VERTISOLIC SOILS OF THE HANANG WHEAT COMPLEX, TANZANIA

- Characteristics, Distribution, Use and Management -

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INTRODUCTION

This paper discusses the characteristics, distribution and management of soils of the "Hanang Wheat Farm Complex" with particular reference to vertisols. The term "Hanang Wheat Farm Complex" is used to describe a group of indivually incorporated and managed farms operated under the overall supervision of Nafco (the Tanzanian National Agriculture and Food Corporation). These parastatal farms are linked as a result of their geographical proximity and also by virtue of their inclusion in the co-operative development project known as the "Tanzania Canada Wheat Project". The project is funded jointly by Tanzania and Canada and has as its goal the achievement of self sufficiency in wheat for Tanzania.

LOCATION AND EXTENT

The farm complex is located above and to the west of the main Gregorian rift wall escarpments in north central Tanzania (see Figure 1). Most of the farms are located in the long gentle incline which forms the backslope of the rift wall escarpment. This area is referred to locally as the Hanang Plateau of its proximity to the imposing presence of near by Mt. Hanang.

The complex is about 280 km south west of Arusha by road. Driving times range from 5 hours to 9 hours depending upon the season and the condition of the roads. There are two airstrips on the complex and trips from Arusha can be made by small plane in about 1.5 hours. A wheat research station staffed with Tanzanians and Canadians is located in Arusha and provides research and logistics support to the farms. Communications, supplies and some administration for the farms are centered in Arusha so there is considerable interaction and traffic between the two locations.

Generally, the farms average about 10,000 acres (4,032 ha) at maturity (see Figure 2 and Table 1). Some of the newer farms are still expanding and have not yet achieved their full acreage. Some of the older farms have expanded beyond their initially planned size. Several are now making plans to reduce acreage in order to concentrate management and machinery resources on the most productive portions.

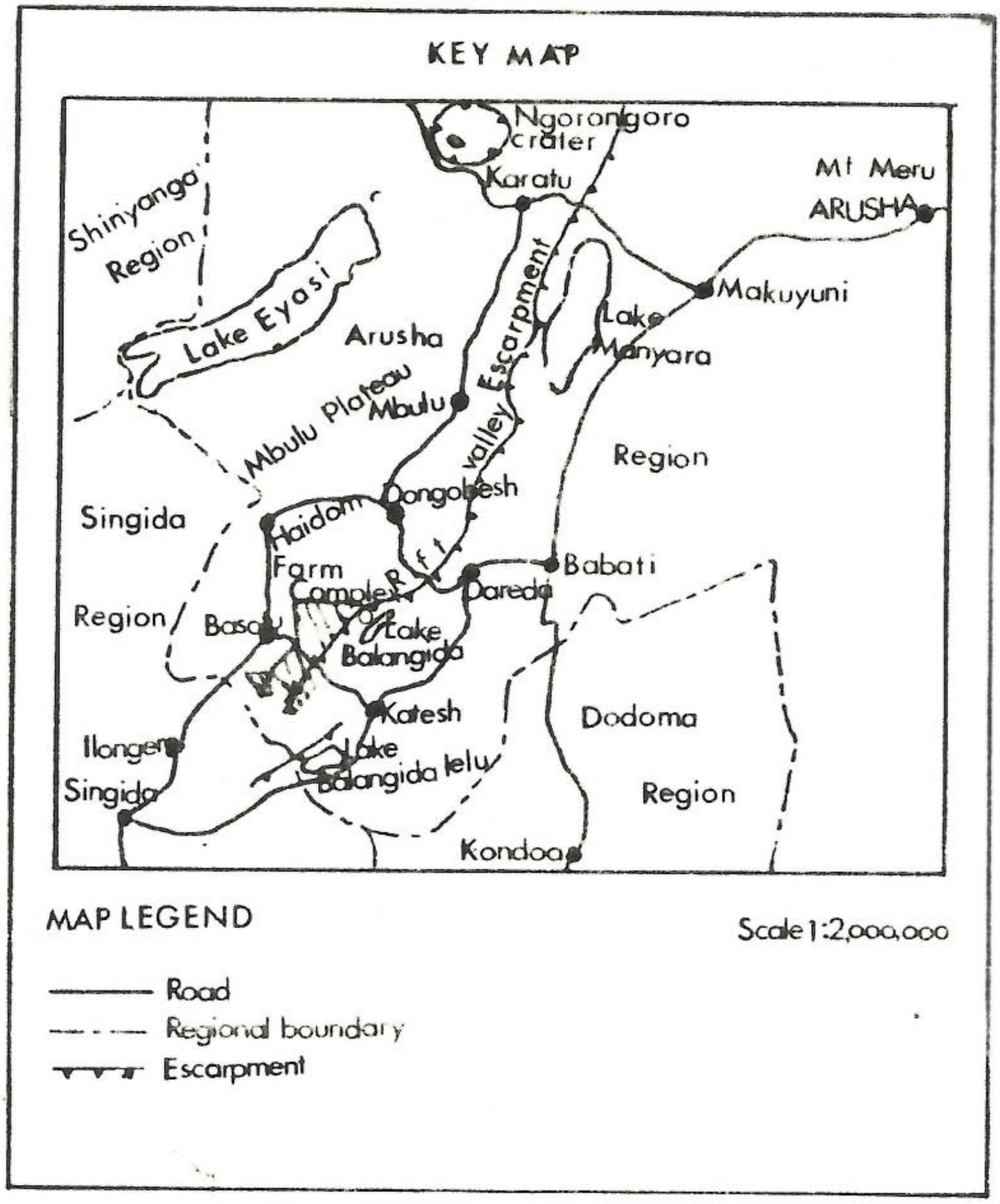


FIGURE 1. LOCATION OF HANANG WHEAT COMPLEX FARMS

FIG. 2 NAFCO WHEAT FARMS LOCATION AND SIZE

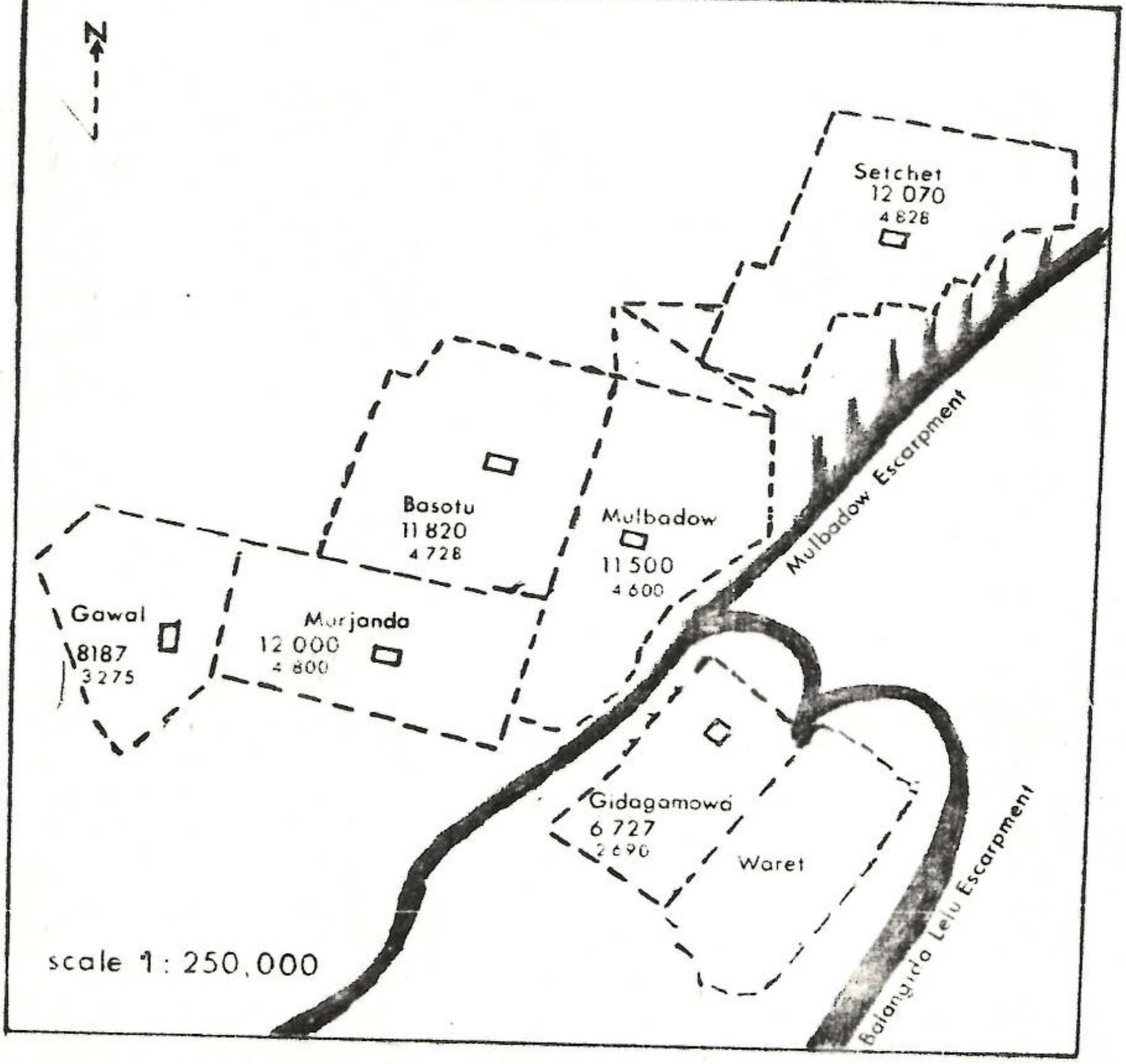


TABLE 1 PRESENT SIZE OF HANANG COMPLEX FARMS

FARM	YEAR ESTABLISHED	ACRES	HECTARES
SETCHET	1975	12,070	4,828
BASOTU	1968	11,820	4,728
MULBADOW	1979	11,500	4,600
MURJANDA	1980	12,000	4,800
GAWAL	1982	8,187	3,275
GIDAGAMOWD	1983	6,727	2,690
WARET	1983	CLEARING & LAYOUT UNDERWAY	

HISTORICAL BACKGROUND

The Hanang Plateau area presently farmed falls entirely within the Mbulu District of the Arusha Administrative Region. Prior to the development of large scale mechanized agriculture it formed a significant portion of the area considered to be the territory of the Barbaig people. These people are semi-nomadic herders with many similarities to the more familiar Maasai. They very rarely become involved in stable farming activities and consequently produce little evidence of physical occupation or ownership of land. Land occupied by the Barbaig can appear to be under-utilized and only slightly populated. Expansion of mechanized farms into this area has required political and community dialogue and resettlement of numerous Barbaig in surrounding areas unaffected by expansion.

A few small private wheat farms operated in the Hanang Plateau area prior to 1967. They averaged about 200 ha in size and utilized mechanized equipment such as Ford 35-60 hp tractors. They reportedly produced yields of about 5 bags/acre (1 bag = 90 kg approximately).

The Tanganian Government developed an interest in farming this area as early as 1967 and approached Canada to assist in the development of a Wheat complex at Basotu (Nielsen, 1982).

The Canadian Government responded with a study team sent to assess the potential and the requirements for successful wheat cultivation in Tanzania. The feasibility report (Beamish et al, 1968) recognized that successful production was possible in Tanzania but recommended that appropriate research be carried out before any committment was made to production. The Tanzanian Government had faith in the future of the Hanang Plateau area and was anxious to prove and develop its potential. President Julius Nyerere intervened personally to obtain a committment to station at least one Canadian farmer at Basotu from 1971 onwards to assist with the initial production efforts.

The first Canadians arrived in June 1971 and most were involved initially in obtaining a research station with apprpriate living quarters and with developing a design for a research program. Productive research began by 1973 (Nielsen, 1982) and by 1975 had produced a series of recommendations which resulted in the release of a preliminary agronomic package judged suitable for successful wheat production.

Meanwhile on the Hanang Plateau, considerable effort was expended in trying to establish a viable infrastructure and farming operation at the initial Basotu farm site. The production efforts at Basotu from 1968 to 1976 are summarized in Table 2 (Nielsen, 1982).

TABLE 2 SUMMARY OF PRODUCTION AND DEVELOPMENT BASOTU FARM 1968-76

Year	Acres (at Basotu)	Yield (Bu/acre)	Comments
1968	300	29	A good start. 1st year of scheme under Ministry of Agriculture & Food.
1969	5560	3	A disaster - crop engulfed by weeds.
1970	8218	13	Encouraging - 1st year of management by Nafco.
1971	7499	9	Looked good but dried out - low yield due to drought and army worm.
1972	8987	16	Quite encouraging - good weather during planting.
1973	6711	7	Disaster - low yield due to excessive rain during planting, weeds and rust.
1974	8149	3	Disaster - wrong time of planting.
1975	2000	7	Disaster - serious consideration given to eliminating the growing of wheat at Basotu.
1976	4500	20	The turning point - implementation of new tillage techniques and time of planting as per proposed agronomic package.

The efforts of the initial research and the early, variable, production both contributed to the improved understanding required to guarantee successful on-going production. The limitations of the area, particularly its low and erratic rainfall continue to be problems which restrict yield and introduce yearly uncertainty. However, from 1976 until 1983 production has been sustained continuously and expansion in terms of number of farms and total acreage has been dramatic. This development is summarized in Table 3.

CLIMATE

A comprehensive compilation and analysis of meteorological records has been prepared for stations within and surrounding the farm complex area (Fenger, Hignett and Green, 1982). Salient aspects of this analysis are summarized below.

The climate is characterized by a rainy season from November to May and a dry season from June to October. Average annual rainfall (adjusted) is 617 mm and has ranged from 408 mm to 820 mm. At Basotu, the rainy season cannot be clearly divided into a short rains and a long rains as is common elsewhere in Tanzania.

Potential evapotranspiration is about 800-900 mm per year and exceeds rainfall in all months with exceptions in some years of December, January or February. There is considerable, unpredictable, variation in rainfall onset, distribution and total accumulation from year to year. Rainfall intensity is also highly variable but several downpours have been recorded with intensities greater than 50 mm/hr. Considerable surface runoff and soil erosion have been noted during these intense rainfalls.

Only slight temperature changes occur from month to month. The coolest months are June and July when average daily temperatures are about 17°C - 21°C and minimum temperatures may reach 9°C. The warmest temperatures occur in October and November just prior to and at the start of the rainy season. They average about 20-25°C and daily maximums may reach 29°C. Throughout the year the daily temperature fluctuations are greater than the month to month changes. Generally temperatures fall to about 10-15°C at night and rise to about 21-28°C during the day.

TABLE 3. SUMMARY OF PRODUCTION & DEVELOPMENT
HANANG WHEAT COMPLEX, 1976-1983

YEAR	1976	1977	1978	1979	1980	1981	1982	1983	TOTAL
FARM									
Basotu									
Acreage	4,500	10,851	13,959	9,673	10,000	10,000	10,093	10,600	79,676
Yield bags/ac	7.0	7.0	5.0	8.8	7.7	7.6	8.0	6.6	7.1
Total Yield bags	31,500	75,957	69,759	85,122	77,000	76,000	80,744	70,384	566,502
Setchet									
Acreage	2,647	5,275	7,862	8,862	11,300	10,290	10,731	11,251	68,218
Yield bags/ac	4.3	5.2	7.2	6.2	6.7	5.1	5.1	3.2	5.4
Total Yield bags	11,382	27,430	56,292	54,944	75.710	52,479	54,728	36,228	369,192
Mulbadow									
Acreage				5,000	5,000	10,174	10,112	10,574	40,860
Yield bags/ac				9.7	7.8	6.1	6.2	5.9	6.7
Total Yield bags				48,300	38,900	62,061	62,694	61,860	273,816
Murjanda									
Acreage					1,300	7,386	8,040	9,800	26,526
Yield bags/ac					3.3	5.0	6.0	5.6	5.4
Total Yield bags					4,303	36,930	48,240	54,390	143,863
Gawal									
Acreage							5,265	8,408	13,673
Yield bags/ac							7.5	4.8	5.9
Total Yield bags							39,488	40,695	80,182
Gidagamowd									
Acreage								2,500	2,500
Yield bags/ac								1.2	1.2
Total Yield bags								2,900	2,900
All Farms									
Acreage	7,147	16,126	21,821	23,535	27,600	37,850	44,241	53,133	231,453
Yield bags/ac	6.0	6.4	5.8	8.0	7.1	6.0	6.5	5.0	6.2
Total Yield bags	42,882	103,387	126,087	188,367	195,913	227,470	285,894	266,457	1,436,455

Little data is available on wind velocities and directions but experience indicates persistent high winds from the east and northeast throughout the June to October dry season.

GEOLOGICAL SETTING

The soils and farming potential of the area are strongly related to the general pattern of geologic development. The sequence of geologic events may be summarized simply as follows (Fenger, Hignett and Green, 1982) see Figure 3.

1. Developemnt of mature granitic peneplain surface during a long period of geologic stability (some of the granitic rocks are up to 600 million years old)

2. Earth movement leading to the formation of major faults, the uplifting of large blocks of terrain and the eruption and growth of Mt. Hanang. (From 3 million years B.P. to about 25,000 years B.P.)

3. Deposition of wind blown calcareous volcanic ash from Mr. Hanang over a large area west and south of the mountain. This ash consolidated to form calcareous volcanic tuff which is concentrated in depressions and on more level terrain. Granitic ridges and monadnocks protrude through the tuff in areas of rougher topography.

4. Development of numerous small explosion craters during the final stages of volcanism, craters resulted from violent release of gases but little new material was deposited.

The effect of these geologic deposits on soil development and farming potential may also be summarized quite simply.

1. Calcareous Volcanic Tuffs

The most fertile and useful soils occur where these deposits are thickest and most continuous. The tuff produces soils which are fine to moderately fine textured, are highly buffered with free lime accumulation within 1-2 metres of the surface, have a large reserve of weatherable minerals and plant nutrients and are generally underlain by a hard petrocalcic horizon. The majority of well developed vertisols occur in

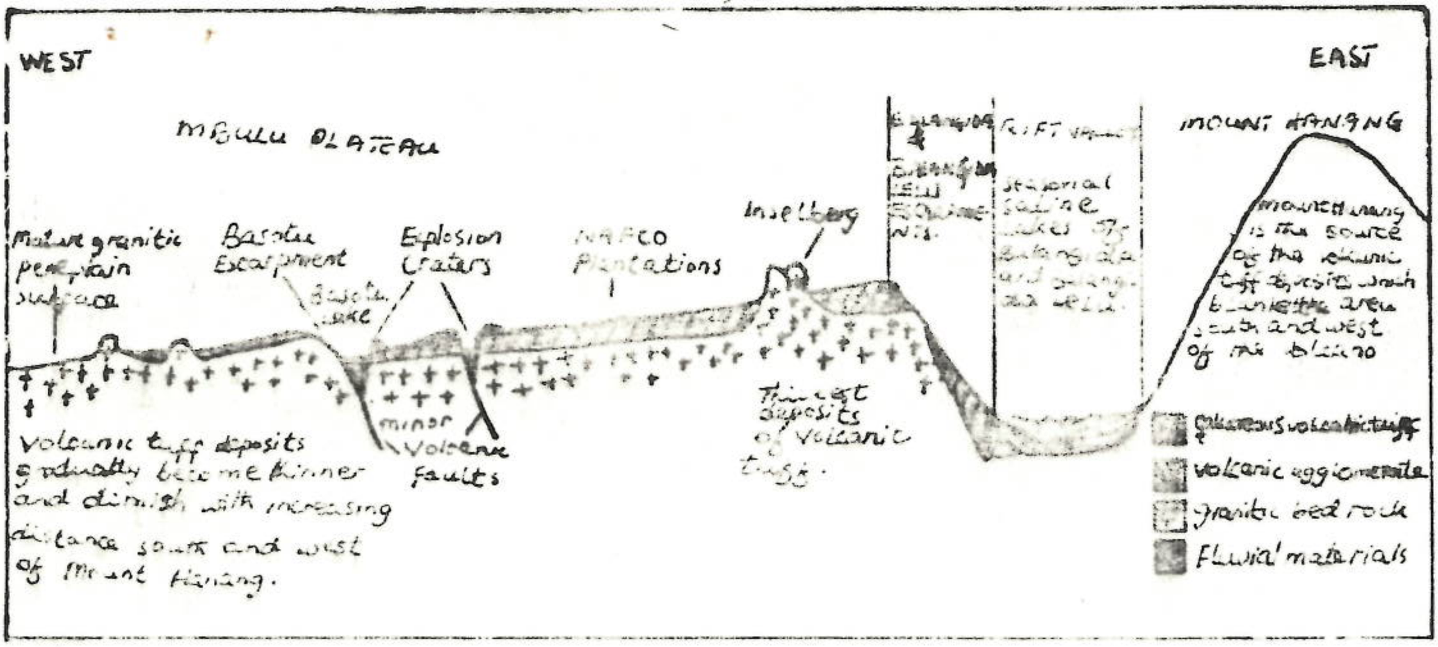


FIGURE 3 GEOLOGIC SETTING OF THE HANANG WHEAT COMPLEX
(from Fenger, Hignett & Green, 1982)

association with these calcareous volcanic deposits. Genesis of vertisols is promoted by the calcium rich nature of the tuff. Some unproductive soils occur where hard bedrock or petrocalcic horizon appears close to the surface.

2. Granitic Peneplain

The soils developed from weathered granite are distinctly less fertile and less suitable for mechanized agriculture. They are coarser textured than the volcanic derived soils and always contain significant amounts of sand sized material. Textures range from sandy clay loam to loamy sand. The soils are generally moderately to strongly leached and have low pH values, low base status and low cation exchange capacities. Water retention is limited due to the sandy textures. Colours are red to reddish brown.

3. Horneblende Schist

A few of the soils within the presently farmed area have developed from weathered horneblende schist. They frequently include minor additions of volcanic tuff as well. these soils are usually midway between the two extremes described above in terms of fertility and usefulness. They are generally bright red in colour and have high contents of non to slightly sticky illite-type clays in contrast to the sticky montmorillonite type clays which dominate the volcanic tuff soils.

The above is a simplified model and exceptions or intergrades do occur. None the less, the presence and influence of volcanic ash deposits from Mt. Hanang is central to the location and formation of most of the soils deemed favourable for wheat production on the Hanang Plateau.

Part II - The Soils

Characteristics and Distribution of Hanang Wheat Complex Soils

Three classes of soil are recognized for the purpose of this discussion. They consist of vertisols, vertic intergrades and non-vertic upland soils. Each class tends to occur on specific portions of the landscape according to the general pattern illustrated in Figure 4. Profile descriptions and analytical data for the major profile types discussed in each class are included in Appendix A. General characteristics of the soils are summarized in Table 4.

FIGURE 4. SCHEMATIC SHOWING GENERAL PATTERN OF SOIL DISTRIBUTION IN CROSS SECTION
(from Fenger, Hignett and Green, 198[illegible])

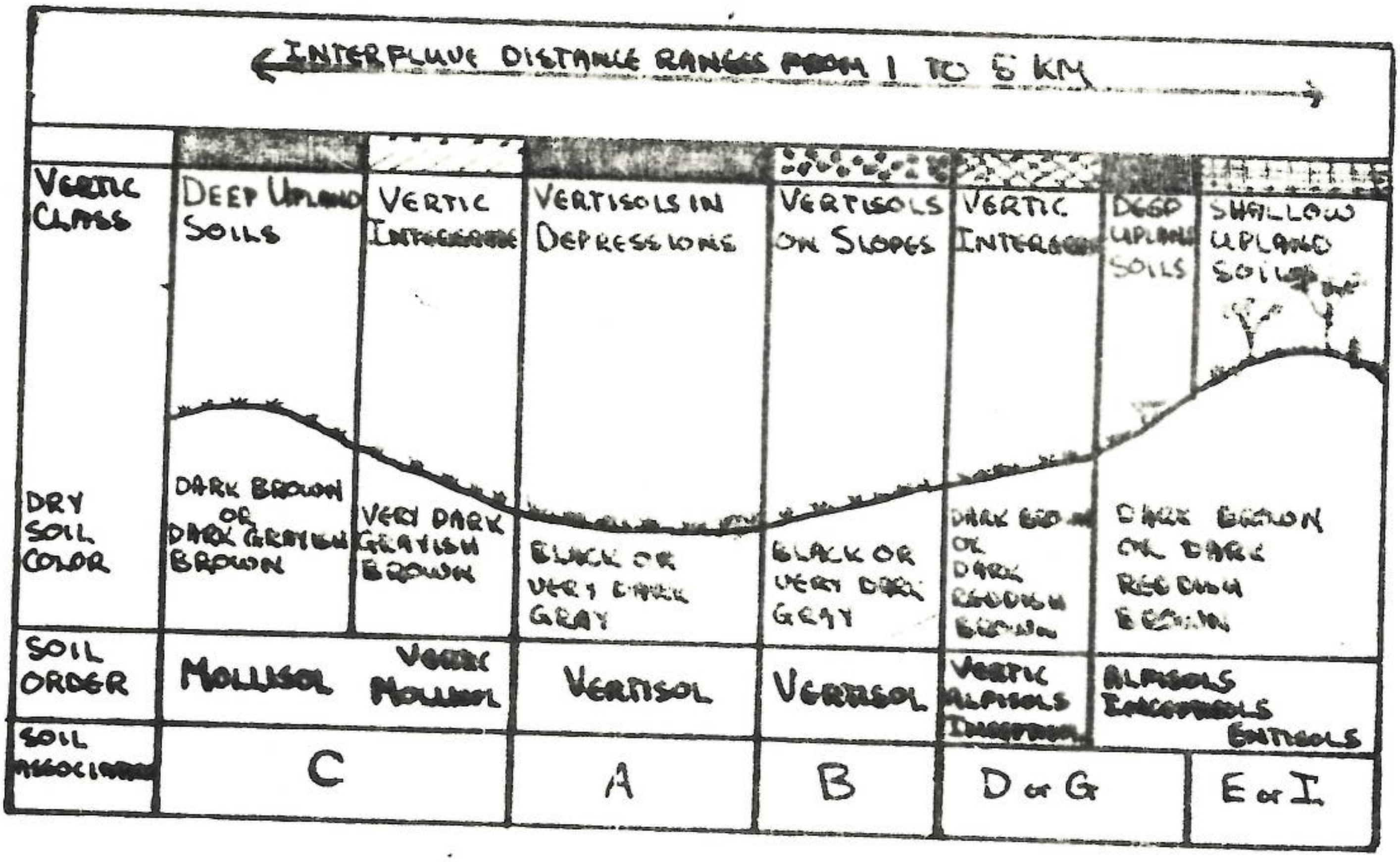


TABLE 4. GENERAL CHARACTERISTICS OF HANANG WHEAT COMPLEX SOILS (FROM FENGER & HIGNETT, 1979)

	VERTISOLS		INTERGRADES		DEEP UPLAND SOILS			SHALLOW UPLAND SOILS	
	DEPRESSIONS	SLOPES	MOLLISOLS	ALFISOLS	MOLLISOLS	ALFISOLS & INCEPTISOLS		ALFISOLS & INCEPTISOLS	
ASSOCIATION	A	B	C	D & G	C	D	G	E (some G, L)	I F
COLOR	black	black	dark grey	Very dark reddish brown	dark grey	dark reddish brown	red to dark red	dark reddish brown	dark grey to black
TEXTURE	HC–C	C	C,CL	C	C–CL	C–CL	C	C,CL,L	SCL–SL
CLAY %	60–70%	50–60%	45–55%	45–55%	30–55%	40–50%	40–55%	35–45%	15–25%
PH	7.5–8.0	6.0–7.5	6.0–7.0	5.5–6.5	6.0–7.5	6.0–6.5	5.5–6.5	6.0–7.0	6.5–7.0
ORGANIC CARBON	1–2%	1–2%	1–2%	1–2%	1–2%	1–2%	1–2%	1–2%	1–2%
C.E.C. (meg/100g)	70–80	45–50	30–40	25–35	35–40	25–30	20–25	20–30	15-20
Ca (meg/100g)	30–50	25–30	20–30	15–20	20–25	12–20	8–14	15–20	20–30
Mg (meg/100g)	16–18	12–15	10–12	8–10	10–12	8–10	6–8	8–10	2–5
% B.S.	85–100	80–95	85–95	70–90	70–95	80–90	65–85	85–95	95–100
P (ppm)	4–5	20–35	50–100	5–10	30–50	10–20	1–2	10–20	4–8
E.C.	1–5.0	0.5–1.0	0.5–1.0	0.5	0.5	0.5	0.5	0.5	0.5–1.0

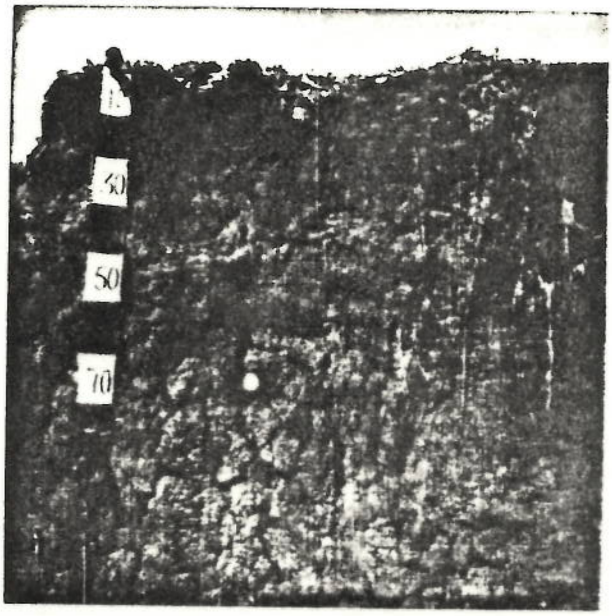


FIGURE 5. VERTISOL SOIL PROFILE SHOWING DEEP WELL-DEVELOPED CRACKS.

Vertisols

Fully developed vertisols occur on two main landscape positions, namely: a) depressions [Association A] and b) lower slopes (and some midslopes affected by high concentrations of calcareous ground water) [Assciation B]. These two main groups of vertisols have many common characteristics (see Figure 5). They are balck and show little or no colour change with depth. They are sticky and slowly pervious when wet and extremely hard when dry. They have uniformly high clay contents (40-80%) throughout their profiles and the clay is dominantly montmorillonite. They exhibit the characteristic tendency of montmorillonitic soils to shrink and swell with changes in soil moisture. This activity produces well developed, deep, wide cracks which open during the dry season and extend to depths of 100-150 cm. Other characteristic signs of this shrink-swell phenomenon include well developed hummocky microrelief (gilgae) and shiny slickensides on ped faces of sub surface horizons.

Chemically, all the vertisols have high levels of surface organic carbon (1.5-2%) which decrease loss rapidly with depth than in the non-vertic soils. PH values are neutral to alkaline. Cation exchange capacities are uniformly high throughout the profile (45-80 meg/100g) and percent base saturation is consistently greater than 80%.

The differing landscape positions give rise to several significant differences between these two groups of vertisols. The depressional vertisols (Assoc. A) are almost always deep (2 meters or more) while the vertisols on slopes are very often less deep and frequently have well developed petrocalcic horizons within 150 and even 50 cm of the surface. Those less than 50 cm deep to petrocalcic usually display excessive surface stoniness. The sloping vertisols (B) characteristically contain significantly lower amounts of total clay (40-60%) than do the depressional vertisols (60-80%). The Bs also have consistently lower values of pH, CEC, %BS., Ca, Mg and Na than do the A's.

In terms of land use, the sloping vertisols (B) tend to exhibit problem gully erosion and occassionally to cause difficulties arising from stoniness or shallow depth to hard rock. The depressional vertisols are subject to rainfall flooding and prolonged inundation. This wetness can adversely affect timely cultivation, seeding and weed control.

Certain differences exist within the two main vertisols groups as well. In the group of depressional soils (Assoc. A) these differences are primarily related to the degree and duration of wetness caused by rainfall flooding and inundation. Thus A1 suffers only short term flooding while A3 and A4 are increasingly limited by extent and duration of flooding. The sloping vertisols are subdivided on the basis of depth to bedrock or hard petrocalcic horizon. B1 contains a mixture of deep and shallow vertisols, B2 is mostly shallow and lithic vertisols and B3 is uniformly deep vertisols.

Vertic Intergrades

Some lower and midslope positions have soils which are intergrades between true vertisols and non-vertic upland soils (Figure 6). These soils characteristically retain elements of the brighter colours, lower clay contents, and higher permeability associated with the upland soils. Simultaneously, they display some or all of the typical vertic characteristics of deep wide surface cracks, uniformly high clay content, gilgae micro-relief and slickensides. Generally, these attributes are less strongly expressed than in the fully developed vertisols.

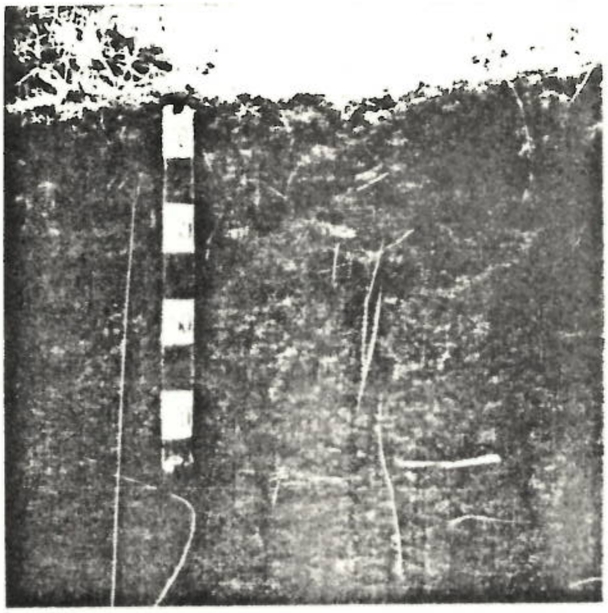


FIGURE 6. VERTIC INTERGRADE SOIL PROFILE SHOWING MODERATE DEVELOPMENT OF CRACKS AND SOFT, GRANULAR SURFACE STRUCTURE.

These intergrades have been mapped as separate association members (i.e. C4, D4, G4) within their respective upland soil associations. The Association C intergrades (C4, C5) are deep and shallow vertic mollisols respectively. They have the thick, dark, friable surface horizon enriched with organic matter which sets them apart as mollisols. However in addition they have enough montmorillanitic clay to exhibit some vertisolic properties. They develop cracks during the dry season but are not as sticky and plastic as the vertisols and do not develop gilgae microrelief. The other intergrade soils lack the deep friable surface mollic horizon of the Association C soils. They invariably display brighter subsurface colours than the A's, B's or C's. They are classified as Vertic [illegible] or Vertic Inceptisols. Association members D4 and E4 devleop from calcareous tuff and weathered hornblende schist. It is usually bright red in colour.

A different variety of intergrade occurs on some fan and toe slope positions subject to ongoing alluvial accretion. In some cases, recent accumulations of slope wash appear to bury previously discrete, well developed vertisols. In this case, the overwash is typically quite sandy and forms a distinctly seperate layer overlying the clayey, cracking subsoil (mapped as Association Member J3). A second toeslope vertic soil may represent more of an equilibrium between accretion and vertisol development than a succession of seperate processes as detailed above. This soil (mapped as Association Member N2) displays the cracking typical of vertisols but has a very subdued

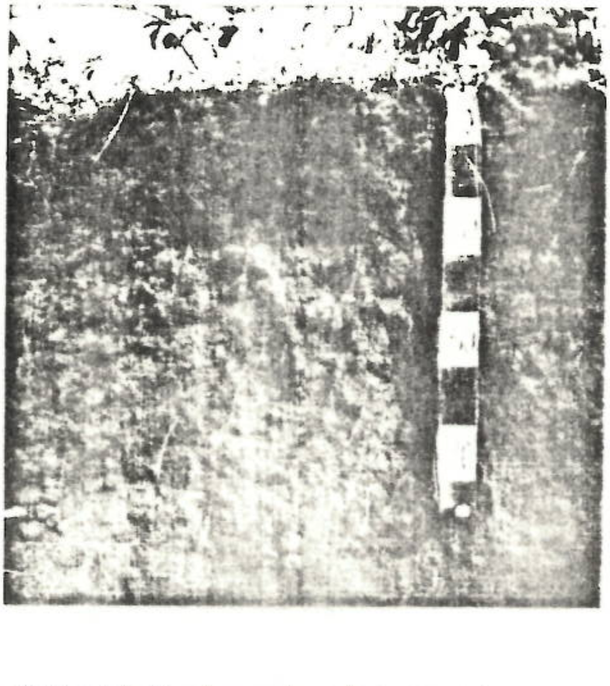


FIGURE 7. NON VERTIC UPLAND SOIL PROFILE. NOTE THE ABSENCE OF CRACKS AND THE SOMEWHAT DARKER COLOUR OF THE SOFT 'MOLLIC' SURFACE HORIZON OF ORGANIC MATTER ACCUMULATION.

expression of most other vertic properties. It would appear that the landscape position favours the formation of vertisols but that continuous accretion of sandy clay loam slope wash acts to retard full development.

Non-Vertic Upland Soils

The upper slope and crest landscape positions within the Hanang farm complex are almost always occuppied by non-vertic soils (Figure 7). From a management point of view these upland soils can be divided into a group of deep soils and a group of shallow soils.

The majority of the upland soils are deep and are derived from weathered calcareous volcanic tuff. Association C soils (mollisols) are characterized by a thick, well developed, dark coloured surface horizon of organic matter accumulation. These mollisols provide the best combination of high fertility and ease of management of any of the farm soils. They can be worked over a wide range of moisture contents and permit cultivation shortly after heavy rains or even during extended dry periods. They are well drained and have high natural fertility. Where the dark coloured 'mollic' horizon is thin or absent, the deep soils on volcanic tuff are mapped as Association D. This group of upland soils has slightly less favourable workability and slightly lower fertility than the mollisols of Association C. It is distinguished by the dominantly reddish brown colour of its profiles. D soils are none the less rated as highly suitable for mechanized farming. Soils of Association member G1 are similar to the D group in most respects except that they develop from weathered horneblende schist, are bright red in colour and are less fertile because of their different clay mineralogy (illite).

Less suitable upland soils include those which are lighter in texture and more shallow to bedrock than those described above. Shallow soils occur where initial deposits of weatherable materials were thin and also in locations where geologic erosion has resulted in the removal of much of the material suitable for soil formation. Soils mapped as Association E are all dominantly shallow (100 cm) as are soil Association members C2, C3, C5, D2 and G2. These shallow soils have less capacity to store moisture and a lower total fertility supply than do their deeper counterparts. Also shallow soil areas generally have patches of lithic and stony soil where rock and stones impede efficient cultivation and damage equipment.

Some very shallow and lithic soils are also mapped within the wheat complex area. These soils are less than 50 cm deep to petrocalcic horizon or hard rock. They are often sandier than the associated deeper soils and are always affected by low moisture holding capacity and reduced fertility. These soils occur at the crests of ridges and along the edges of the major fault escarpments and explosion craters. They are mapped as Association members E2, E3, F2, F3, G3, I2 and I3. They are considered unsuitable for sustained mechanized agricultural production however some of these soils are currently included in cultivated fields.

DISTRIBUTION AND EXTENT OF VERTISOLS ON THE HANANG FARMS

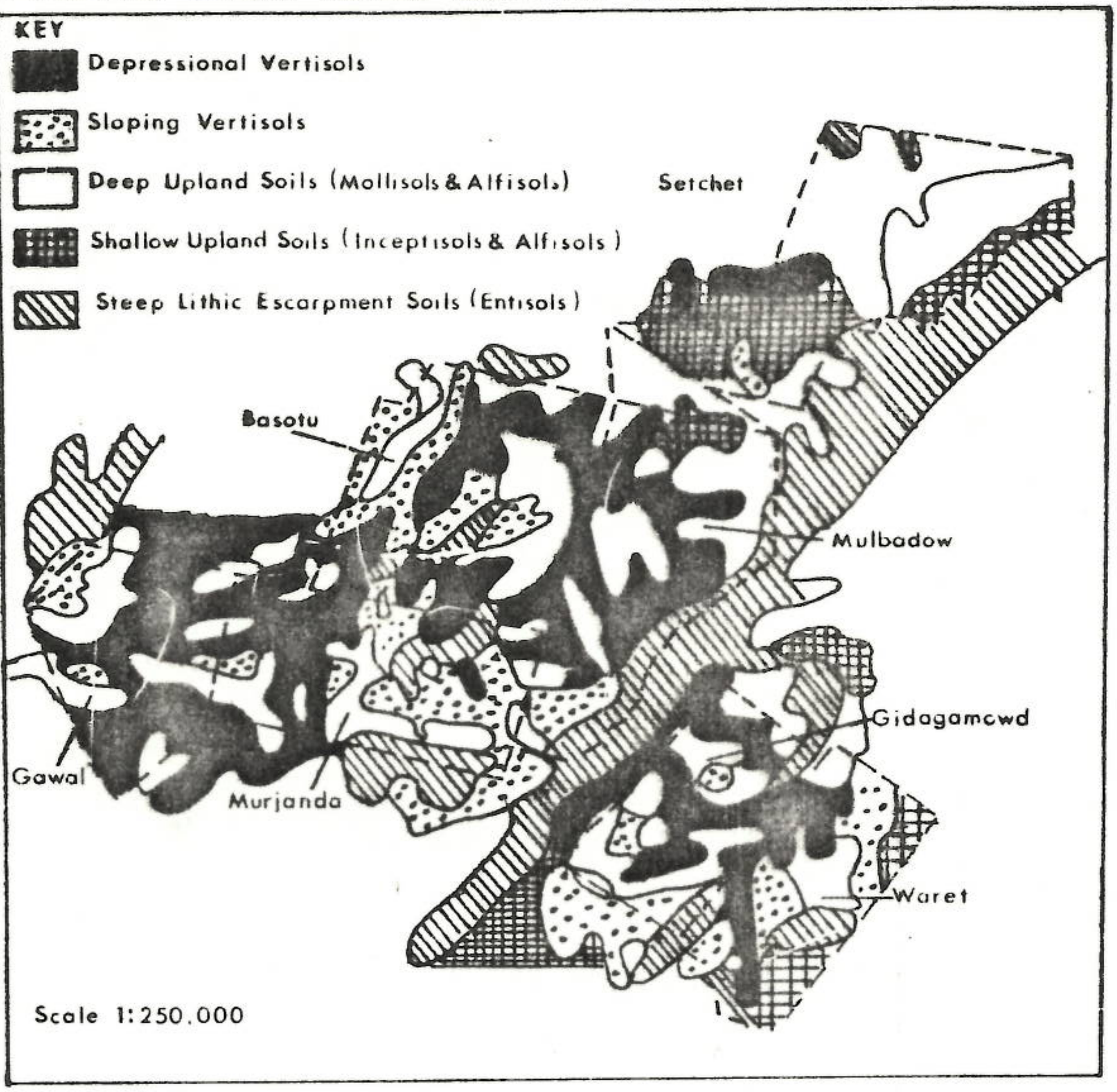
The distribution and proportions of the various mapped soil association members were obtained from consultation of the Basotu map sheet soils map (Fenger, Hignett and Green, 1982). The farm boundaries used to determine the extent of each farm are those presented on the SIAG. Foratek compiled base map of the farm area (SIAG, 1981). The actual boundaries may be somewhat different than those shown on the map used as they are subject to regular alteration. However, only small changes are likely so the relative acreages of each soil type should remain roughly the same regardless of exact boundary location.

The computed acreages of each soil association member on each farm are tabulated in Appendix 1. This raw data has been summarized into simpler classes for the purposes of this discussion (see Table 5). The classes used for the discussion are depressional and sloping vertisols,

TABLE 5. SUMMARY OF SOIL ACREAGE & PROPORTIONS OF VERTISOLS AND NON-VERTIC SOILS FOR THE HANANG WHEAT COMPLEX FARMS

FARM NAME	VERMSOLS		VERTIC INTERGRADES	UPLAND SOILS		TOTAL AREA
	IN DEPRESSION	ON SLOPES		DEEP	SHALLOW & LITHIC	
SETCHET	107 ac 43 ha 1%	403 ac 161 ha 3%	400 ac 160 ha 3%	7,768 ac 3,207 ha 65%	3,392 ac 1, 357 ha 28%	12,070 ac 4,82 8 ha 100%
BASOTU	3,626 ac 1,450 ha 31%	2,168 ac 867 ha 18%	187 ac 75 ha 2%	5,245 ac 2,098 ha 44%	594 ac 238 ha 5%	11,820 ac 4,728 ha 100%
MULBADOW	3,932 ac 1,573 34%	1,475 ac 590 ha 13%	118 ac 47 ha 1%	5,292 ac 2,117 ha 46%	686 ac 274 ha 6%	11,503 ac 4,601 ha 100%
MURJANDA	3,893 ac 1,557 ha 32%	3,156 ac 1,262 ha 26%	210 ac 84 ha 2%	4,236 ac 1,694 ha 35%	510 ac 204 ha 5%	12,004 ac 4,801 ha 100%
GAWAL	3,666 ac 1,467 ha 45%	1,080 ac 432 ha 13%	907 ac 363 ha 11%	2,492 ac 997 ha 30%	44 ac 17 ha 1%	8,189 ac 337 ha 100%
GIDAGAMOWD	1,520 ac 608 ha 23%	1,631 ac 652 ha 24%	1,800 ac 720 ha 27%	1,737 ac 695 ha 26%	40 ac 16 ha < 1%	6,728 ac 2,691 ha 100%
TOTAL	16,744 ac 6,698 ha 26%	9,912 ac 3,964 ha 16%	3,622 ac 1,449 ha 7%	26,770 ac 10,708 ha 43%	5,266 ac 2,106 ha 8%	62,314 ac 25,025 ha 100%

FIG.8 **NAFCO WHEAT FARMS GENERAL SOILS DISTRIBUTION**



vertic intergrades and deep or shallow upland soils. The approximate distribution of these various broad classes is shown in Figure 8. It was not possible to illustrate the distribution of vertic intergrades in Figure 8 as these soils frequently are mapped as inclusions in areas dominated by other soils. In addition on all farms but Gawal and Gidagamowd they are insignificant in extent.

Vertisols make up about 42% of the total area on all farms and are divided into vertisols of depressions (26%) and vertisols on slopes (16%). They form a significant portion of the soils everywhere except on Setchet where they occupy less than 5% of the total farm. Basotu and Mulbadow have very similar distributions of all soils. They have a good mix of about 50% vertisols and 50% upland soils. More of the vertisols on these farms occur in depressions (31-34%) than occur on slopes (13-18%). Murjanda has a slightly higher percentage of vertisols on slopes (26%) than Basotu and Mulbadow but otherwise is more similar to these two farms than to any of the others. Gawal and Gidagamowd have the highest proportions of vertisols and vertic intergrades. They are also the only farms to have significant distributions of intergrade soils. Gawal has a total proportion of 69% vertisols and vertic intergrades of which the most dominant are vertisols of depressions (45%). Gidigamowd has a total proportion of 74% but in contrast to Gawal is dominated by vertisols and vertic intergrades which occur on slopes (51%).

Upland soils make up just over 50% of all soils in the combined farm complex. Of this total about 43% of the soils are deep and about 8% are shallow or lithic. These figures are somewhat deceptive due to the disproportionate amount of upland soils on Setchet farm (95%). This farm lacks any significant component of vertisol soils. It also is the only farm with a significant proportion of shallow and lithic soils under cultivation. The other farms all have less than 50% upland soils and none has more than 5% shallow soils. Farm by farm discussion of the proportions of upland soils is unnecessary but one interesting observation is warranted. When viewed in chronological order of development each succeeding farm has tended to incorporate fewer upland soils and more vertisols than the ones preceeding it. This may not have been doen intentionally but it does reveal an increasing reliance on vertisol soils.

POSSIBLE SIGNIFICANCE OF DISTRIBUTION PATTERNS

A few general comments and conclusions can be extracted from an investigation of the soil distribution figures (Table 4) in conjunction with average yield data (Table 3). The most immediately obvious comment is that the long term poorer performance by Setchet farm (5.4 bags/acre) must be at least in part due to its very different soil assemblage.

Reports circulate that Setchet recieves less rainfall than the other farms and lower yields are generally ascribed to this cause. However the dominant distribution of upland soils particularly the large component of shallow and lithic soils must also be considered as a factor. In years of low rainfall the lighter textured upland soils, especially the shallow ones, have a lower capacity to store moisture for supply to the crop throughout the growing season than do the vertisols. Consequently, it is to be expected that yields on Setchet farm would not match those on the other farms in dry years. In years of plentiful and timely rainfall, moisture storage capacity of the soils is less important and crop yields on Setchet could match those elsewhere.

It is of interest to note that a large area of depressional vertisols exists just north west of the Setchet farmstead but was not included in the original farm because it was politically unavailable (it had been allocated as village pasture). The inclusion of this mbuga area along with the exclusion of marginally productive shallow soils would have resulted in a better mix of soil types for Setchet and perhaps have permitted greater success.

A second comment is that the mix of vertisols and deep upland soils characteristic of most of the other farms seems to favour more consistent yields with less extreme variation. Presumeably the vertisols hold yields up in the dry years and the upland soils perform well in years of higher rainfall.

Several remarks about potential land use problems may also be deduced from the data. The significant acreage of sloping vertisols on Murjanda and Gidagamowd suggests that these two farms may be the most subject to deterioration through erosion (particularly gully erosion). Conservation measures to minimize this problem have already been started on Gidagamowd. They should likely be completed and extended to Murjanda next in order of priority. Gawal has a much high proportion of depressional vertisols than any other farm. It is therefore most strongly affected by

The need to be able to complete timely cultivation and seeding of these soils during the short periods during which conditions are favourable for these activities. This farm will have to learn to make the most efficient use of its power capability in order to achieve maximum timeliness of operation. management at Gawal should concentrate on establishing the most favourable methods of weed control and seedbed preparation on depressional vertisols.

In summary, the soil assemblage varies considerably from farm to farm with Setchet being the most anomolous. The various soil types all have different characteristics and capabilities but the most significant seperations are those of depressional and sloping vertisols versus deep or shallow upland soils. It would be advisable for both farm managers and wheat research personnel to retain an awareness of the differences in distribution, characteristics and capabilities of these major soil varieties when planning their production or research operations.

PART III - The Management - production techniques and problems on vertisolic soils.

The following discussion summarizes in very general non-technical terms, the sequence of activities followed by the Hanang Wheat Complex farms during a typical crop year. The discussion concentrates on how each operation is carried out on the vertisol soils and highlights any significant contrasts between operations on vertisols and those on upland soils. Problems specific to the vertisols are mentioned for each operation as are the solutions which have been found to be most effective for these problems. A list of machinery and implements currently used on each farm (Table 6) is provided to compliment the discussions of each operation.

PRESEEDING.

Preseeding operations are conducted primarily for weed control. Secondary considerations are seedbed preparation, enhancement of infiltration, and improvement of surface structure. Some seedbed preparation may take place im-mediately after harvest.(July and Aug. It is usually confined to the upland soils in order to control weeds in years in which there have been late rains. In dry years little post harvest tillage is done and it is rarely if ever applied to vertisols. Vertisols are generally not as weedy and the deep cracks which form each dry season permit rapid in filtration of the next seasons rain. The rough, cracked surface of the vertisols further discourages post harvest tillage as it is very hard on machinery.

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TABLE 6.

MACHINERY AND IMPLEMENTS CURRENTLY USED ON HANANG WHEAT COMPLEX FARMS.

MACHINERY	BASOTU	SETCHET	THE OTHERS MURJANDA, MULBADOW GAWAL, GIDAGAMOWD
TRACTORS			
VERSATILE 875 (280HP)	–	3	4
IHC 1486 (148HP	8	8	–
IHC 986 (98 HP)	–	–	12
IMPLEMENTS			
CHISEL PLOWS			
16 FT MORRIS	–	–	4
28 FT IHC 55	8	8	–
45 FT MORRIS	–	3	4
DISCALS IHC 300 16FT	10	10	3 DUPLEX(12FT&16FT)
TANDEM DISC HARROWS.			
12 FT IHC	1	–	–
16 FT IHC	–	1	–
24 FT IHC	–	–	1
ROME PLOW 35 FT	SHARED AMONG ALL FARMS WITH VERSATILES USED FOR INITIAL BREAKING ONLY		
TINE TOOTH HARROWS			
FLEXCOIL 60FT	1	1	1
FIELD SPRAYERS			
60 FT	–	4	4
100 FT RITEWAY	5	–	–
SWATHERS			
16 FT IHC 75	5	4	4
21 FT IHC 75			
SEED DRILLS IHC 620	10	10	10
COMBINES			
IHC 914	6	8	–
JOHN DEER 6601 40 FT	–	–	8
RODWEEDER (42 FT)	1	1	NONE

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Most seedbed preparation and weed control begins in late November or December after the arrival of the first rains. The onset of the rains is usually characterized by a series of heavy showers, interrupted by short dry periods. The vertisols require some rain to soften the surface, to close the wide cracks, and to initiate weed germination and growth. It is critical to begin cultivation for weed control on these soils after the weeds exceed 1in. height but before the early short dry periods are succeeded by heavy, continuous rain. If cultivation begins too soon the ground is to hard and dry. The result is breakage of equipment, particularly shanks, a rugged cloddy surface which forms a poor seedbed and poor weed control.

If cultivation is delayed too long, the heavy rains set in, some areas are covered by standing water, and most of the vertisols become too wet. Machinery compacts this wet soil, creates ruts and produces soil compaction. If heavy rains delay operations for long periods, the situation can become even more serious. Weeds can get very well established and can no longer be controlled by 1 or 2 operations. Several supplimentary operations are then required for weed control on the vertisols. Time and equipment resources may not allow for completion of all necessary operations with the result that crop growth is adversely affected by weed competition.

In summary, the vertisols require more critical timing that the upland soils in order to ensure good seedbed preparation and weed control. They can only be worked effectively during the short dry periods characteristic of the early rains. However they do offer

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some advantages over the upland soils. Most important of these is that effective weed control can be established with one or two passes if they are timed correctly. The upland soils require five (5) or more passes at 2 - 3 week intervals in order to keep control of the weeds. The upland soils are also considered to be more severely infested by weeds that the vertisols. This is primarily because one of the worst weeds, lovegrass, does not appear to favor vertisol soils.

Seeding.

Seeding takes place sometime from early Feb to mid March. The time is not fixed but depends upon the arrival of the first rains and the total accumulated rainfall. A practical rule of thumb is that seeding should begin once the soil is wet to 1 meter (A. Ngoma, personal communication, 1983) At present, all farms seed all soils using IHC 620 press drills and about 2 inch penetration. The average rate of seeding is 90 lb/acre and the recommended range is 80 - 100 lb/acre. To date, no fertilizer is applied to the vertisols at time of seeding. Some response to P may be expected from the upland soils but so far no production scale fertilization has been used.

There are definite differences in seeding techniques between the vertisols and the upland soils. The vertisols appear to be best suited to late seeding for several reasons. Seeding these soils too early can result in significant crop kill from water logging or from loss or burial of seed due to erosion. It is better to wait until the heavy rains are nearly over and the surface has begun to dry. The soils is then at its best in terms of trafficability and the dangers arising from flooding and erosion are past. In addition, since these soils hold and store water so effectively, they are able to supply the crop well into the dry season. It therefore makes sense to concentrate early seeding efforts on the lighter textured, upland soils which are less able to supply needed moisture during the dry season.

There is also a difference in the wheat varieties recommended for vertisols and for upland soils. The better yielding varieties (Trophy-Mbuni) have generally been sown on the vertisols.(A. Ngoma, personal communication, 1983) Ngoma states that the good moisture storage capacity and high natural fertility of the vertisols guarantees a good crop if seeding takes place after a minimum acceptable amount of rain has been recieved. If subsequent rains fail the vertisols have the capacity to carry the crop through to harvest while the upland soils do not.

In contrast to the vertisols, different seeding techniques are required for the upland soils. They are seeded earlier than the vertisols in order to take advantage of the early rainfall and to enable the crop to mature before the really dry weather in May and June. At the same time, there are several reasons not to seed too early. Crops can be severely set back by the early growth period droughts which occur during the early rains. Crops seeded too soon may have to be reseeded if subsequent heavy rains produce severe crusting as can happen on the upland soils. Also, effective weed control on the upland soils requires several passes thereby setting back the earliest date at which seeding is possible. These considerations lead to the recommendation (A. Ngoma, 1983 personal communication) that shorter period (90 days) varieties be used on the upland soils. These

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varieties can avoid serious moisture stress by maturing before it gets too dry in May and June.

Post Seeding.

The two main post seeding operations are surface cultivation using the harrow or rod weeder and chemical spraying to control weeds. The harrow and rod weeder are used if heavy rains following seeding have resulted in the formation of a surface crust which prevents seedling emergence. This problem is confined to the lighter textured upland soils where the crust needs to be broken up. The vertisols do not crust badly and even if they did it would be very difficult to work them immediately after seeding while they were still slippery and sticky.

Weed control techniques definitely are influenced by soil type. About 50% of spraying is done by air and 50% by ground. Ground spraying is cheaper but there is not sufficient time to get it all done at the proper stage with the ground equipment available. In addition the mbuga soils are often still wet and sticky at this time and prevent efficient use of ground machinery. Consequently air spraying is concentrated on the vertisols and ground spraying on the upland soils. Spraying is done at the three leaf stage so timing is determined by seeding date and subsequent rainfall pattern. The main chemical used is 2-D-4 at a rate of 1 pint per acre. Ground spraying utilizes 60 or 100 ft Riteway sprayers with .0082 nozzels.

Between seeding and harvest the major problems which can harm the crop are heavy rains, drought and hot windy weather. The heavy rains occur just after seeding. They harm crops sown on vertisols through flooding or waterlogging. The upland soils are harmed by surface crusting.

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Drought can affect the crop at any time but usually strikes right after seeding or at the end of the growing season. Drought affects crops sown on the upland soils for more severely than it does these on vertisols, which have superior moisture storage. The strong winds which begin with the dry season around May, can cause lodging and sometimes deposits dust which buries small plants. Both of these problems are more severe on the upland soils than or the vertisols.

Harvest.

Harvesting commences about 90-125 days after seeding when the crop has matured. The actual length if time to maturity is governed by the wheat variety and by moisture stress as controlled by rainfall pattern. In most years, harvest is expected to begin about the last week in May. The preferred method of harvesting all soils involves swathing followed by combining. Swathing is used to force the crop to maturity and to permit earlier combining. If left standing too long yields can be reduced by shattering or bird infestation. Thin crops may be harvested by straight combining. This is done because for these poor crops it doesn't pay to have two operations and in addition the thin swath is often difficult to pick up. Combining is done with pull type IHC 914's on the two older farms (Basotu, Setchet) and with John Deer 6601's on the other farms.

The vertisol soils present some special management problems at harvest. It is best to try to harvest the crop from the vertisols as soon as possible. If left too long, the cracks become wide and deep and cracking can actually knock plants down. Other problems include having the swath fall into the cracks, tires bursting from being wedged in cracks, and machinery breakdown

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due to rough terrain. Yield may also be reduced when some areas cannot be harvested due to severe erosion gullies which develop on some sloping vertisols.

The upland soils present few of the problems found on the vertisols. They retain good trafficability and except for Shunkase the bird problem and the need for efficient operation can be harvested at leisure.

Post Harvest.

After harvest, the wheat is transferred by truck to the farmsteads where it is bagged for transport to market. Bags average about 90 kilos and most are transported to Arusha by road for use by the National Milling Corporation. Stubble and trash are left on the fields to help control wind and water erosion but considerable removal may occur due to unauthorized grazing by Barbaig herds. Culling of the fields and bagging areas by the local inhabitants is also a frequent activity.

Evaluation.

Yield and Cost Inputs.

The yields in total bags and bags per acre (1 bag-approx 3.2 bushels) were given earlier for all the farms. (Table 3) Published yields range from a low of 0.9 bags/acre to a high of 9.7 bags per acre. The average yield for all farms falls in the range of 5 to 8 bags per acre depending mostly upon rainfall levels and timing and effectiveness of weed control. No systematic evaluation has yet been carried out to document any differences in yield by soil type. Opinions of managers can differ sharply on the performance of the vertisols versus the upland soils. At Basotu, the manager believes that yields are consistently higher on the verticols than on the upland soils (about 8 bags/acre vs 6 bags/acre)

(A. Mrone, 1983 personal communication). He attributes the higher yields to the moisture reserve of these soils and the good weed control he has been able to achieve. On other farms some of the poorest yields have been on the vertisol soils. These low yields can be attributed to several causes all related to timeliness of operation. For instance, Gidagamowd farm was forced to break late and seed into a rough, cloddy, dry seedbed in its first year of operation (1983) due to late arrival of machinery. This poor seed-bed preparation resulted directly in the poor yields obtained (1-2 bags/acre) Similarly, Gawal farm recieved poor yields from its vertisols in 1983 due to the development of a hard, massive, compact surface after seeding. Possibly seeding was done when the soil was still too wet and plastic. At Setchet, untimely weed control has allowed a severe weed problem (thornapple) to develop on several fields of vertisols. The yields in these fields are disappointingly low.(1-3 bags/acre).

Obviously then, the vertisol soils do not by their nature guarantee good yields. They present some severe management problems which must be overcome if desireable yields in the range of 8 bags/acre are to be obtained.

The costs of operating on vertisolic soils are generally similar to those applicable to the farms in general. (see Table 7) but certain differences are worthy of note. Costs can be less than on upland soils if cultivation and seeding operations are timely. However a small mistake or unforseen development can lead to great expense such as necessitated by reseeding or by a major weed control effort. Higher costs may be caused by a higher level of machinery damage if vertisols are worked at inappropriate times or by increased down time if vehicles become stuck while working wet soils.

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TABLE 7 MAJOR SOURCES OF COSTS AND INCOME HANANG WHEAT COMPLEX FARMS 1979-83 (ADAPTED FROM 1981 ANNUAL REPORT WHEAT RESEARCH PROGRAM)

ITEM	VALUE (MILLIONS TSh)	% VALUE	VALUE/ha (THOUSANDS TSh)
INCOME			
WHEAT SALES	25.67	63	2.4
BARLEY SALES	1.28	3	0.1
NAT. MILL CORP. REBATE	10.34	26	1.0
MISCELLANEOUS INCOME	1.53	4	0.1
INVENTORY CHANGE	1.72	4	0.2
TOTAL INCOME	40.5	100	3.8
EXPENSES			
FUEL, OIL, LUBRICANTS	4.97	15.6	0.5
BAGS, CROP TRANSPORT, HANDLING	10.80	33.8	1.0
MANPOWER COSTS (SALARIES, INSURANCE, BENEFITS)	2.79	8.8	0.26
MACHINERY (UPKEEP, REPAIR, RENTAL)	1.55	4.8	0.15
SEED, CHEMICALS, ETC	1.67	5.2	0.16
FINANCIAL CHARGES (INTEREST, AUDIT)	1.24	3.9	0.12
MISCELLANEOUS EXPENSES	0.81	2.6	0.08
DEFERRED EXPENSES (PROV YEARS)	0.95	3.0	0.09
TOTAL OPERATING EXPENSES	24.78	77.7	2.36
DEPRECIATION ON BUILDINGS	0.22	0.7	0.02
DEPRECIATION ON EQUIPMENT	4.56	14.3	0.43
INVESTMENT	2.34	7.3	0.22
TOTAL FIXED EXPENSES	7.12	22.3	0.68
TOTAL CURRENT AND FIXED EXPENSES	31.9	100%	3.04
NET INCOME	8.6	% PROFIT 21%	0.82

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In terms of initial clearing costs, the vertisols have so far been the cheapest soils as (within the present farm area) they contained no trees.

PROBLEMS AND PROSPECTS FOR IMPROVEMENT.

Of the possible problems forseen for the farm soils, the vertisols are likely to be most severely affected by erosion. Gully erosion on sloping Association B vertisols has already forced some fields on Setchet to be taken out of production. Subjective assessments suggest that the peculiar stunting of growth in a circular pattern known as Basotu Soil Problem (BSP) is more extensive on the vertisols than on the upland soils. This observation has yet to be validated by research but may indicate that the potential exists for either further deterioration or improvement of yields on these soils. Salinity has been identified a potential problem on the vertisols (Fenger, Hignett & Green, 1982) but to date has not been noticed to be extensive or spreading. Loss of organic matter and accompanying loss of fertility is just beginning to be studied at the farms. (L. Llowen Rudgers, 1983, personal communication). However it is likely that this problem will affect the upland soils sooner and to agreater degree than it will effect the vertisols. The vertisols have the highest levels of natural fertility and have distributed their organic matter and fertility throughout the thickness of the profile not just at the surface.

Improvement of yields and reduction of costs seen as major challenge on both the upland soils and the vertisols. Fertilization is not expected to provide any cost effective benefit on the vertisols for quite some time. Improved weed control via chemicals is also unlikely to produce economical improvements. It is thought that some benefits could be realized by adjusting field layouts and installing conservation measures such as grassed waterways and contoured strips. This would help to reduce erosion and control runoff thereby limiting flooding and improving infiltration and moisture conservation. Perhaps the best hope for significant improvements lies in more intensive and knowledgeable on the spot management. Timeliness of cultivation, weed control and seeding are the critical factors in realizing top yields. Careful management of every field, according to the most suitable approach for that soil type, will probably result in the most significant improvements which can be expected.

Subjective Assessment of Vertisols.

In general, the consenses among farm managers appears to be that the vertisols are now their best soils for high, dependable yields. If the farmers had sufficient power to achieve all the required operations during the short periods dictated by moisture conditions they would be happy to farm on vertisol soils exclusively. The approximate time required to complete each major operation on a farm of 10,000 acres using the currently available machinery complement is indicated in Table 8. The limitations imposed by current power capabilities presently prevent efficient use of exclusively vertisol soils.

In the absence of sufficient power capability it is thought that a mixture of vertisols and upland soils makes the best use of current equipment.

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Table 8: Time Required for Various operations to be completed on 10,000 acres with typical current machinery complement.

OPERATION	NUMBER	EQUIPMENT USED	WIDTH	DAYS TO COMPLETE
Cultivation	2	Versitile	43'	13
	3	IHC 1486	27'	
Seeding drill	3	IHC 1486	42'	13
discall	2	IHC 1486	20'	
Spraying	4	IHC 844	60'	11
Swathing	5	IHC 844	20'	21
Combining	6	IHC 914&1486		28

The different characteristics of vertisols and upland soils allow most equipment to be used over a longer time period and a broader range of conditions in any given crop year. The subjective evaluation of vertisols by the various farm managers is tabulated in Table 9.

Table 9 Subjective Rating of vertisols by Hanang Wheat Complex Farm Managers.

Farm Manager	Best Rated Soil	Preferred Situation
Setchet Basotu Mulbadow Murjanda Gawal Gidagamowd	Vertisols	Mixture of Vertisols & Up

It is interesting to contract the present subjective evaluation of the vertisol capabilities based on up to 10 years of farming experience with the earlier technical evaluations made by soils personel. The initial Canadian reconaissance report (Beamish 1968) strongly recommended against the used of depressional vertisols. It was noted that they were subject to extensive flooding and were too hard when dry and sticky when wet to be farmed successfully. Somewhat later, semidetailed soil maps were prepared for the areas occuppied by Basotu and Setchet farms (Peasant 1973, Stonehouse and Duff, 1975). In both these reports the vertisols (particularly those in depressions) were rated as having very poor agricultural capability (4 on a scale of 5). They were acknowledged to display high levels of natural fertility but reservations about poor drainage, flooding, high salt contents, adverse physical structure and consequent management difficulties convinced these authors to rate the soils as unsuitable. This rating was adjusted upwards by subsequent soil surveyors (Fenger, Hignett and Green, 1982) in light of the increased level of successful experience with these soils. The new rating is still only moderately suitable (2 on a scale of 4) and reservations are still expressed regarding management constraints induced by adverse soil consistence and structure and the succeptibility to flooding or to erosion (Fenger et al, 1982).

In the future, once proper management techniques have been confirmed to be effective and high, sustainable, yields have been documented the rating may be raised to highly suitable for mechanized wheat production. Continued experience and improvements appear likely to achieve this result.

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PART IV:

Summary and Conclusions:

This paper was constructed as an introduction to and overview of the Hanang area wheat farms participating in the Tanzania-Canada Wheat Project. The development and growth of the farms from 1967 to the present was charted in the introductory section. After initial difficulties, the farms now appear to have achieved a capability for sustained, profitable production. The project farms are now responsible for almost all of the domestically grown wheat available for distribution in Tanzania. In this respect the project is a successfull example of international cooperation in agricultural research andproduction.

Discussion of the soil characteristics and management techniques in place on the farms focused on the special properties and requirements of vertisols. These black, cracking clay soils make up just under 50% of the total area now in production. Neither Canada nor Tanzania could claim extensive experience with use of these soils for mechanized agriculture prior to the establishment of the farms. The experiences of 15 years of increasing use have revealed serious management problems and encouragingly high potential. The soils have a very narrow moisture range over which they have an acceptable workability. At other times they have adverse structure, either hard and blocky or sticky and muddy. Operations must therefore be carried out in a timely fashion under appropriate conditions. Power requirements for efficient cultivation and use of large areas of vertisols are high but can be met by present equipment. Despite the disadvantages and problems; high, sustainable yields have been obtained from these soils.

In view of the demonstrably different properties and potentials of the vertisols and the upland soils it is recommended that both research and production be designed to recognize these differences. To date, there has been limited recognition of the important differences between these main soil types. This has led to the blanket (and sometimes inappropriate) application of research findings and recommendations from one type of soil to all others. It has also led to the use of unsuitable production techniques on the vertisols in some cases. Understanding of the nature and production requirements of these soils has improved continuously. It is now necessary to circulate this knowledge and to promote planning of future research and production activities accordingly.

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