CHAPTER 4

SYNTHESIS OF THE RESULTS OF THE DISSERTATIONS AND THESES SUMMARIZED IN CHAPTER 3

4.1 INTRODUCTION

In this chapter data regarding all the important factors that play significant roles in the erodibility of soil that have been presented in the previous chapter are synthesized. It is important to note that in some cases the findings of the researcher(s) per soil property/factor may be related to published data from elsewhere.

4.2 PARENT MATERIAL

The results presented in the previous chapter by Sumner (1957, Section 3.5 and D'Huvetter 1985, Section 3.2) showed that soils derived from basic igneous rocks, especially dolerite, had higher stability against erosion as compared with the majority of other soils, mainly those from sedimentary rocks of the Beaufort and Ecca groups. As a result of high base content, soil that form from dolerite are dominated by smectite (2:1 swelling clays) except in the humid tropics and subtropical regions.

The Beaufort (i.e. shales and mudstone) and Ecca groups are associated with substantial amounts of magnesium, sodium and the clay mineral illite and as a result they produce soils with silt percentages. Furthermore they produce unstable duplex soils that are incredible erodable. It is well known that high Mg give rise to very poor structure resulting in very compact soils and high erodable soils. Generally it is accepted that soils derived from Beaufort and Ecca series are more subject to water erosion. It is important to note that Sumner (1957, Section 3.5) found that soils associated with Beaufort and Ecca group have a marked ability to swell, especially in the subsoils.

Soils derived from dolerite such as Shortlands, Hutton and Arcadia soil forms in the Mavuso pedosystem, Amatola basin and Middledrift were characterised by a significantly higher stability against erosion compared with the majority of other soils in these areas, D'Huyvetter (1985, Section, 3.3).

In Comparison of dolerite and granite as parent material, Smith (1990, Section 3.2), found that soils developed on dolerite have higher amounts of cations, free iron and aluminium, higher amounts of clay (higher amounts of clay forming minerals present) and also generally higher pH values (higher amounts of basic cations) as compared to soil developed on granite. It was found that soils that form from granite usually contain large amounts of course sand that originate from the quartz. Smith (1990, Section 3.2, Table 3.1) also found that granite soils are rich in potasium but very poor in calcium and magnesium. In granite soils, the weathering of the clay minerals progresses easily to the 1:1 phase.

4.3 CLIMATE

The combination of rainfall and temperature, especially, dominates soil formation. In general South Africa is a dry country. At least 65% of the country has a mean annual rainfall of less than 500 mm.

In all of the areas studied by Sumner (1957, Section 3.3) and D'Huyvetter (1985, Section 3.5) rainfall was found to be more than 500 mm per annum. In South Africa this can be regarded as good rainfall when one considers the other parts of the country. All areas studied by Sumner (1957) and D'huyvetter (1985) can be regarded as warm and humid regions. It is well known that warm and humid conditions promote weathering and therefore soils in the humid tropics and sub-tropics are in a very advanced stage of weathering.

Sumner (1957, Section 3.5) found that Northern Kwazulu Natal receives rainfall in the form of aggressive thunderstorms. The three main pedosystems of the former Ciskei, namely, Mavuso, Keiskammahoek and Middledrift also receive rainfall in the form of aggressive thunderstorms (D'Huyvetter, 1985) – reducing their efficiency and increasing their erosivity. As a result of low rainfall, poor quality soils develop. In areas where there was a combination of low rainfall and unfavourable parent material, shallow soils were found, E.g. Valsrivier, Vilafontes, Kroonstad and shallow Glenrosa in the Middledrift pedosystem were formed on colluvial mudstone.

Large differences between soils were observed over short distances in the higher Tabamhlophe as a result of sharp differences in climatic conditions (Turner, personal communication). Sumner (1957, Section, 3.5) found that soils developed in high rainfall areas in the higher Tabamhlope were stable against erosion when compared with those from low rainfall areas. This clearly indicates the role of climatic conditions on the stability of soils

4.4 SOIL FACTORS

4.4.1 Clay mineralogy

The erodibility of soils can largely be derived from their clay mineralogy. From the results presented by Levy (1988, Section 3.4), Stern (1990, Section 3.7) and Rapp (1998, Section 3.8) it is clear that clay mineral type is an important factor influencing the stability of soil aggregates and hence erodibility. Clay mineralogy also determines the fundamental physical and chemical properties of the soil surface and therefore has large effects on the degree of sealing and the nature of the seal (Stern, 1990).

The results presented by Levy (1988) and Smith (1990) showed that most of South African soils were dominated by either kaolinite or illite with smectite and interstratified material as the secondary minerals. Levy and van der Watt (1988) found that if soil is dominated by illite it could be expected to be susceptible to crust formation. Soil from Aliwal North was dominated by illite and, as expected, was prone to crusting (Stern, 1990).

Soils which contain pure kaolinite form stable aggregates, maintain high IR and have low erosion. Conversely, kaolinitic soils which contain small amounts of smectites are dispersive. The high erodibility of the Westleigh soil form in Thabazimbi is attributed to its kaolinitic clay mineralogy "contaminated" by smectite, low organic carbon content and very high soil salinity Rapp (1998, Section 3.6). Soils which do not contain smectite are more stable, less erodible, and are less susceptible to seal formation.

4.4.2 Texture

Sumner (1957) indicated that the amount of water absorbed by the soil is influenced by its mechanical composition and structure. In sand and other light textured soils, the coarseness of the particles is probably the most important factor contributing to rapid water absorption and permeability and decreased erodibility. In heavy soils, there is apparently no direct relationship between the clay content and the amount of erosion. Degree of aggregation and size and stability of the aggregate, therefore might have a pronounced effect upon rate of percolation and, consequently, upon amount of runoff. Bloem (1992, Section 3.8) showed that clay content is the soil parameter with the biggest effect on surface sealing of the soil.

D'Huyvetter (1985) found that fine sand content of the A horizon was statistically correlated with the degree of erosion. High fine sand levels partly explains the high degree of erodibility of the Kroonstad and Glenrosa soils of the Middledrift pedosystem. In all three main pedosystems of the Eastern Cape studied, namely, Mavuso, Keiskammahoek and Middledrift, topsoils with less than 20 per cent clay content were found to be highly erodable while those which had clay contents of more than 20 per cent were found to be less erodable.

Rapp (1998, Section 3.8) found that as clay content in soil increases, cohesion forces between soil particles increased as a direct effect, while at the same time the interparticle spacing increased (lower bulk density and higher saturated moisture content), leading to lower attraction between soil particles as an indirect effect. Also, indirectly with increased clay content, the hydraulic conductivity of the soils and the infiltration rates decreased, leading to high shear stress and transportability.

The results presented by Sumner (1957, Section 3.5) showed that clay content affected crusting. He indicated that crust formation could develop with any type of texture except sand with very low silt and clay. Although sandy soils may not develop crusts, they can exhibit low intakes after several irrigations due to surface sealing. The crusts formed in medium textured soils of South African and Israeli soils were found to be the most dense and maintained the lowest final infiltration value (Levy, 1988, Section 3.4).

4.4.3 Chemical factors

The results regarding the effect of exchangeable K and exchangeable Ca on the hydraulic properties of soil (i.e. hydraulic conductivity and infiltration rate) have been presented. Levy (1988, Section 3.4) found that K had different effects on the soils than did exchangeable Ca. Increasing the amount of K in the exchangeable phase resulted in a decrease in the HC as well as in the infiltration rate of the soil.

The study on the effects of exchangeable Mg on hydraulic properties of soils shows that exchangeable Mg is not as efficient as exchangeable Ca in maintaining HC under sodic conditions. However, from the IR experiments, it is evident that Mg treated soils are similar in their behaviour when exposed to rain. The presence of Mg in the exchangeable phase probably enhances clay dispersion in comparison to Ca and therefore the HC obtained with Mg treated soils was found to be lower (Levy, 1988).

The exchangeable sodium percentage (ESP) in soil was also studied. Normally an ESP of 15 is considered to be the threshold above which problems occur. In South Africa and Australia, sodium induced dispersion, crusting, and erosion start at much lower ESPs (in some soils low as 2 or 3 per cent). Magnesium is another problem cation, and high magnesium: calcium ratios (usually above 1.7:1) are often the cause of dispersion and enhanced erosion in many parts of SA and elsewhere in the world, such as Australia and Russia. Calcium is a flocculating cation thus counteracting dispersion, but it cannot stabilise aggregates against disintegration (Laker, 2000).

Rapp (1998, Section 3.6) found that the presence of exchangeable sodium in kaolinitic soils influences crust formation only when the soils contain some smectite. Furthemore, in soils with moderate to high ESP values, where clay mineralogy is "contaminated" with smectite, dispersive conditions prevail and the efficiency of clay particles as cementing agents between soil particles is very small.

A highly significant correlation exists between the exchangeable sodium percentage (ESP) of the soil and the degree of erosion. In general this correlation is stronger for the A horizon than for the B horizon. The highest ESP values were found in soils of the Valsrivier, Vilafontes, Westleigh, and Kroonstad forms of the Mavuso and Middledrift pedosystem, all of which have high erodibilities. Soils with low A and B horizon ESP values, such Oakleaf and Shortlands soils, in Middledrift were associated with weak to moderate degrees of erosion. The Glenrosa form, having low ESP values in both A and B horizon, yet showing severe erosion, was an exception. A relatively high ESP in the A horizon induces colloidal dispersion, resulting in the formation of dense surface crusts. Such crusts strongly reduce infiltration of water into the soil. The resulting increase in surface runoff is conducive to erosion (D'Huyvetter 1985, Section 3.3).

Soils showed different responses to ESP levels. Some soils were affected by exchangeable Na at low levels, others at moderate and high levels. It was found that FIR decreases with an increase in ESP, and it is important to note that some soils were hardly affected by sodicity up to an ESP level of 9 (Fig. 3.15).

4.4.4 Degree of weathering

The results presented by Smith (1990) showed that many soils have features which relate them to the parent rock from which they were formed. Some minerals like quartz, muscovite mica and some feldspars were found to be more resistant to weathering than other minerals.

Conditions in the soils play a significant role in determining the types of clay minerals that formed from weathered products. In soil conditions where the Si and basic cations are not removed by the leaching, 2:1 type clay minerals, such as smectites and micas, will dominate in the soil environment. Highly weathered soils in humid tropical and subtropical areas, where intensive weathering and leaching of bases and silica has occurred, are dominated by minerals that represent advanced stages of weathering, Examples of this are Clovelly and Griffin soils of Tabamhlope in KwaZulu Natal (Turner, personal communication, 2001).

It was found in the mineralogical data (Table 3.5), that soils from high rainfall areas contain mainly some of end-products of weathering and resistant clay-size mineral. The amounts of 2:1 minerals was found to decrease with an increase in rainfall in soil samples representing both acidic and basic parent material.

In general the results presented indicated that fine crystalline structured rocks (basic rocks) are much more resistant to weathering than coarse crystalline rocks (acidic rocks).

4.4.5 Types of soils

Different types of soils have been studied from different areas in South Africa. Soil forms and the stabilities of these soils against erosion differed from region to region. One should note that major part of South Africa is covered by very poor quality soils. Most of the country is dominated by shallow soils.

It was found that different soils have different slope-erosion relationships, different threshold slopes and they respond differently from treatment e.g. application of phosphogypsum (PG). Ultimately they vary in regard to their erodibility.

Soil losses varied markedly between the stable and unstable soils and were also affected substantially by slope gradient and PG amendment (Table 3.30). Stern (1990) found that low soil losses from the stable soils is associated with high infiltration rate and low runoff (Table 4.2).

Generally it has been found that red soils are much more stable against erosion than those of other colours, probably because the hydraulic properties of these red soils are better than that of non-red soils. Example of this is the very stable red soils of the Shortlands and Hutton forms that have studied as compared to other soils, such as the Sterkspruit, Valsrivier, Vilafontes and Estcourt forms. These soils occurred on footslopes and valley bottoms.

In most of the developing areas in South Africa, and especially in semi-arid and sub-humid regions, the lower landscape positions are dominated by very unstable duplex and pseudo-duplex soils which are extremely vulnerable to water erosion. Due to unfavourable textural properties of most of the deep soils on the river terraces these soils are also very vulnerable to erosion.

4.5 SLOPE

From the soil-slope-erosion data, D'Huyvetter (1985) attempted to derive models which could be used to predict threshold slopes, above which erosion would be a danger under normal cropping practices, for unknown sites where land use planning has to be done. The topographical factors which received attention were: slope length, slope gradient, slope form (convex, concave or plane) and slope feature above the point of study.

D'Huyvetter (1985) found out that for a few soil forms the length of the slope above the point of observation, especially very long slopes, resulted in increased erosion as a result of increased surface runoff.

The soil-slope-erosion relationships depicted in Figures 3.3 to 3.14 revealed clear differences between different soils in regard to inherent erodibility. D'Huyvetter (1985, Section, 3.3) and Stern (1990, Section 3.7) showed that slope percentages have the greatest influence on the degree of erosion.

The threshold slope criterion of 12 per cent used in the past was far too steep for the vast majority of soils in the Mavuso, Keikammahoek and Middledrift pedosystem. The criteria were found to be more-or-less valid for only the small areas of Hutton and Shortlands soils.

The relationhip between slope gradient, IR and soil loss in soils which are susceptible to crusting depends on the properties of the seal (Stern, 1990). Increase in slope gradient from 5 to 30% resulted in soil losses increasing by 520 and 570% for the untreated Msinga (D) and Jozini soils respectively (Stern, 1990, Section 3.7). The rapid increase in soil loss from the untreated Jozini soil with increasing slope gradient started from the flattest slope, with a higher increase rate between 20 and 30%. Stern (1990) found that treatment with phosphogypsum (PG) reduced soil loss.

4.6 THE IMPORTANCE OF PLANNING

Planning involves anticipation of the need for change as well as reactions to it. Its objectives are set by social or political imperatives and must take account of the existing situation. In many places, the existing situation cannot continue because the land itself is being degraded (FAO., Guidelines for Land Use-Planning, 1993).

Environmental and/or social disasters caused by incorrect land use planning in the former homelands are numerous. D'Huyvetter (1988) gave an example of poor planning, which lead to disastrous erosion, as a result of lack of understanding of the resource base.

In the former Ciskei, large parts of the arable areas which were "scientifically" selected and planned since the mid-1950's have suffered devastating erosion, despite good countouring and other measures. This has been the result of lack of basic soil chemical and soil physical knowledge (Laker, 1990).

In the Mavuso, Keiskammahoek and Middledrift pedosystems, for example, a slope of 12% was used as the cut-off point above which soils were deemed to be non-erodable due to erosion hazard, irrespective of the inherent stability and erodibility of the specific soil. It was found that even at low slope gradients many soils suffered serious erosion. This clearly indicates that generalized criteria cannot be used in a situation where there are different types of soils (D'Huyvetter, 1985, Section 3.3).

A large fraction of the areas in the former Ciskei covered by the Glenrosa, Mispah, Sterkspruit, Valsrivier, Swartland, Vilafontes and Westleigh soils should never have been cultivated. The land use planner did not have the necessary data regarding the different degrees of stability and appropriate critical slope criteria for the different soils, and as a result this led to the severe erosion (D'Huyvetter, 1985).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The major part of South Africa is dominated by very poor quality soils. These soils are inherently unstable and extremely vulnerable to erosion. Most of the country is, in fact, dominated by shallow soils. This is caused by low and inefficient rainfall, which limits soil formation, and the hard geology (Laker, 1990). Runoff, besides depriving crops of essential moisture supplies, is also the cause of soil erosion. South Africa, with its poorly distributed, relatively unreliable rainfall and frequently shallow soils can ill afford moisture and top soil losses resulting from often avoidable runoff. One should note that soil erodibility varies seasonally and the magnitude of seasonal variation varies with soil texture.

It is well known that soils formed on basic parent material have higher amounts of clay, iron, aluminium and basic ions when compared to acidic parent material. This is the result of the higher amounts of primary minerals in basic rocks than in their acidic counterparts (Smith, 1990).

The data presented in the previous Chapters have conclusively shown that Beaufort and Ecca soils are highly erodible and their subsoils are extremely impermeable to water and are almost structureless. The erodibility of the Beaufort and Ecca soils is due, firstly, to the low infiltration capacity which gives rise to a large amount of runoff. Secondly, the instability of aggregation and the dispersibility of these soils are additional factors contributing to erodibility (Sumner, 1957). The actions of raindrops are additional factors contributing to erodibility. When comparing the Ecca and Beaufort soil with dolerite soils on the basis of infitration alone, it has been found that the Beaufort and Ecca soils are more erodible than the doleritic soils. The impermeability of the Ecca and Beaufort soils is due primarily to the compact nature of the subsoil and the highly dispersed nature of the colloidal complex. The relatively low infiltration capacities recorded for the Beaufort and Ecca topsoils which have a reasonably good structure and are not readily dispersible, can only be explained on the basis of crust formation.

The doleritic soils in all areas studied were found to be stable due to a good water stable structure, low dispersibility and high infiltration capacity. Such properties are conducive to low runoff and consequently very little erosion results. It was also found that soils like Shortlands and Hutton forms, both derived from dolerite, are characterised by a significantly higher stability against erosion compared with the majority of other soils, mainly formed on mudstone.

Vast differences in erodibility have been found between different soil forms, resulting in vastly different threshold criteria (D'Huyvetter, 1985).

The clay mineralogy affects the swelling and shrinkage potential of a soil, which in turn affects soil structure.The mineralogical composition of the clay in the soil accounts for the differences in seal formation, infiltration rate and soil loss rates of soils. In most areas where studies have been carried out, it was found that the kaolinitic and illitic soils have a greater resistance to the impact of raindrops than smectitic soils and the surface conditions of these soils maintain higher infiltration rates, which in turn increase the amount of water taken up by during rain. Furthermore, in a soil in which kaolinite is virtually the only clay mineral, crust formation is not affected by the presence of exchangeable sodium up to an ESP of 10. The presence of exchangeable sodium in kaolinitic soils influences crust formation only when the soil contains some smectite.

In a comparative study of South African and Israeli soils it was found that crusts formed in South Africa soils were less dense and more permeable than those formed in Israeli soils. The differences are ascribed to differences in clay mineralogy between the two groups of soils (Levy, 1988).

From the results presented by Rapp (1998) it is evident that rill erodibility decreases with an increase in clay and organic carbon content, conversely rill erodibility increases with an increase in total electrolyte concentration and increases with an increase in soil exchangeable sodium percentage. The effect of organic carbon content on rill erodibility was found to be high in kaolinitic soils, low in smectite soils and intermediate in the soils dominated by illite. It was also found that high rill erodibility values are associated with soils with interstratified illite/smectite mineralogy and coarse soils with kaolinitic mineralogy. The relative order of rill erodibility of soils composed of different clay mineralogy depends mostly on the organic content of the soil and its exchangeable sodium percentage.

5.2 RECOMMENDATIONS

In considering possibilities for the utilization of land, a prediction should be made on how a certain land use or technology is going to affect the land, before any damage is done. The range of technical approaches must be broad, and specific techniques matched carefully with environment- both physical and socio-economic.

Every piece of land should be used optimally i.e. to the best advantage of the people, without causing soil erosion. Erosion can be horrific on steep slopes when land is cleared

Cultivation should be avoided in any area where Beaufort soils (shales and mudstone), Ecca soils and unstable duplex soils are dominant. The main reason for this is that ploughing leads to exposure of subsoils, which is highly undesirable. In a situation where there are animals in the field, good pasture management is needed on these soils. There should be no overgrazing nor overstocking as these practices lead to erosion. A judicious system of veld burning should also be introduced. It is imperative to maintain maximum vegetal cover at all times in area(s) where the soils mentioned above are prominant.

Soil analysis should be undertaken prior to the establishment or rehabilitation of any irrigation project, or for that matter for cultivation of any suitable land.

A single slope criterion cannot be used for all soils, simply because the differences between different types of soil are too great. Appropriate threshold slope criteria should be identified for the different soils in an area, or according to soil properties determining the erodibility of the soils (D'Huyvetter, 1985).

People involved in the planning of farming areas, residential areas, etc. should have adequate knowledge of how to correctly evaluate the qualities of the resources. One would not want a situation whereby people use generalized norms, in view of the vast variation in resources, as this would simply aggravate the situation.

Mapping and classification of eroded areas must be regarded as a priority research area, since regular updating of erosion maps can give a clear indication of the rate of soil erosion and the efficiency of soil conservation measures. Remote sensing and GIS can be employed and play a vital role in identifying and monitoring soil erosion at various levels of management.

Efforts should be made to prevent recurrence of the mistakes of the past. This may be achieved by involving a multi-disciplinary task team in a project.