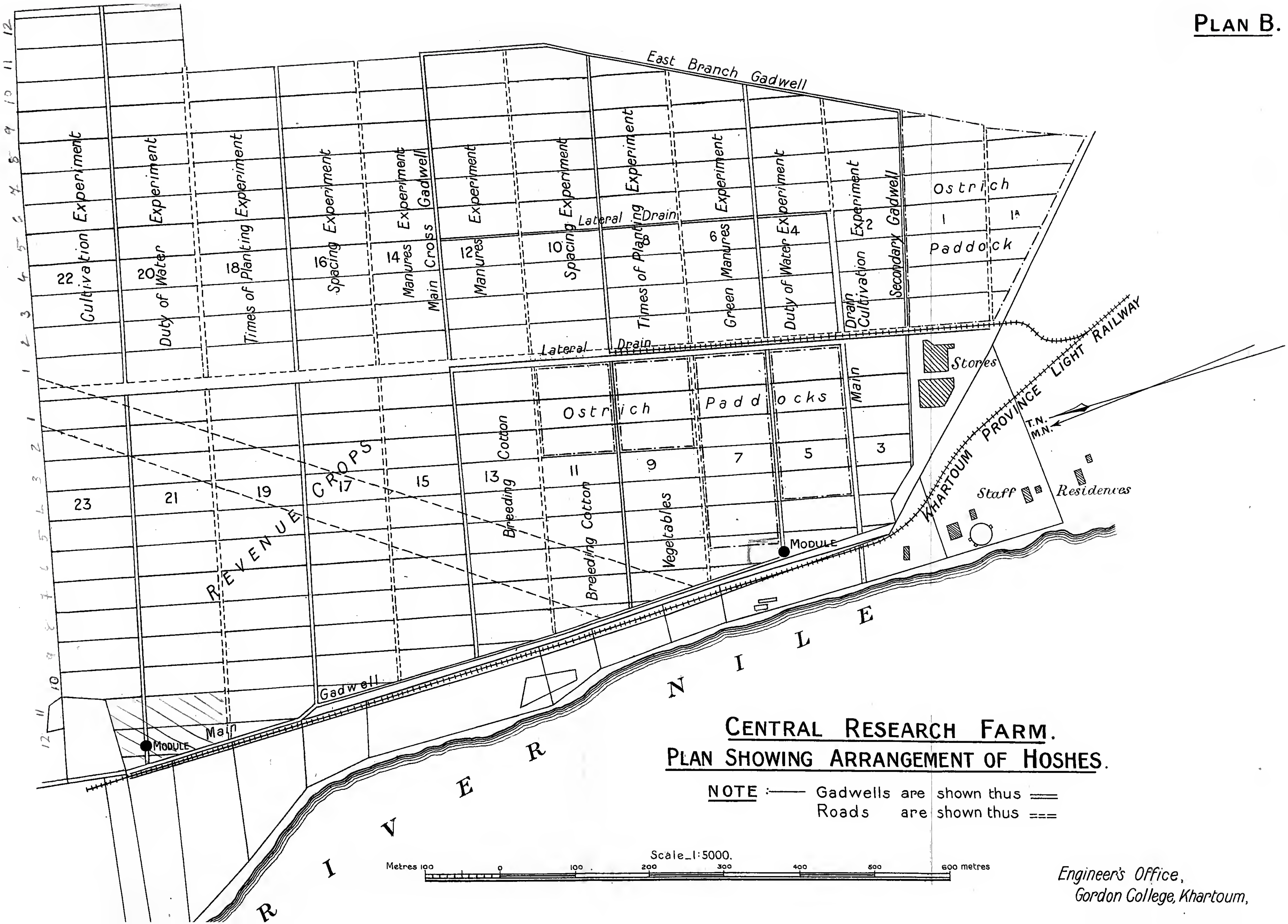
ENGINEER.

PLAN B.



CENTRAL RESEARCH FARM.

PLAN SHOWING ARRANGEMENT OF HOSHES.

NOTE :— Gadwells are shown thus ══
Roads are shown thus ===

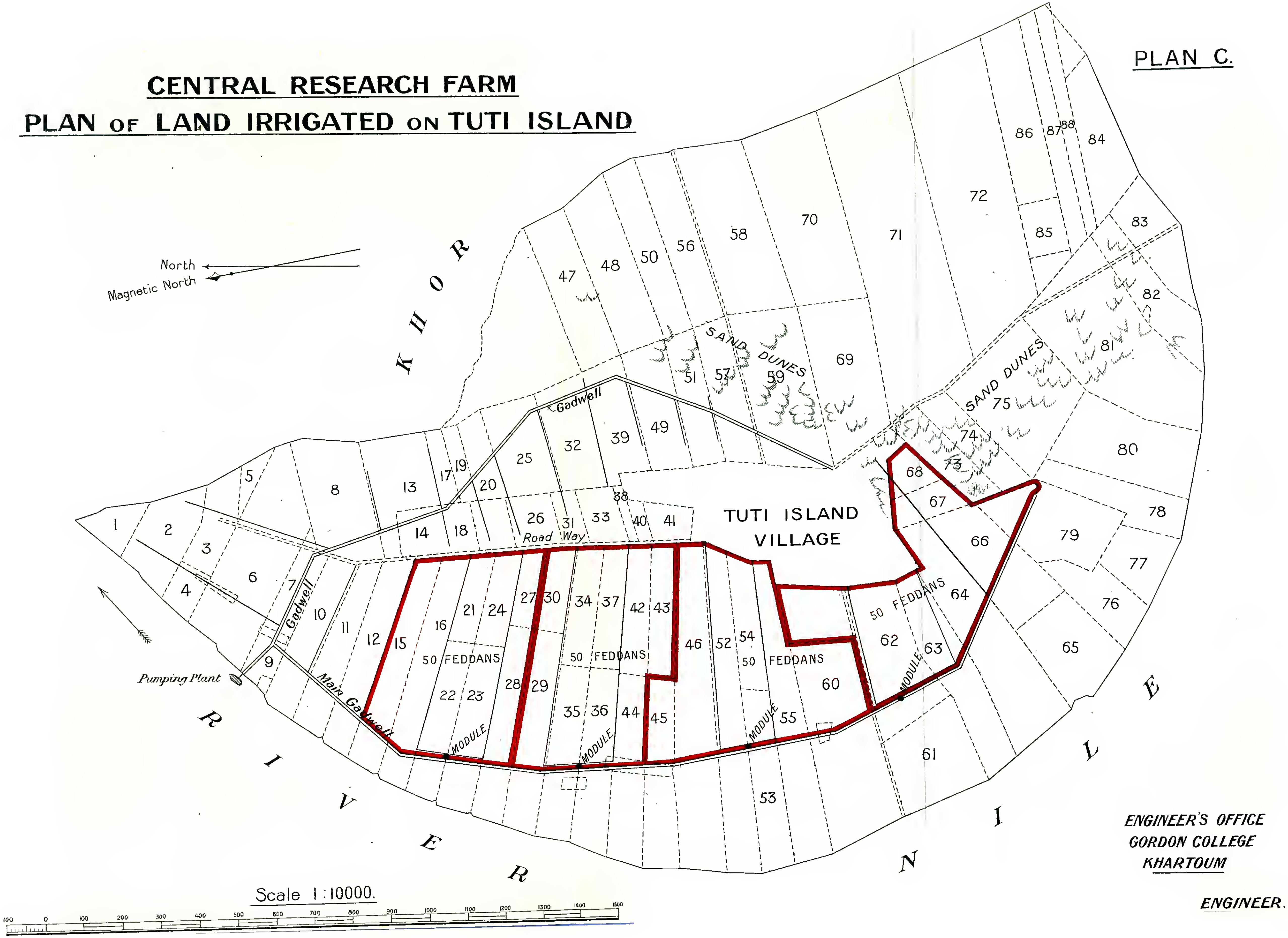
Scale_1:5000.

Engineer's Office,
Gordon College, Khartoum,

PLAN C.

CENTRAL RESEARCH FARM

PLAN OF LAND IRRIGATED ON TUTI ISLAND



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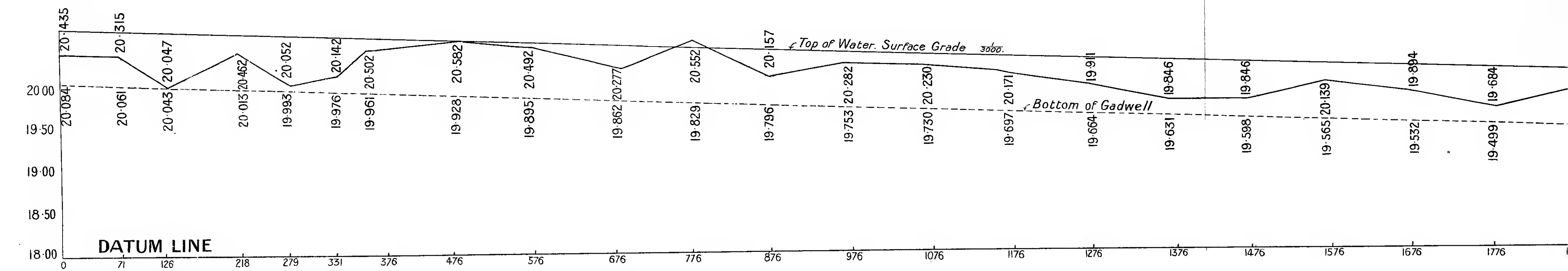
CENTRAL RESEARCH FARM.

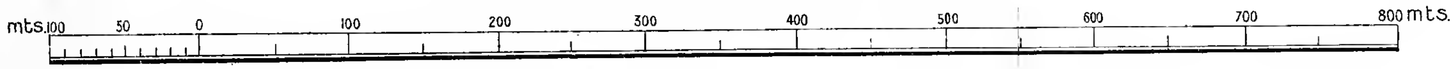
IRRIGATION OF TUTI ISLAND.

LONGITUDINAL SECTION OF MAIN GADWELL.

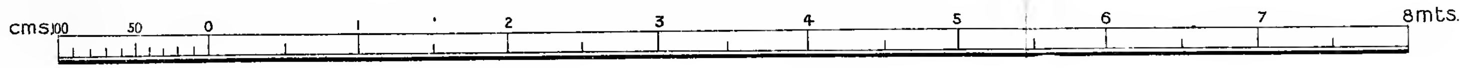
Peg No.	1	2	3	4	5	6	7	9	10	11	12	14	15	16	18	19	20	21	22	23	24
Depth of Cutting	·361	·254	·004	·449	·059	·166	·541	·654	·597	·415	·723	·361	·519	·502	·474	·247	·215	·248	·574	·362	·185



Horizontal Scale – 1 : 5000.



Vertical Scale – 1 : 50

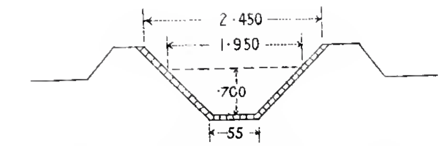


PLAN D.

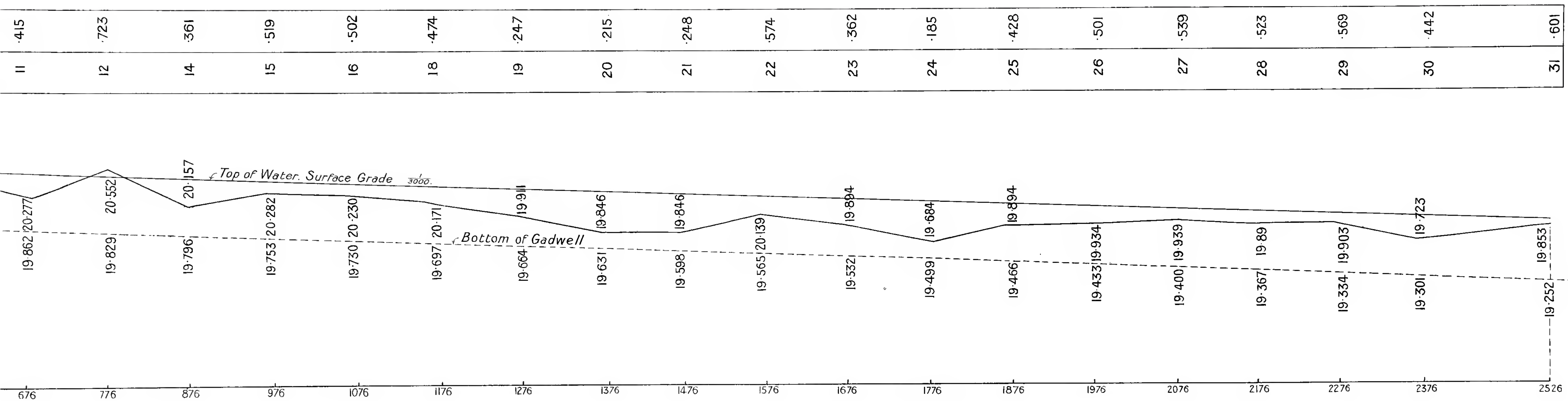
CENTRAL RESEARCH FARM.

IRRIGATION OF TUTI ISLAND.

LONGITUDINAL SECTION OF MAIN GADWELL.



Cross Section of Gadwell from Pump.
Scale 1:100.



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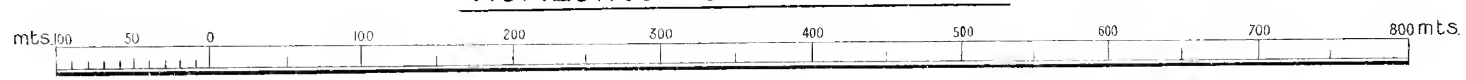
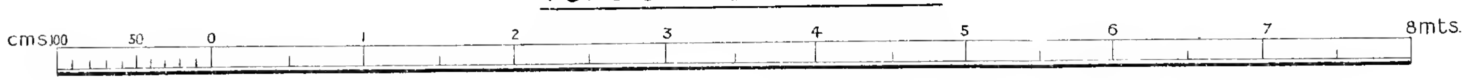


Vertical Scale – 1:50



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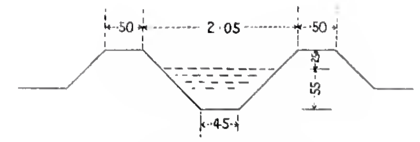
Engineer.

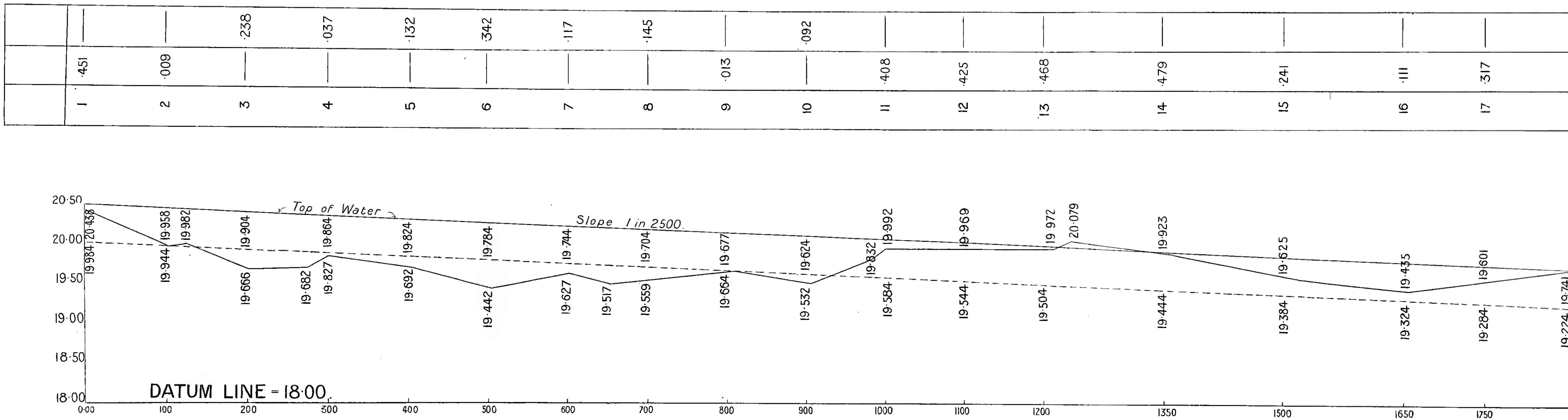
CENTRAL RESEARCH FARM.

IRRIGATION OF TUTI ISLAND.

LONGITUDINAL SECTION OF GADWELL ROUND EAST SIDE OF TUTI VILLAGE.



Section of Gadwell.
Scale 1:100.



Horizontal Scale - 1:5000

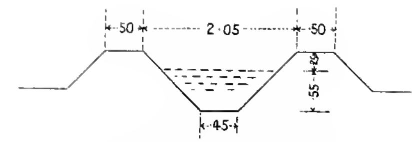
Vertical Scale - 1:50.

CENTRAL RESEARCH FARM.

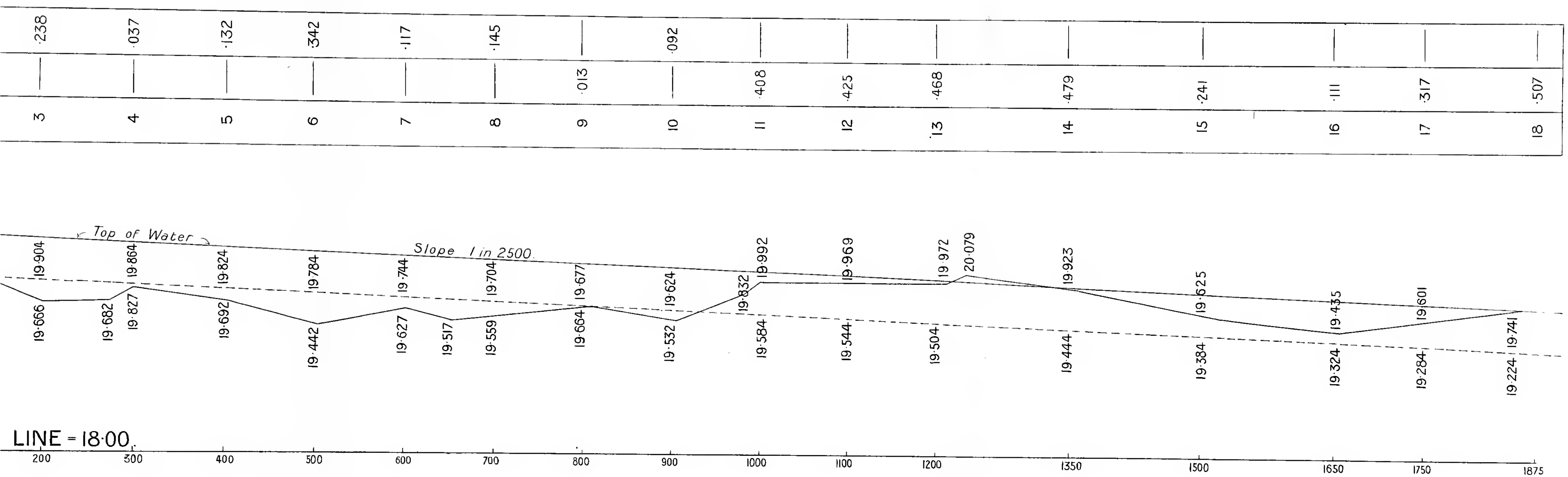
IRRIGATION OF TUTI ISLAND.

LONGITUDINAL SECTION OF GADWELL ROUND EAST SIDE OF TUTI VILLAGE.

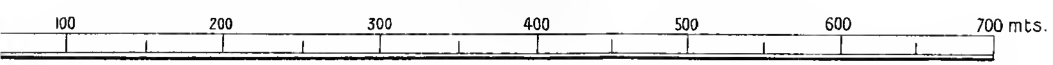
PLAN E.



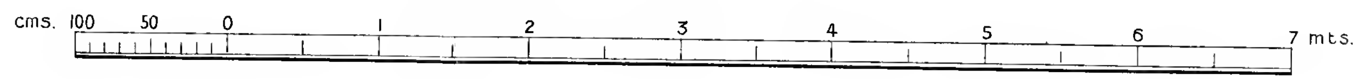
Section of Gadwell.
Scale 1:100.



Horizontal Scale - 1:5000



Vertical Scale - 1:50.



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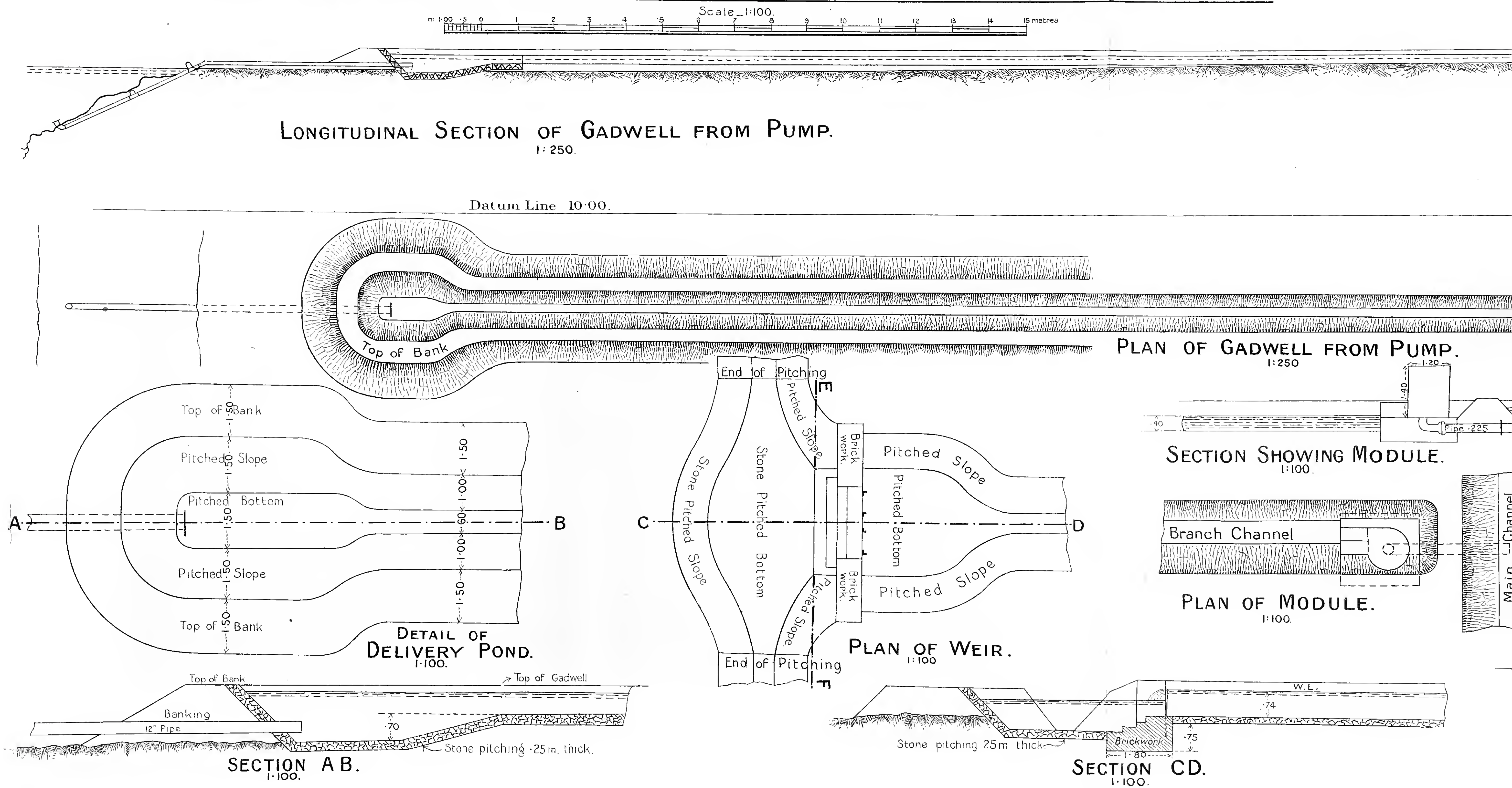
Engineer.

CENTRAL RESEARCH FARM. IRRIGATION OF TUTI ISLAND.

PLAN SHOWING GADWELL FROM PUMP WITH DETAILS OF DELIVERY POND, WEIR AND MODULES.



Research Farm. Irrigation of Tuti Island.

from Pump with details of Delivery Pond, Weir and Modules.

Plan F.