REDDISH BROWN SOILS OF HOLETTA REGION, ETHIOPIAN HIGHLANDS

by

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1. INTRODUCTION

The FAO-UNESCO Soil Map of Africa (1973), scale 1:5,000,000, prepared under the auspices of the Soil Map of the World Project, exhibits that vast areas on the Ethiopian highlands, in particular Northwest, West, Southwest and South of Addis Ababa, have been mapped as Eutric Nitosols in various associations with other soils.

At present relatively little is known about the kinds of soils, their extent and geographic distribution in Ethiopia. Therefore, at this stage it could not be ascertained whether, for example, the vast expanse mapped as Nitosols are really dominantly that kind of soil. However, some studies in the region around Addis Ababa have revealed that at least many of these soils are in fact not Nitosols, but Phaeozems, which resemble in certain respects the Nitosols. It is quite likely that in a first attempt to map the soils according to the FAO-UNESCO Legend some were incorrectly classified. In this context it must be remembered that many of the highland soils have been subjected to erosion ever since their deforestation, and subsequently lost their mollic epipedon; in which case, for example, an incipient Luvic Phaeozem may have become an Eutric Nitosol.

On account of the various aspects mentioned above, this paper deals with the Luvic Phaeozems in the Holetta region, where they have been studied in some detail.

Rhodic Ferralsols are expected to occur in the higher rainfall (1500-2000 mm annual rainfall) regions of Western and Southwestern Ethiopia, especially in the Administrative Regions of Wollega, Illubabor and Kefa. Since these soils have not been adequately studied as yet, they will not be discussed in this paper.
2. CLIMATE

Latitude: 09°03'N  Longitude: 38°30'E  Altitude: 2400 m.

As can be seen from the seven years' (1969-75 inclusive) weather record for Holetta Research Station, the Station has a mean annual air temperature of 13.5°C that varies from 10.8°C in November to 15.0°C in April. The mean maximum is 21.9°C while the mean minimum is 5.1°C. The absolute maximum of 29.2°C and minimum of -9.0°C occurred on 22 December 1970 and 28 December, 1969, respectively.

The average sunshine hours is 6.4 hours/day in a year and this varies between 2.7 hours/day in July and 9.1 hours/day in November.

This distribution of the weather elements results in an average of 47 days with early morning frost in a year (mainly radiation frost). This frost occurs between October and March when the cloud cover of the sky is minimal. It has its highest frequency of 19 days in December and its lowest in October and March with intermediate values of 14.3 days in November, 7.4 days in January and 4.5 days in February. This frost causes a moderate to severe hazard to the crops particularly to those caught at flowering stage and to those that are very sensitive to it such as fruits and vegetables.

The mean soil temperature at 50 cm depth oscillates around 18°C throughout the year and is about 4.5°C higher than the mean air temperature.

Holetta receives an average total rainfall of 1056.2 mm annually. This is spread over all months and ranges from the lowest of 2.6 mm in December to the highest of 281.7 mm in August. The rise is gradual from January to June when the monsoon-type rainy season starts. Then the amount increases abruptly and reaches its highest mean value of 281.7 mm in August. Towards the end of the season the decrease is even more rapid and whereas September receives 138.5 mm, October, November and December get only 8.9, 7.5 and 2.6 mm respectively. As can be seen from the climatic data more than 74% of the rain falls in the four summer months of June, July, August and September. It is evident that, according to the calculations made using Thornthwaite's equations, the period from October to March can be considered dry as the amount of rain received in these months is low compared to the water needs. When there is theoretically water stress in most parts of the year, there is just enough rain to balance water needs in April, May and June, and more than 56% of what falls in June, July, August and September is excessive and goes to form the runoff. This has strongly influenced the processes of land form development in the area.

Evaporation from the open pan is high and even in the month of the highest rainfall it reads more than 60 mm. In other months it is about 130 mm with the maximum of about 175 mm in both February and March.
Fig. 2.1 HOLETTA CLIMATE DIAGRAMS 1969—75
FIG. 2.2

OMBROTHERMIC DIAGRAM of HOLETTA
1969 - 75

Annual rainfall 1056.2 mm
Monthly rainfall
Monthly temperature

Dry period: Rainfall (mm) < 2 × Temperature (°C)
These lavas formed a high plateau landscape, built up in steps (terraces) due to successive eruptions or flows. Subsequently it was subject to erosion and dissection, the result of which is now a hilly landscape of degraded plateaux with here and there steep and rocky edges.

The irregular topography of the underlying basalt flows gave rise to the formation of an undulating to rolling landscape which subjected the terrain to different intensities of erosion, and that further emphasized the irregular topography of the land, as well as the complex origin of the soil.

The reddish brown, heavy clays of the Holetta region have an undulating to rolling topography. The underlying geology consists mostly of normal basalt, olivine basalt and trachy-basalt, originated from flood lava. There is evidence that pyroclastic material (unconsolidated volcanic ash) forms part of the parent material from which the soils have developed, especially in the upper part of the profile. Nearby volcanoes such as Posta, Nachacha, Menagesha, Watodalacha and Furi could have contributed to the spread of the ashes during their eruptions.

At present it seems clear that these soils have developed in materials weathered in situ and partly from formation processes in re-worked, locally transported material. Often where rock is found in the profile it occurs as round boulders of varying size, detached from the main basalt formation through physical weathering and finding a place in the soil profile through horizontal and/or vertical displacement, indicating that a certain amount of re-working took place in the profile.

4. **SOIL MORPHOLOGY**

In general terms these soils are characterized as deep, fairly uniform, dark reddish brown clays with shiny ped surfaces below 25-40 cm depth and dark metallic, bluish black Mn-oxide mottles that are often more prominent below 70 cm. Faint yellowish brown Fe-oxide mottles may occur at various depths.

In the upper 25 cm of the profile there is normally a moderately developed, blocky structure whose matrix becomes hard and rather compact when dry. Below this, a coarse prismatic primary structure breaking into fine angular blocky aggregates is common.

Shiny ped surfaces, which are apparently coatings of clay often with Mn- and Fe-oxides, occur from 25 cm depth and frequently from 40 cm downwards. In a deep profile they have been observed undiminished in quantities at a depth of 3.5 m, whereas elsewhere they were common right down into the underlying weathered rock.
Fe-oxide mottles are difficult to distinguish due to the reddish brown colour of the soil matrix.

Mn-oxide mottles are clearly visible at various depths, often concentrating in several zones, usually below 50 cm depth. They vary in size from 5-15 mm and in density up to approximately 40%. Moderately hard, dark and rusty nodules of 2-5 mm, consisting of Fe- and Mn-oxide occur also at various depths. In the upper profile they are rare; below 75 cm they are often common.

Occasional rock fragments are found in the lower profile.

In the flat areas the soils are moderately well drained. On sloping land with slopes up to 15% but commonly 5-8%, they are well drained or even somewhat excessively drained due to increased run-off. There they are susceptible to erosion, especially to sheet erosion but also to a certain extent to gully erosion. Under cultivation adequate soil conservation measures are required.

5. PHYSICAL PROPERTIES

Texture

Although it has been mentioned earlier that those are fairly uniform clays, they show a particular trend in the granulometric composition of the profile, i.e.:

- the clay content of the surface horizon Ap varies between 45-65% while in the subsoil it increases abruptly to 70-80% and remains practically constant with increasing depth (up to 2 meters).

- the silt content of the Ap horizon varies between 20-40%, while in the subsoil it decreases abruptly to between 15-25% and is usually around 20%.

- the sand content of the Ap horizon varies between 5-20%, while in the subsoil it varies usually between 5-10%.

Shiny ped surfaces are clearly visible throughout the profile down to great depth, except in the surface horizons. However, in thin sections under the microscope void argillans have been observed throughout the profile, though only in small numbers in the surface soil and below 100-150 cm their numbers also decrease appreciably. The occurrence of argillans is largely restricted to fine pores.

The shiny ped surfaces as such are not the evidence for translocation of clay whereas the argillans in fine pores indicate that the present profile as a whole is argillic and that the original surface soil under which this argillic profile was formed, must have been lost due to erosion, leaving a truncated soil behind.

It is also suspected that the lower clay content in the Ap horizon and the abrupt increase of clay in the subsoil, as indicated by the
analytical data, is rather artificial, possibly due to incomplete dispersion, and therefore misleading.

Naturally, it is not unusual to find in an otherwise uniform profile a somewhat lower clay content in the Ap horizon due to loss of fine material as a result of water and wind action and this may well be the case here to some extent. However, the spectacular and abrupt change in the clay percentage, and the inverse in the silt percentage between the Ap and the subsoil is actually hardly noticeable in the profile in the field. At most there is a significant difference in structure and consistence between the Ap and the rest of the profile; the soils being quite hard and compact in the Ap, while they are well structured and more friable below.

Significant differences in the granulometric composition can be expected to be reflected in the cation exchange capacity (C.E.C.) of the soil. Here this is not the case, C.E.C. is fairly consistent, normally exhibiting only minor variations within the profile, which do not account for a 10-20% increase in clay content. Table 5.1 below presents the trends in the profile.

Table 5.1: Comparative averaged data on silt, clay and C.E.C. for Ap horizon and subsoil, Holetta I.A.R.

<table>
<thead>
<tr>
<th>Silt + clay %</th>
<th>Clay %</th>
<th>C.E.C. meq/100g soil</th>
<th>Org.C %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>88</td>
<td>56</td>
<td>30.6</td>
</tr>
<tr>
<td>Subsoil</td>
<td>93</td>
<td>72</td>
<td>31.4</td>
</tr>
</tbody>
</table>

It must be mentioned here that these soils contain appreciable quantities of amorphous material, though the exchange complex is not dominated by it. The NaF test confirmed with pH of 8.9-9.2 that amorphous material represents an estimated 30-40% of the exchange complex.

From the above some significant observations can be made:
- clay percentages in the Ap increase by an average 14% in the subsoil, while combined silt + clay percentages increase only by an average 5%.
- the presence of appreciable quantities of amorphous material — increasing slightly in quantity with depth — may cause somewhat erratic results in silt and clay figures in the mechanical analysis, whereas the sand percentages are much less affected by this. Therefore, silt + clay percentages are a more reliable trend indicator than clay and/or silt alone.
the C.E.C. is an average 31.2 meq/100 g soil, while the difference between the C.E.C. of the Ap and below is only an insignificant 0.8 meq.

organic carbon contributes an average 5 meq/100 g soil to the C.E.C. in the Ap. Amorphous material is estimated to contribute 30-40% of the C.E.C., i.e. 2-12.5 meq. As the organic C decreases with depth to roughly 1% at 50 cm and to 0.5% at 100 cm, while the amount of amorphous material apparently increases slightly with depth, it seems that an order of magnitude of 14 meq throughout the profile can be attributed to these two components. This leaves roughly 17 meq/100 g soil throughout the profile attributable to crystalline clay.

there is neither any indication nor any reason to assume a drastic variation in the composition and nature of the clay.

On account of the phenomena listed above, in addition to field observations, it is assumed that in fact there is no drastic and abrupt increase in clay content between the Ap horizon and the subsoil, as suggested by the data of the mechanical analysis. It is more likely that for one reason or another the clay in the Ap horizon is less easily dispersed, so that part of the clay is reported as silt or possibly even as sand.

At this stage of investigation it is not yet clear what causes the aggregation of clay into silt size particles to be so much more pronounced in the Ap than in the subsoil.

There is no significant increase of clay with depth in the subsoil; the clay percentages are so closely similar, within the range of analytical error, that one cannot certainly assume the clay content to increase even slightly with depth. In fact, a comparative analysis conducted by successive sedimentation produced no significant difference in clay content within the profile.

Structure

In the Ap horizon, i.e. the upper 20-30 cm, there is normally a rather weakly developed, very coarse prismatic structure in a hard and rather compact soil when dry, which breaks into moderately developed fine angular blocky aggregates. Further down is a well developed, very coarse prismatic structure also breaking into well developed, fine angular blocky aggregates.

In the dry season 1-2 cm wide cracks develop in a large polygonal pattern, down to a depth of about 50 cm. There are, however, neither slickensides nor wedge-shaped parallelepiped structural aggregates.
FIG 5.1: ANNUAL SOIL MOISTURE CURVE OF LUVIC PHAEZEM3 HOLETTA I.A.R.

MEAN OVER 1972–75 FOR P1, P14 AND P41 IN WEIGHT %

LEGEND
Depth 0—10 cm
50 cm

Period of moisture stress in root zone
Permanent Wiltting Point

AVERAGE PRECIPITATION OVER 1972–75
In mm.
When the soils become moist, however, their consistency changes considerably. They may still be firm initially but increased moistening, e.g. during the early rains in March-April, makes them gradually more friable and easier to handle with peasant implements.

During the main rains in July-September when nearly 750 mm rain falls, the surface soils become temporarily very moist to wet. Then again they are difficult to manipulate due to extreme stickiness which hinders the efficient functioning of farm implements.

Consequently the soil must be tilled in successive operations with the oxen-plough during March-April and again from around mid June, when soil moisture steadily increases, but before it becomes very moist. In fact, trials at Holetta Station have proved that optimum yields are obtained when seedbed preparation and planting are completed in the second half of June.

6. CHEMICAL PROPERTIES

pH and cation exchange

The pH of these soils in a 1:2.5 soil-water suspension is normally 5.5-6.0; below 75-100 cm the average pH is 6.0. In 1N KOH the pH is usually 4.5-5.0.

The cation exchange capacity (C.E.C.) is around 31 meq/100 g soil throughout and does not show any particular trend. C.E.C. determinations of the silt fraction alone yielded values of about 11.5 meq/100g, which supports the assumption that the silt fraction contains an appreciable amount of aggregated clay.

For the base saturation percentages the following averages were obtained:

- 0-50 cm depth – 67%
- 50-100 cm - 72%
- >100 cm - 71%

There appears to be a slight increase in exchangeable bases from the Ap to the subsoil below, as is also confirmed by the moderately acid pH.

The cation balance for well developed soils derived from basaltic parent material is of the order Ca++: Mg++: K+ = 70: 24: 6. Here the ratios are:

0 - 50 cm
50 - 100 cm
>100 cm

From the above ratio it is noticed that:
- the order of magnitude of the ratios remain the same throughout the profile, showing no significant change.
- the ratios as well as the analytical results indicate that the available (i.e. exchangeable) K is adequate both in absolute terms – normally well over 200 p.p.m. – and also proportionally in relation to Ca++ + Mg++.
on the other hand, there is a striking imbalance between Ca\(^{++}\) and Mg\(^{++}\), the former being too low—by about 15% of Ca\(^{++}\) + Mg\(^{++}\) + K\(^{+}\)—and the latter naturally too high by the same order of percentage.

This Ca: Mg imbalance could be corrected through application of lime, which would raise the pH of the soil and simultaneously correct other imbalances such as the improvement of the uptake of phosphorus and the suppression of the availability of the large amounts of Mn.

Determination of exchangeable Mn, assumed to be easily available especially under acid conditions as is the case here, revealed the presence of an average 50 p.p.m. in the surface soil, which normally falls rapidly to a level of about 7 p.p.m. below 50 cm depth.

**Nutrient Status**

Organic carbon is around 2% in the surface soil. It decreases to about 1% at 50 cm depth and to 0.5% at 100 cm depth. It continues to decrease gradually with depth to 0.3% at 200 cm.

Total nitrogen is around 0.2% in the Ap horizon, resulting in an average C/N of 9.5. At 50 cm the nitrogen content averages 0.12%, giving a C/N of about 8. The total N status of the root zone is moderate to low. The soils were sampled in late June–early July at the onset of the rains.

Available P\(_2\)O\(_5\), determined by lactate method, varies largely between 5-15 p.p.m, with an average of 9-10 p.p.m in the Ap, which is very low. Moreover the presence of free Fe- and Al-oxide, as well as amorphous material in appreciable quantities adversely affects the availability of phosphorus to the plants. Consequently one may expect a good response of crop to phosphate application. On the other hand with the high fixation capacity of the soil for phosphorus one should have no illusions regarding the residual effect from the use of phosphate fertilizer.

Determination of free Fe-oxide in a few samples gave an order of magnitude of 9% while the total amount is only 13% of the soil. Besides 64% of the Fe-oxide in the clay fraction seem to occur as free Fe-oxide when the total is 14%.

The determination of micro-elements in one representative profile with NH\(_4\)Ac–EDTA extract produced normal values for most of them with the exception of Mn. The analysis revealed nearly 900 p.p.m of Mn in the Ap and 200-350 p.p.m. in the solum below. The critical level being about 200 p.p.m., the Mn level in these soils is obviously very high and well in the range of toxicity. An indication of this unfavourable condition and its proposed remedy through liming has already been mentioned above when dealing with the exchangeable Mn. The analytical results also show that Zn is just above the critical level of 3 p.p.m., where it becomes deficient, justifying some further studies.
7. MINERALOGICAL AND MICROMORPHOLOGICAL FEATURES

The sand fraction of these soils, which here forms only a small proportion of the fine soil, consists mainly of the following minerals:

- feldspars, which are dominant in the sand fraction throughout the profile.
- volcanic glass makes up about 35% of light minerals in the surface soil and decreases to about 5% at 100 cm depth, thus giving evidence of a larger proportion of pyroclastic material in the upper profile.
- quartz and amorphous silica occur in small quantities.
- zircon and augite are the dominant heavy minerals.

The silt fraction, excluding silt size aggregate clay, is dominated by the presence of quartz and feldspars, some micas, occasional olivine and some amorphous substances.

The clay fraction contains significant amounts of amorphous material. Though it apparently consists dominantly of mica-clay - illite - minerals rich in Fe or Mg due to which the lattices are opened to some extent, together with appreciable amounts of disoriented kaolinite, traces of nontronite, quartz, feldspars and intermixed layer minerals.

Micromorphological examination revealed a somewhat massive, crumb microstructure in the Ap horizon, but with increasing depth the soil becomes more porous with an increasing number of vughs, compound packing voids and channels. In the lower profile (C-horizon) porosity decreases and the microstructure becomes irregular, jointed and partly cracked.

The matrix consists essentially of a reddish brown, dotted plasma of strongly iron coloured clay. The skeleton grains which, due to their distribution in the plasma give it a porphyroskelic character, are mostly very fine quartz, some feldspars and amphiboles. The plasma has an argillasepic fabric throughout the profile, weaker developed in the upper part and stronger below.

Plant remains and very fine roots have birefringent streaks and are abundant near the surface; their number gradually decreases with depth until they are practically not found anymore at 100-150 cm depth. In association with these occur single and coalesced faecal pellets which include both clay and skeleton grains.

Common throughout the profile are void argillans, particularly ferriargillans. They are less frequent and thin in the Ap and below a depth of about 100 cm - in the lower B- and C-horizons - where they occur only occasionally in fissures. In between - in the B-horizon - they are thick and prominent. Besides these ferriargillans occur the widespread and also prominent ped cutans, reported earlier as shiny ped surfaces; these may be stress cutans or orientation cutans, possibly caused by the differential movements of the peds relative to each other along natural cleavage planes and along pressure planes.
On account of the above characteristics these soils are, according to the FAO-UNESCO Legend of the Soil Map of the World, PHAEOZEMS as they have a mollic epipedon. The presence of an argillic B horizon qualifies them as LUVIC PHAEOZEMS.

In the USDA Soil Taxonomy (1975) these soils belong to the order of the MOLLISOLS on account of the presence of a mollic epipedon. Moreover, they have an argillic horizon with a base saturation of more than 50% throughout. The differentiation at the suborder level is largely governed by the ustic soil moisture regime, which qualifies them as USTOLLS. As they have an argillic horizon that has a vertical clay distribution such that the clay content does not decrease by 20% of the maximum clay content within 1.5m of the soil surface and as they also have hues redder than 10YR, though the chroma of the matrix in the lower part is not greater than 4, but normally 4, the relevant great group is PALEUSTOLLS. Since they have neither a calcic horizon, nor soft powdery secondary line at any depth, they are in the subgroup of USTM DACHIC PALEUSTOLLS. At the family level they are very fine clayey, mixed, isothermal.

Although the Paleustolls may not reflect in an ideal manner the nature of these moderately leached, reddish brown clay soils of the cool temperate tropical highlands, their typical characteristics, however, are possibly best reflected in the subgroup arrived at above.

9. LAND USE AND SUITABILITY

Predominantly the present land use on the reddish brown clays of Holetta region is a rainfed arable mixed farming with annual crops and livestock.

The average farm size is about 5 ha occupied mainly with annual crops such as teff (*Eragrostis tef*), wheat, barley, horsebean and peas, and linseed. Besides these there may be a small area set aside for wood production, often eucalyptus. The livestock component consists of a few heads of cattle, a pair of work oxen, a donkey, a few sheep and poultry. Normally the reddish brown clays are not used for grazing land; nearby areas and enclaves of Vertisols are commonly used for grazing.

As mentioned earlier the surface soils are very hard and compact when dry and it is practically impossible to till them with the oxen-plough. This type of plough does not turn the soil; actually it is a single cultivator opening up the surface soil to a depth of about 15 cm. As from the early rains in March the farmer prepares his land through repeated ploughing operations, i.e. at least 4-5 ploughings depending on the crop. In fact upto and including seed-bed preparation is all done with the same implement. Successive operations are never in the same direction, but usually cross-wise. Since these are light operations there is no evidence of significant structure deterioration.
Crops are planted in July and harvested in November and December. Traditionally the farmers have not been using fertilizers. Recently, however, the nation-wide establishment of peasant associations together with the change of land tenure, has facilitated the access to improved seeds and fertilizer, the use of which is expected to gain significance steadily even though fertilizer application may not yet reach optimum levels in the immediate future.

The order of magnitude of peasant's yields for various crops without the use of fertilizers is:

- Teff 5 q/ha
- Wheat 7 q/ha
- Barley 9 q/ha
- Horsebeans 7 q/ha

In the Holetta region major characteristics of the environment as a whole, which govern the general land suitability and which simultaneously appear to represent the principal constraints, are various aspects of the climate, the topography and the soil. These significant aspects, now briefly discussed here, are all very closely interrelated.

Naturally, in the evaluation of land suitability for rainfed arable farming various features of the climate are of paramount importance. Without going into details which have been discussed in section 2, here emphasis is given to the nature and effects of particular climatic limitations:

- The ill-distributed rainfall results in roughly 750 mm or 71% out of the annual total of some 1050 mm, falling in a relatively short period of 3 months, i.e. from late June to late September. Out of this amount of rain an estimated 55-60% is lost as run-off. During the remaining part of the year there is insufficient precipitation over a period long enough for a crop to establish and mature.
- During the months mentioned above the crops planted in June-July are in a stage of maximum vegetative growth. However, at the same time the general state of overcast, causes sunshine intensity and day temperatures to be low, which has a marked adverse effect on crop development.
- Frequent night- and ground frost in November and December have an unfavourable effect on frost sensitive crops such as teff.
- Strong desiccating (cool) easterly winds during October to March aggravate the already precarious soil moisture conditions in the ripening stage of many crops.

The macro-relief is closely associated with the erosion hazard, which may call for soil and water conservation measures that are beyond the means of the peasant farmer. The relief also has a bearing on the ability of the soil to absorb surface water. The discussion on soil
moisture characteristics in section 5 has already indicated that moisture absorption of the soil is inadequate and also that the period without soil moisture stress for the plants is rather short.

Land improvement measures commonly required, depending on the topography, are the introduction or establishment of:

- Contour ridging.
- Contour grass strips.
- Infiltration/diversion ditches, grassed waterways.
- Broad base terraces on slopes of more than 5%.

Upon implementation of the suggested land improvement measures as required, these lands are considered moderately suitable for:

- rainfed arable mixed farming with annual crops including forage crops, and livestock. Proposed crops are:

  - cereals - teff, wheat, barley, triticale.
  - forage - fodder oats, vetch, lupin.
  - pulses - horse bean, field pea.
  - oil crops - early rape and linseed.

- animal production with pasture, forage and livestock.
- deciduous fruit orchards including apple, peach, plum, apricot, almond, walnut, grape.
- wood production for fuel and poles, using eucalyptus.
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THE DEVELOPMENT OF A CHAIN AND WASHER PUMP
FOR SMALL SCALE IRRIGATION
(Research Project AE/ip 3.1 1977)
BY
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Addis Ababa
April 1980
THE DEVELOPMENT OF A CHAIN AND WASHER PUMP FOR SMALL SCALE IRRIGATION

INTRODUCTION

In 1976 it was decided to study and develop suitable low lift water pumps for small scale irrigation. The basic criteria for such pumps was that they should be suitable for local manufacture, cheap to produce, easy to maintain & cheap to operate using locally available sources of power (wind, water, animal or human).

The most promising type of pump for such a purpose was considered to be a chain & washer type. A research & development programme was therefore put into operation at the Appropriate Technology for Farmers (ATF) workshop at the Nazareth Research Station of the Institute of Agricultural Research (IAR).

The chain and washer pump system is very simple and, unlike most pumps, does not require valves. It is also possibly the oldest form of rotary pumps in the world after the Persian wheel. The system works as follows — (see drawing DR 1.) A drive wheel (1) pulls a continuous loop of chain (2) through the lift pipe (3). Fitted to this chain are circular washers (4) which fit closely to the inside diameter of the lift pipe. Rotation of the drive wheel draws the chain up the lift pipe, water is trapped between the pump washers spaced on the chain and lifted to the outlet (5) at the top of the pipe. A bell-mouth (6) helps the washers to enter the pipe smoothly.

Practical maximum lift with this type of pump is said to be twenty metres, but this would depend, among other things, on the bore of the pipe speed and available drive force. It is also possible that at depths over twenty metres the length of the chain would become unmanageable. In practice it is preferable to restrict the height of lift to about 15 metres.

The reasons for choosing this pump design are:

1. Low working speed making it possible to use the low grade materials available locally.

2. Construction is such that the pump could be manufactured in a rural workshop with limited equipment.

3. This type of pump has shown itself to be effective in use; details of tests in Ethiopia are given later in this report.
4. All the working parts are easily seen and, when running, this type of pump can be used in the technical education of its users. Specific features of interest are:
- transmission of power from ox (or wind) for use in lifting water;
- change in direction of power through 90°;
- use of simple gears;
- how bearings function; and
- chain and pump washer action.

The basic aim when the ATF team decided to develop a chain pump was to find a design that could be used to irrigate small areas such as horticultural plots. Therefore, the design that has been developed would not be very suitable for supplying domestic water needs as the flow for domestic requirements is generally lower than that needed for irrigation. This is not to say the pump could not be used to supply water to a village under suitable conditions, i.e., were a river or shallow well is available. Delivery details are given later in this report.

**Développement of the Chain Pump at the ATF Unit**

Work started on the development of a chain pump in early August 1977 at the ATF workshop in Nazareth. A tower was constructed to give a test lift height of five metres.

During all the early tests, the pump was operated by turning a crank handle mounted direct on to the drive wheel. This gave a drive speed of 20 to 30 r.p.m., but due to the load, this could not be sustained for more than one minute by one man. Later for test purposes and long term running tests a low-speed (60 r.p.m.) geared electromagnetic motor was used: the speed was first reduced to 30 r.p.m. and then later 20 r.p.m.

**Pump Components**

- **Lift Pipe** - (3) in D1 1. Plastic drain pipe with a 72 mm bore was chosen. At 5 Eth. Birr (US 2.50) a metre of this type of pipe is expensive but has the advantages of being:
  - non-corrosive in water;
  - flexible; and is
  - light and easy to work with.
Chain and Washer Pump

1. Drive Wheel
2. Chain
3. Lift Pipe
4. Pump Washers
5. Outlet
6. Bell Mouth Entry

Ground Level

Water Level

Well

DR 1
Alternative materials, such as steel pipe, are available but the cost is as high without the advantages mentioned above.

System 1. (DR2)

Drive wheel: In the early stages of development the drive wheel consisted of a steel structure 40 cm in diameter with six sides. Each of these sides had 2 wood blocks for driving the chain - see DR 2.

Chain and pump washers -DR 2-1: The chain on this early model was made of 4 mm diameter iron wire 18 cm long with a ring at each end; the links were joined with rings 15 mm in diameter. The 70 mm x 25 mm wooden pump washers were held in place on the links by two small steel washers welded to the links. The wooden pump washers were used to drive the chain as they rotated over the drive wheel - each washer sitting between the wooden blocks on the drive wheel. These pump washers were made of soft wood soaked in hot used engine oil. Later in the development wooden washers were discarded.

Problems with System -1.

Drive wheel: The drive wheel itself did not give many problems, but its construction was too complicated and material intensive. Attachment of the wood blocks to the wheel gave some problems as the wood became loose because it expanded when wet and then contracted when dry. It was also felt that the wheel may not have been large enough in diameter for effective long-term work.

Chain and pump washers: The chain itself was no problem to manufacture and the 4 mm wire was inexpensive. However, it was found that it was not a good idea to drive the pump through the washers. The wooden washers tended either to fail to enter the spaces on the drive wheel, or jam on exit. The fault was in the depth of engagement of the pump washer on the drive wheel which was 35 mm—equal to half the diameter of the pump washer.

The pump washers were made of soft wood soaked in old engine oil which had been heated. A total of 2 mm clearance (1 mm all round) was given between the washers and the lift pipe. This may seem a lot but with a pipe 5 m long and washers spaced at 20 cm there would have been 25 washers at any one time in the pipe. Each washer was 25 mm wide and thus there would have been 625 mm of contact between the pipe and the washers. If the washers fitted the pipe too well this 625 mm would represent a great amount of friction between the washers and the pipe. The 2 mm clearance given allowed for water to pass between the washer and the wall of the pipe. This water acted as a lubricant and kept the friction to a minimum.
In action the pump did not run smoothly and tended to jam as the chain and washers tode over the drive wheel. One reason for this has been explained in the problem of engagement of the pump washers on the drive wheel. A more serious problem was that the chain tended to become 'link locked'. The explanation this that as the chain rotated a twisting action took place as the chain curved to enter the lift pipe and this caused the links to lock. This locking that changed the pitch dimension of the chain so that it no longer fitted the drive wheel.

System 2

System 2 was similar toll. The only changes made were that the pitch of the chain was halved by shortening the length of the links. This gave more flexibility in the chain resulting in smoother running over the drive wheel. However, the 'link locking' still persisted.

System 3

In system 3 the chain was changed in favour of dog lead chain. This chain is available locally at Eth. Birr 1.50 a meter. The chain links are of 3 ofmm diameter chrome plated wire twisted to form a figure-of-eight. The wooden pump washers were still maintained at this stage.

The wooden blocks on the drive wheel were replaced by box tube sections 30 x 30 x 100mm welded to the existing six-sided metal wheel.

This system worked better than systems 1 and 2. The chain ran more smoothly over the drive wheel and did not lock when moving round the bend before entering the pipe. The wooden pump washers were spaced at 32cm so that at any one time there were 2 washers in the driving position on the wheel.

Problems with system 3

Pump washers: With prolonged running the pump washers slipped over the drive wheel; they also started jamming in the lift pipe. The reason for the jamming was traced to swelling of the wood. The washers in use on the pump had expanded by 2-3mm. Tests were made on un-used washers. These were soaked in water for there days and then measured. The diameters of the water soaked washers were no greater than the non-soaked washers. We feel what the reason the working washers expanded was because they were working under hydraulic pressure (the washers we soaked were not) and water was being forced into them even though they had been soaked in hot oil.
This situation may not have arisen had we used hard wood in making the washers. However, we felt that at some time soft wood would be used by some local artisan if hard wood was not available. Some of the washers also started to show signs of splitting due to the constant wetting and drying.

After the experience described above, it was decided not to use wood for pump washers on chain pumps that were to be used for large volumes and/or depths of over two meters. However, wooden washers could be used on small domestic pumps where the lifting requirements and volumes are small. Even so it is recommended that only hard wood be used.

**Drive system:** As stated above, the wooden washers tended to slip over the drive wheel. With the decision to change the drive system and to drive the pump from the chain and not from the washers. This would not only give a more positive drive, but would also mean that the spacing of the washers on the chain need not be related to the design of the drive wheel.

**System 4 (DR 3)**

**Drive wheel:** The new drive wheel was circular at the rim and had 14 drive pegs (80 mm x 60 mm x 10 mm) set at a pitch of 128 mm. This gave a rim diameter of 450 mm. See drawing DR 3-1 for the details of the drive pegs.

**Chair (DR 3-2):** The chain links were bent up on a jig made in the workshop to ensure uniformity. See drawing DR 3-2 for details of the chain.

**Pump washers (DR 3-3):** After some thought a suitable design was drawn up for the pump washers, DR 3-3 shows the construction. Steel plates were cut square for ease of manufacture. The plates were cut with a slot into which the chain would fit and then jig drilled to ensure accurate assembly. Rubber sealing washers were cut from heavy motor inner tube (such as Land Rover). They had two holes punched to fit the chain with a cut made at 45° for assembly.

The plates and link were assembled with the rubber washer in place: the plates being clamped whilst two small welds were made between the link and the plates. With the drive being through the chain it was not necessary to have the washers so closely spaced: they were placed at 36 cm intervals.

**Testing:** In practice system 4 did not work at all well. It had been expected that the chain would be self-aligning with the rotation of the drive wheel. This was not the case and the links tended to twist on one side and not engage on the drive pegs. However, for short periods the chain would run correctly and when it did so the pump ran very smoothly.
SYSTEM 4

Pump Washer
Exploded View

DR No 3-3

CHAIN LINKS

LINK

RIVETS

FLAT PLATE

RUBBER WASHER

FLAT PLATE

DR 3-2

Scale=Full Size

HP 79
Another problem was that the drive wheel was reluctant to release the chain. The dead weight of the water in the 5 metre lift pipe was about 20 kg (this load increases as the lift gets greater).

Engagement of the chain on the drive wheel must be positive on the lift side whilst the chain must release readily on the drop (down) side.

At this point it would be useful to list the problems identified as system 5 has become the final system which overcomes these earlier difficulties.

1. Wooden pump washers were not found suitable for heavy duty pumps with long running periods, such as are needed for irrigation.
2. Long chain links tend to bend when going over the drive wheel.
3. When moving the chain tends to twist around its own axis which gives problems of chain alignment over the drive wheel.
4. Driving the pump from the piston washers puts too much strain on the washers and is not positive enough.
5. With pegs for chain driving, the chain tends to slop off the drive wheel on the lift (up) side and/or jam on the release (down) side.

System 5 (Dr 4)

As a result of the development of systems 1 to 4, in particular information gained from work carried out on system 4, a final positive result was achieved with system 5. The basis of this system is the drive wheel and construction of the chain. In system 4 a peg engaged with the ring of the link to provide the drive, but system 5 uses an opposite system with a fork engaging with the intermediate links of the chain—see drawing DR 4.

Drive wheel (DR 4+1): The drive wheel is of the same dimensions as in system 4 but a fork arrangement is used to drive the chain. The forks are made up of 3 flat pieces of metal put together as in DR 4-2: 14 lighting forks are set equal distance apart around the 450 mm diameter rim of the drive wheel and welded in place. The drive wheel runs on hard wood bearings and has a ratchet device to prevent the pump from running backwards.

Chain (DR 4-3): The chain is made up two types of links: plain oval links (free links) and intermediate drive links which have a ring or loop at each end—see DR 4-3 for details of the links. The important factor with the chain is that it must be accurately constructed. If the links are not consistent in length the pitching will change resulting in poor or rough running and jamming.
General arrangement of chain engagement System 5, on test pump driven by electric motor, Nazareth ATF unit
Drive Wheel
Scale = 1/4

DR No 4-1
System No 5
Drive Wheel

DR No 4-2
Detail of drive forks
Scale = 1/2

HP 79
Fixtures were made in the workshop to ensure that the links of the chain were accurate. The chain was constructed from 6 mm iron. It is not welded.

**Pump Washers**: Several changes were made in the design of the pump washers. A tool constructed to punch out round metal discs 6 cm in diameter. These discs had a hole punched in them off-set from the centre and through which the closed side of the plain chain link is threaded. Each washer consisted of two metal discs either side of a rubber inner-tube disc which was cut 2-3 mm bigger than the 72 mm bore plastic pipe. With this system slots are not needed in the rubber disc. For assembly only two small welds are required, one each side of the metal discs which fix the discs to the chain link and clamp the rubber in place.

**Running and Testing**: This system was first tested by turning the drive wheel by hand. It soon became apparent that the pump was working well and it would be possible to drive it for long periods using a low speed electric motor. A safety device in the form of a small pin, 6 mm in diameter was included in the drive system: should any great over-load occur the pin would break disconnecting the drive and preventing damage to the pump. The electric motor used was a 2 HP geared down to 60 r.p.m. For driving the pump it was further geared down first to 30 r.p.m. and later to 20 r.p.m. As there is far more power available than is required to drive the pump, the safety device is very much needed.

The first tests with the motor were at 30 r.p.m. (drive wheel speed), but this speed was found to be a little too fast as it tended to throw the chain off the wheel. It was also felt that this speed would be too high when using oxen or wind as a power source. The speed was therefore geared down to 20 r.p.m. Delivery of water at 30 r.p.m. was 260 litres a minute with a lift of 5 meters: with the drop in speed to 20 r.p.m. delivery dropped to 180 litres a minute.

Long term running tests started on 5 February 1979 and by 14 May 1979 the pump had been working for 500 hours. Records of all running have been kept on forms similar to the sample attached to this report. Some small modifications were required to the drive wheel during this time. However, it never had to be removed from the tower.
SAMPLE OF DAILY RUNNING TEST CHART FOR PUMP AT NAZARETH P.R.S.

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME START</th>
<th>TIME STOP</th>
<th>REMARKS</th>
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</tbody>
</table>
SYSTEM 5

DR 4-4
Pump washer, Exploded view

DR 4-3

Scale = Full size
After the first 125 hours of running one pump washer was removed in order to study the wear on the washers over time. Other washers have since been removed after each 125 hours of running. These washers have been replaced with new ones in order to keep the system balanced.

Testing has also examined the amount of submergence needed for the lift pipe. It has been found that maximum lift (5 metres in this case) can be achieved with only 15-20 cm of the lift pipe submerged in the water source. At first it was thought that the minimum depth for effective lift would have to correspond to the spacing of the washers on the chain. In system 5 the washers are spaced at 52 cm but effective lift is achieved with 15-20 cm submergence. The explanation is that the pipe once filled with water becomes air-tight and a vacum is formed at the entrance which causes water to rise up into the pipe. We found that with as little as 1 cm of the lift pipe (bell mouth) submerged there was little or no change in delivery of water. However, the deeper the pipe is in the water, the less is the effort required to lift this water.

Field testing: Using system 5 a double lift pump has been constructed in the ATF workshop. In this pump there is a single frame and drive shaft fitted with two sets of drive wheels, chains and washers and lift pipes.

This pump was installed on the ATF test well situated at Adama 27 km from Nazareth near the banks of the Awash river. The well is 10 metres deep with the water table at 7 metres. The pump was driven by oxen and delivered 200-250 litres a minute. It was found that the capacity of the pump was too great for the well. Therefore, it was decided to move the pump to the banks of the Awash river. A shallow pit 4 metres deep was dug and connected to the river by an underground pipe 6 metres long. Chains and lift pipes were shortened to 3 metres and the pump installed over the pit.

A local farmer has been using this pump to irrigate a quarter hectare plot of tomatoes. The pump is lifting 200-250 litres of water a minute. We feel that this is below capacity as the drive wheels were constructed to run at 20 r.p.m. with the pump being driven by oxen.

In fact the drive wheel speed is now about 14-15 r.p.m. a modification to the gear system will be made to correct this. The farmer's reaction has been good but the oxen being used are in very poor condition and are unable to operate the pump for more than one, or at the most two, hours at a time. The pump itself is not hard to turn and a small boy can push it round at oxen speed for 5-10 minutes.
Please note that research on this pump is continuing and from time to time new information will be added to this report to bring it up-to-date. Anyone interested in this development is welcome to visit the ATF workshop at Nazareth to study this or any other of our research projects/

**Technical details of the pump on test at Nazareth Research Station**

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
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<tbody>
<tr>
<td><strong>DRIVE WHEEL</strong></td>
<td>450 mm Ø steel welded construction</td>
</tr>
<tr>
<td><strong>CHAIN</strong></td>
<td>6 mm Ø Rod, jig bent, not welded</td>
</tr>
<tr>
<td><strong>LIFT PIPE</strong></td>
<td>72 mm Ø plastic pipe /Local Manufacture/ inside diameter</td>
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<tr>
<td><strong>PUMP WASHER</strong></td>
<td>rubber sealing discs between 2 metal plates</td>
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<tr>
<td><strong>WASHER SPACING</strong></td>
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<tr>
<td><strong>MAX. DELIVERY AT 5m DEPTH</strong></td>
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<td><strong>DRIVE WHEEL SPEED</strong></td>
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<tr>
<td><strong>CHAIN SPEED</strong></td>
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<tr>
<td><strong>PRODUCTION COSTS</strong></td>
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