GENOTYPE AND NITROGEN FERTILIZER INFLUENCE ON GRAIN YIELD AND PROTEIN CONTENT OF WHEAT *(Triticum aestivum L.)*

By

GERARD LEKULA MAKHALE

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DECLARATION

I, GERARD LEKULA MAKHALE, do hereby declare that this dissertation represents my own work and that, to the best of my knowledge, it has not been previously submitted for the award of a degree at this or any other University.

Signed..........................

Date...19\03\2001.......

APPROVAL

his dissertation of GERARD LEKULA MAKHALE is approved as fulfilling part of the equirements for the award of the degree of Masters of Science in Agronomy by the University of :ambia.

:xaminer	Signature	Date
Prof Obed I. Lungu		18.04.2001
Dr. D. N. Mbewe		18/04/01
Dr. O. A. Yerokun		18/04/01

ABSTRACT

The grain yield of wheat grown in Lesotho is low because of poor soil fertility, and the wheat is regarded by the millers to be of poor quality and therefore of less value. A field study was therefore conducted at three sites in Lesotho (Maseru, Leribe and Mafeteng) to evaluate the influence of genotype and nitrogen application on grain yield and quality of wheat (*Triticum aestivum* L.). The varieties assessed were Tugela DN, Betta DN, SST 124 and Caledon at a seeding rate of 50 kg ha^{-1}. Nitrogen was applied at five rates of 0, 20, 40, 60 and 80 kg N ha^{-1}. The experiment was arranged in a split-plot design, with varieties as the main- plot factor and nitrogen rates as the sub-plot factor. The treatment combinations were replicated three times. Grain yield and yield parameters (thousand-kernel weight, grain number per head, number of heads per square meter and harvest index) were measured. Quality parameters were protein content percent and Mixograph development time. Grain yield significantly ($P \leq 0.05$) increased with N application at Leribe averaging 3000 kg ha^{-1}. Number of heads per square meter was also significantly ($P \leq 0.05$) increased while thousand kernel weight was significantly ($P \leq 0.05$) decreased at rates of N application higher than 40 kg N ha^{-1}. At Maseru and Mafeteng, applied N had no effect on grain yield. In fact grain yield decreased with application of N over 20kg N ha^{-1} at Mafeteng. The number of heads per square meter also significantly ($P \leq 0.05$) decreased, suggesting poor emergence or tillering. At Maseru the thousand Kernel weight was significantly ($P \leq 0.05$) decreased with increasing nitrogen application. Across the three sites grain yield increased significantly ($P \leq 0.05$) when N was applied over 20kg N ha^{-1}. The number of heads per square meter also significantly ($P \leq 0.05$) decreased at higher rates of N application. Applied N fertilizer significantly ($P \leq 0.05$) increased grain protein content. However, the protein contents of wheat at Maseru and Mafeteng were higher, averaging 11 % and 15 % respectively. This observation is probably due to a concentration effect of protein content due to small grain size. Mixograph development times were within the acceptable range of 2.5 – 4.0 minutes for wheat from all the three sites. The four varieties did not significantly differ in grain yield or quality at all the three locations. However, they significantly differed in mixograph development times, with Tugela DN giving the highest value averaging 4.0 minutes, and the lowest being Caledon at 2.5 minutes. This study has shown that wheat yields and quality in Lesotho can be improved by applying adequate amounts of N and correct choice of variety. This experiment needs to be repeated before recommendations of N fertiliser rates and management strategies under dryland conditions can be made to farmers in Lesotho

DEDICATION

To my dear 'Matapo Amelia Makhale and my four sisters, Tapo, 'Mammuru, Pulane and Popi, for their untiring help and support throughout my two years study program away from home.

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ABBREVIATIONS AND ACRONYMS

ANOVA – Analysis of Variance

CIMMYT – International Maize and Wheat Improvement Centre

DN – Diuraphis Noxia

GNH – Grain Number per Head

GPC - Grain Protein Content

MDT – Mixograph Development Time

NHSM – Number of Heads per Square Meter

TKW – Thousand Kernel Weight

CHAPTER 1

INTRODUCTION

1.1 The Importance of Wheat

Wheat (*Triticum aestivum L.*) is the most widely cultivated cereal crop in the world, and in terms of world production it ranks first followed by rice and maize (Leonard and Martin, 1963). They show that it is mostly grown in the temperate zones between 30° and 60°N and 26° and 40°S. The major producing countries of the world are the Ukraine, the Russian Federation, the United States of America, China, India, France and Canada (Martin *et al,* 1975). World wheat statistics show that there are about 214 million hectares under wheat production, averaging a total of 541 million metric tons, or average yields of 2.5 metric tons per hectare (CIMMYT, 1996).

In Lesotho, which is 30°S and 28°E, wheat was first grown in 1833 when missionaries first arrived in the country (Mokitimi; cited by Namane, 1992). The cultivation of wheat in Lesotho coincided with the development of a very good market in the latter part of the 19^{th} century when South African mines were opened. This development saw a rapid increase in the hectarage under wheat, quickly making wheat the second most important crop after maize. The major advantage of wheat is the high calorie and protein content in the grain which are the most important factors in human nutrition, in flour quality for bread, and in animal feeds (Leonard and Martin, 1963; Terman, 1978; Hanson *et al,* 1982).

Currently, wheat is the most important winter crop in Lesotho. It is a staple food in the mountain areas of Lesotho where other cereals such as maize and sorghum are less adapted to the lower temperatures, and commercially in the lowlands to supply flour mills. The area of Lesotho under wheat is 33,349 hectares, giving a national total production of 16,675 metric tons, that is, an average yield of 0.50 tons per hectare (Lesotho Agricultural situation Report, 1983/1984 – 1994/1995). According to the Bureau of Statistics of the Ministry of Planning in Lesotho, a subsistence farmer must produce at least 500 kg ha^{-1} to pay for production costs, whereas a commercial farmer must produce 2,000 kg ha^{-1} to break-even.

1.2 Constraints to Production

Low yields are a major constraint to wheat production in Lesotho. The average yield of 0.5 tons per hectare is lower than the 3.5 ton per hectare reported in neighbouring South Africa (Small Grain Institute, 1997). One contributing factor to low yields in Lesotho is the long cropping history of low manure and fertiliser inputs coupled with the low nutrient status of the soils, which can no longer support most crops (Soil Surveys of Lesotho Report, 1976).

The amount of nitrogen applied to wheat in Lesotho is 0 to 5 kg ha^{-1} by a subsistence farmer and 15 to 20 kg ha^{-1} by a commercial farmer. However, according to the Small Grain Institute, the optimal rate of 30 kg ha^{-1} of nitrogen should be applied in order to achieve 2,000 kg ha^{-1} of yield. Nitrogen is the most limiting nutrient for cereal grain production in the majority of soils throughout the world (Olson *et al*, 1975). Hence its importance cannot be over-emphasised in both increasing yield and protein content of wheat.

The low quality of wheat is another constraint to production in Lesotho. This is the main reason for the decline in production of commercial wheat from the lowlands. The hectarage planted with wheat in these areas is devoted to varieties which are graded by millers as class B on account of their low protein content. In Lesotho the problem is exacerbated by the low application rates of nitrogen fertilisers, which limits yields and protein content. The small amount of fertiliser used is attributed to poor pricing and low incentives to the growers.

1.3 Strategies to Improving Yields and Quality

To obtain both high yields and quality of wheat involves the selection of high yielding, disease and pest resistant varieties, the use of recommended amounts of fertilisers and optimising other production factors. Several reports, especially in the United States and Canada, have documented varietal differences in grain yield and protein content of wheat. The studies were conducted on hard red, soft-red and other wheat genotypes, and significant varietal differences were measured in both grain yield and protein content (Baker, 1969; Terman, 1978).

Nitrogen fertilisers can be used to substantially improve protein content in some cereals when soil nitrogen levels are increased above that required for maximum grain yield (Pierre *et al*, 1977). Thus, fertiliser nitrogen is positively correlated with grain yield and protein content. The possibility of increasing grain yield and protein content through the use of improved varieties of wheat and the application of nitrogen fertiliser can be an important intervention for improving the nutritional status of the Basotho living in the mountain areas, who solely depend on wheat as a source of carbohydrate and protein. Success with this technology can also raise the status of the farmers who depend entirely on wheat production as a source of income.

The research that is conducted in Lesotho is basically adaptive, that is, varieties are mainly evaluated for high yields and adaptability to different environments within the country. No attempt has been made to correlate yields with quality. To make up for this gap in data, therefore, this study was conducted to investigate the influence of nitrogen fertiliser and genotype of winter wheat on grain yield and protein content under three different environmental conditions in Lesotho. The objectives of the study were firstly to investigate whether there are significant differences in yield potential, protein content and the quality of local Lesotho wheat varieties. The second objective was to evaluate the influence of nitrogen fertiliser on grain yield, protein content and quality of local Lesotho varieties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and History of Wheat

No accurate record is available of the exact date and place of origin of wheat (Wilson, 1955; Poehlman and Borkhakur, 1959; Martin *et al*, 1975; CIMMYT, 1996). Shellenberger (1969) reported that in spite of extensive research, it is still not known exactly where wheat was first cultivated. What is known, however, is that it was cultivated in the Middle East as early as 15,000 to 10,000 BC and in other parts of the world it was grown around 550 BC (Leonard and Martin, 1963; Quisenberry and Reitz, 1967). The distribution of wild wheats which are believed to be the progenies of cultivated wheat supports the view that wheat originated in the Middle East (Poehlman and Borthakur, 1959).

According to Leonard and Martin (1963) and CIMMYT (1996), most of the cultivated wheats originated in the Middle East where domestication of wild varieties was first attempted. The introduction of wheat into Western Europe occurred approximately 3,000 BC and into the United States, along the Atlantic Coast early in the 17^{th} Century. From here its cultivation spread westward as the country was settled (Martin *et al*, 1975). The bread wheats, the ancestors of those grown today, are believed to have come to Europe from Southern Russia approximately 2,000 BC (Shellenberger, 1969).

2.2 Botanical Description

Wheat is a winter-annual crop which belongs to the family *graminaea* and the genus *Triticum.* There are about 18 species classified into three distinct groups: diploid (7 chromosomes), tetraploid (14 chromosomes) and hexaploid (21 chromosomes) (Wilson, 1955; Leonard and Martin, 1963). Cultivated wheat belongs to the hexaploid group (Poehlman and Borthakur, 1959).

Wheat is a self pollinating crop, but natural cross pollination does occur in one to four percent of the flowers (Martin *et al,* 1975). Flowering normally starts several days after the wheat spike emerges, and it is completed two to three days after the first anthers appear (Poehlman and Borthakur, 1959; Martin *et al,* 1975). According to Poehlman and Borthakur (1959), the main culm flowers bloom first and those on tillers later according to order of their formation.

Wheat normally produces two to three tillers when densely sown, but where the plants are sparse and the soil is fertile individual plants may produce as many as thirty to a hundred tillers (Martin *et al*, 1975). The average spike of common wheat contains fifty to seventy-five grains (Poehlman and Borthakur, 1959; Martin *et al,* 1975). The grains are usually three to ten millimetres long and three to five millimetres in diameter. The shape of individual grains depends on the crowding within a spikelet. The spikelet at the base and tip of the spike usually contains smaller grains. The second set of grains from the base are usually the largest. Half a kilogram of wheat may contain about 8,000 to 24,000 grains of wheat depending on the size and weight of the individual grain (Martin *et al,* 1975).

Physiological maturity in wheat, just as in other small cereals, is indicated by the thumb nail dent in the grain remaining visible for sometime (Martin *et al,* 1975). In larger cereals, such as maize, the hard dough stage and black layer are indicators of maturity.

2.3 Adaptation to Environment

Being a cold-season crop, wheat is grown mostly in the temperate regions of the world where the annual rainfall averages between 254 mm and 1,777 mm. High rainfall preceded by high temperatures is not favourable for wheat as this combination of conditions favours development of wheat diseases (Martin *et al*, 1975). Wheat can, however, be grown in many climates and at various latitudes and altitudes. This is borne out by the fact that cold-hardened winter wheat has been known to survive at temperatures as low as – 40°C while spring wheat cannot survive temperatures below 9.5°C especially in the early stages of growth (Leonard and Martin, 1963; Shellenberger, 1969). It is for this reason that Wilson (1955) described wheat as being capable of adapting to a range of climates.

Wheat has a longer growing period, and it can better withstand lower temperatures than most other small grains. In frost-free regions where temperatures are favourable, wheat can be grown during a season of less than 100 days, and early maturing varieties can be grown in even less than 90 days (Leonard and Martin 1963; Martin *et al,* 1975).

According to Leonard and Stamp (1963), Martin *et al,* (1975) the best soils for wheat are fertile, medium and heavy soils that are well drained such as Silt and Clay Loam which give high yields. Wheat can also be grown successfully on either Clay soils or fine Sand

Loam, although sandy or poorly drained soils produce poor yields. Where soils are very fertile and high in organic matter content, wheat tends to grow very tall resulting in lodging.

2.4 Classification of Wheat Grain

Wheat grain is classified on the basis of texture and colour. The main objective of classifying wheat is to reflect the use of wheat grains for different purposes (Poehlman and Borthakur, 1959). The red and white hard-textured wheats of *T. aestivum* are mainly used for bread because in general these wheats tend to have high protein content and a strong gluten which produces a larger loaf volume when baked. The red and white soft-textured wheat of *T. aestivum* and *T. compactum* are mainly used for pastry products and only to a lesser extent for bread-making (Poehlman and Borthakur, 1959; Martin *et al,* 1975). The soft wheats tend to have lower protein content and weaker gluten than hard wheats, (Poehlman and Borthakur, 1959). These characteristics may be modified by climate during the growth of the crop.

Durums are other types that are hard to vitreous in texture. They are mainly used in the production of macaroni products. In Lesotho all wheat varieties grown are milled to produce flour for bread and other bread related products.

2.5 Chemical Composition of Wheat

According to Martin *et al,* (1975) the composition of wheat varies with geographical region and agronomic practice. The average chemical composition of wheat grain at physiological maturity is 68% carbohydrate, 13% crude protein, 13% water, 2% crude fibre, 2% fat and 2%ash.

2.6 Effect of Nitrogen on Grain Yield

Nitrogen has a marked influence on grain yield of crops. The response of wheat to N fertiliser depends, among other factors, on the stage of plant growth, the method of application and the amount applied (Martin *et al*, 1975; Small Grain Institute, 1997). High rates of N fertiliser application during seeding adversely affect germination and therefore, the plant population (Small Grain Institute, 1997). Mengel and Kirby, (1987) reported that excessive N fertiliser during late vegetative growth limits yield because it promotes lodging as a result of the development of weak culms. Martin and Leonard (1975) observed that high rates of nitrogen often reduce wheat yield, not only by increasing plant lodging, but also by delaying the maturity of the crop, and so subjecting the crop to greater damage from rust diseases. Semi-dwarf wheats, which have strong culms can take up more nitrogen without lodging and so they give higher yields.

Researchers from the International Maize and Wheat Improvement Center (CIMMYT) who conducted experiments in the irrigated and rainfed areas of Pakistan in 1984 showed that adequate application of N is critical for high yields. Yield reductions of 51 to 73% were recorded with low N application (0 to 10 kg ha^{-1}). This result clearly demonstrated that wheat yields can be substantially reduced if inadequate amounts of N fertiliser are applied. The Small Grain Institute (1997) recommends 15 kg ha^{-1} of N fertiliser be drilled with the seed under rainfed conditions. Any application above this rate should be applied shortly before planting, or banded beside the seed during planting. De Geus (1973) recommends that where irrigation is not possible 15-20 kg N ha^{-1} should be applied at sowing.

Trials conducted at Rothamsted Experimental Station in the United Kingdom between 1987 and 1990 by Glendining *et al,* (1996) gave a maximum grain yield of 7.60 t ha^{-1} with application of 192 kg N ha^{-1}. In Canada a maximum grain yield of 3.9 t ha^{-1} was obtained with 160 kg N ha^{-1} (Gehl *et al,* 1990). In the United States, Terman (1978) reported an increase in grain yield with applied N fertiliser up to 100 kg ha^{-1}, but with 200 kg ha^{-1} there was a decrease in yield. In India the highest yields were achieved with 80 kg N ha^{-1}. Increase in grain yield with more than 80 kg N ha^{-1} was reportedly marginal (Singh *et al,* 1978). The small response to N fertiliser with applications above the 80 kg ha^{-1} has been attributed to water stress (Singh, 1960; Singh *et al,* 1978).

The response of winter wheat to N application and previous legume crop on soil was reported by Zebarth and Sheard (1991). They found that there was a significant incremental yield of (930 kg ha^{-1}) and protein content (2%) during the two years of the experiment. Dyke (1973) showed that a green legume increased yields of barley as well as the protein content. On the other hand, Spratt (1966) and Lopez-Bellido *et al,* (1996) reported greater yields of wheat in the year following a summer-fallow because there was more N than where no legume crop was included in the rotation.

Studies conducted by Duberts (1972) at two locations in Southern Alberta, Canada using two varieties of wheat showed significant differences in both grain yield and protein content when the crop received higher and varying rates of N fertiliser. Similarly, at two other locations in Saskatchewan in Canada, results varied with different cultivars grown under similar management practices (Lafond, 1991). In Manitoba, Gehl *et al,* (1990) reported that the quantity of N fertiliser required to give high yield varied with wheat cultivars, location and season. Furthermore, they observed that the amount and distribution of soil moisture was the predominant factor influencing the response of specific cultivars to N fertiliser. It was reported that semi-dwarf cultivars responded more positively to higher rates of N fertiliser than tall cultivars. This observation was attributed to the former's superior resistance to lodging under normal environmental conditions.

Dubetz and Bole (1973) and Davidson and Campbell (1984) reported that the relative efficiency of N fertiliser in increasing wheat yield is largely dependent upon the availability of adequate soil moisture during the growing season. In addition, they reported that when moisture is limiting excessive nitrogen application reduced grain yields because the resulting large vegetative growth leads to a depletion of soil moisture reserves before the flowering and grain-filling stages occur.

2.7 Effects of Nitrogen on Protein content

Nitrogen is the most important quality determinant of bread wheat (Terman, 1978; Hanson *et al*, 1982). In spite of advances in breeding to produce high quality bread wheat, several studies have shown that N still plays a major role in determining the quality of the wheat crop. Nitrogen fertiliser experiments carried out in India under rainfed conditions by Gandhi and Nathawat (1968) showed that the protein content in wheat increased with nitrogen increase in rate. Gluten is the most important component of protein in wheat grain. It is this component which makes wheat superior to other cereals for the production of leavened bread because it makes it possible to produce a dough which retains carbon dioxide produced by yeast, or chemical leavening agents (Leonard and Martin, 1963). Stark and Tindall (1992), working with four varieties of hard-red spring wheat in Idaho, USA reported an average increase of 1.0% and 2.0% in grain protein content with application of 30 kg N ha^{-1} and 60 kg N ha^{-1} respectively over the control treatment.

Other studies where N fertiliser was applied early in the growing season showed that grain yield and protein content are inversely related (Langer and Liew, 1973; Whitfield *et al,* 1989). Nitrogen uptake decreases rapidly prior to grain development, and N used in protein synthesis comes principally from the remobilization of vegetative N (Smith *et al,* 1989). A decrease in leaf N content reduces the photosynthetic efficiency, which in turn may reduce yield (Campbell and Davidson, 1979; Evans, 1983). According to Morris and Paulsen (1985), late season N application reduced the remobilization of vegetative N. It was also observed that high levels of available soil N during grain development increased N uptake relative to carbohydrate accumulation in the grain, resulting in high grain protein. Partridge and Shaykewich (1972) reported very low protein content in Neepawa spring wheat at low rates of nitrogen application but measured high contents at high N application rates.

Protein content of wheat grain is not only regulated by primary N uptake but also by the remobilization and translocation to the grain of N previously taken up and incorporated in vegetative tissues during the vegetative stage of growth (Oscarson *et al,* 1969). Sender and Peterson (1968) reported declining wheat protein content in cultivars from Nebraska USA, more especially in soils with inadequate soil N and low N fertiliser application.

2.8 Effects of Genotype of Grain Yield

Grain yield of cereals is dependent on several factors including the variety of crop. Genotypic differences of wheat have been reported to affect yield and yield components (Costa and Kronstad, 1993). They reported significant differences in grain yield and yield components among the varieties.

Wheat yields, like those of any other crop, vary with the variety used. Gehl *et al*, (1980) reported that grain yield was affected by genotype quite independently from location and rate at which N fertiliser was applied. The three Canadian cultivars, Glenlea, Katepwa and HV320 used in the study produced comparatively higher grain yields than three American cultivars, Len, Marshal and Solar. Similarly, Fowler *et al,* (1990), reported significant differences in grain yield among two varieties of wheat and rye.

2.9 Effects of Genotype on Protein Content of Wheat Grain

Pushman and Bingham (1976) evaluated several cutivars of wheat with reference to grain yield and protein content, and they showed an inverse yield/protein relationship among cultivars, especially when soil moisture is limited and when high N rates are applied. Also identified were inherent differences in protein content of different cultivars at low rates of N fertiliser application which was in contrast to the findings of Terman (1978). He reported that grain yield increased consistently with application of N up to 80 kg ha^{-1} above which yields decreased. Cultivars showed no significant variation in protein content. Rao *et al,* (1992) showed that protein content of several soft white winter wheat cultivars varied with season at most locations, with mean protein contents ranging from

6.2% to 13.4%. Grain from dry areas tended to have high protein content. The variation that was observed at different locations was attributed to differences in climatic parameters, nitrogen management, residual soil N and available soil moisture during the grain-filling period.

CHAPTER 3

MATERIALS AND METHODS

3.1 Soil Analysis

Field studies were conducted at three locations in Lesotho during the Winter of 1997. The experiment was on the Sofonia Light Sandy Clay Loam (*Fluventic Hapludolls*) at Maseru, Leribe Loam (*Typic Hapludolls*) at Leribe and Patsa Fine Sandy Loam (*Typic Natraqualfs*) commonly known as claypan soils of Maseru at Mafeteng. In 1996 the fields were cropped with oats (*Avena sativa*) in Maseru, winter wheat in Leribe and peas (*Pisum sativum*) in Mafeteng.

Three months before planting (March, 1997), 10 random soil samples at each of three sites were taken from two depths of 0 – 25cm and 25 – 50cm in each main plot using a soil auger. The soil cores were thoroughly mixed before a composite sub-sample was obtained for determination of available N. The NO_3 -N, NH^+_4 -N were determined colorimetrically on the **Tecator Fiastar 5010 Autoanalyser**. The extraction was made with 2M KCl solution from a 10.0g sample of soil. A 10.0g soil sample was weighed into a 250ml conical flask and 100ml 2M KCl solution was added. The flask was shaken for 30 minutes. The suspension was filtered through Whatman No.42 filter paper and the filtrate collected in a beaker. The clear filtrate was analysed within 24 hours of extraction.

Available P was determined using the Bray No.1 method. A 3.0g soil sample was weighed into a glass tube and 20.0ml of acid-flouride extractant was added. The tube was shaken for 1 minute, the suspension filtered through Whatman No.42 filter paper into a plastic bottle. A 1ml of filtrate was pipetted into another glass tube, 1ml of acid-flouride extracting solution was added to make a 2.0ml volume of sample which was subsequently diluted to 8.0ml with distilled water. To this sample was added 2.0ml of Malachite Green reagent and the contents mixed. After 30 minutes the absorbance of the sample was read at 650nm on a spectrometer.

Exchangeable K, Ca, Mg and Na were extracted by neutral ammonium acetate. Air dry soil was passed through a 2mm sieve before a 10g sample was weighed into a 100ml plastic bottle. Then 50ml of the ammonium acetate solution was added and the contents shaken for 30 minutes before the suspension was filtered through Whatman No.42 filter paper. To a 5ml sample of filtrate was added 20ml of strontium solution and the mixture diluted to 100ml before the sample was read on the Atomic Absorption Spectrophotometer. The pH measurements in the soil suspension were made potentiometrically using a glass electrode connected to a pH meter. Soil suspensions were prepared by mixing a 1:1 ratio of soil in 1.0M KCl (10kg:10ml).

3.2 Design of Experiment, Planting and Management of the Crop

There were 20 treatment combinations of four wheat varieties and five rates of N fertiliser. Nitrogen was applied as Limestone Ammonium Nitrate (28%N) at the rates of 0, 20, 40, 60 and 80 kg ha^{-1}. The four wheat varieties were Tugela DN, Betta DN, SST 124, and Caledon. The treatments were arranged in split-plot design replicated three times. The varieties were assigned to the main plot and nitrogen fertiliser to the sub-plot.

Primary land preparation was done early in March 1997, using a tractor-drawn mould-board plough. This operation was followed by secondary disc cultivation soon afterwards in order to conserve soil moisture. Secondary seedbed preparation was done four days before planting, using a secondary disc cultivator, followed by rotary cultivator to ensure a fine tilth for good early root establishment.

The plot sizes were 10.6 m x 5 m for the main plot and 1.8 m x 5 m for the sub-plot. The main plots were separated by a 1 m border, and 0.4 m was allowed for the sub-plots. There were 6 rows per sub-plot, spaced 30cm apart. Sowing was done manually on June, 17^{th} at Maseru, 18^{th} at Mafeteng and 19^{th} at Leribe.

All plots received an equivalent of 20 kg ha^{-1} of single superphosphate (9%P) and potassium chloride (53%K) applied in hand-hoe open furrow rows of 30cm apart and 5cm deep. This was then followed by application of limestone ammonium nitrate (28%N) at the different N treatment rates. The fertilisers were incorporated into the soil using hoe-handles, covering the furrows with a thin layer of soil before seed was manually sown.

Daily precipitation, maximum and minimum temperatures were obtained from meteorological stations close to each site. The first weeding was done manually by hand-pulling weeds during the second week of September i.e. 12 weeks after sowing. The second weeding was done 6 weeks later, using hand-hoes between the rows and hand-pulling within the rows. No chemicals were used at any stage of growth of the crop.

3.3 Yield and Quality Components of Wheat

The middle four rows ($6m^2$) of each sub-plot were harvested using hand sickles three weeks after the crop had reached physiological maturity in December 1997. Grain yields were obtained after threshing the harvest using a stationary thresher, following drying of the crop under the sun for four days.

3.3.1 Days to 80% Physiological Maturity

This is the number of days from planting to maturity as indicated by the attainment of a hard dough stage when the photosynthesis process ceases. This was determined by physical inspection in the plots when more than 80% of the plants within the harvest area matured.

3.3.2 Number of Heads per Square Meter

One week before harvesting, one row within the middle four rows of each harvested sub-plot ($6m^2$) was randomly selected for the evaluation of this parameter. The plants were harvested, the number of heads counted and the value divided by two to obtain the number of heads per square meter. The heads from different sub-plots were threshed separately and the grain stored in plastic bags. Later this grain was added to the rest of the harvest from respective sub-plots.

3.3.3 Number of Kernels per Spike

Counts were made of the number of kernels from five heads selected randomly from the total harvest of 60 plots at each site in order to obtain an average number of kernels per spike. Five heads from each plot were threshed separately and the average number of kernels per spike for each plot determined.

3.3.4 Harvest Index

The harvest index was calculated at harvest as a ratio of grain yield to the total biological yield (dry matter) and expressed as a percentage. Only the above-ground portion of the crop was used in the calculation. The material was dried in the sun for four days to obtain a constant dry weight.

The mathematical relation described by Stoskopf (1981) was used:

$$HI = (EY/BY)100$$

where:
HI is the harvest index in percent
EY is the grain yield in kg ha^{-1}
BY is the total biological yield in kg ha^{-1}

3.3.5 Grain Yield

Grain from the $6m^2$ harvest plot, a total of 60 plots at each site were weighed separately and yield was extrapolated to units of kg per hectare. All yield figures were corrected to 12% moisture content at the time of weighing, using the following relationship:

$$\text{Grain Mass(g) at 12\% moisture content} = \frac{\text{Mass (g) of grain sample x DM of grain at weighing}}{\text{12\% moisture content DM}}$$

3.3.6 Thousand Kernel Weight (TKW)

This parameter was determined by taking a 50g sample of grain from each of the 180 samples from all sites. The sample was placed in a **NUMIC-RAL** electrical seed counter which randomly selects 1000 grains. The sample was then weighed on an electronic balance in order to obtain the mass of the 1000 grains in grams.

3.3.7 Determination of Protein Content

The Near-Infrared Method 39-11 (American Association of Cereal Chemists, 1994) was used to determine protein content. The Infrared Reflectance Spectrophotometer is calibrated using the same wheat flour samples to be analysed in order to obtain constant numbers. These constant numbers are then entered into the instrument before test samples are read. In this case wheat grain was milled using the **junior quadrant laboratory mill** and the flour was thoroughly mixed before a sub-sample was placed in the test cell and readings taken. The instrument gives a readout of percent protein of the sample.

3.3.8 Determination of Mixograph Development Time

The Mixograph Method 54 - 40 (American Association of Cereal Chemists, 1995) was used to determine this parameter. A 100g grain sample from each of the 180 samples was equilibrated to a moisture content of 14% for 24 hours at room temperature. Thereafter the grain was milled to flour using the **junior quadramat laboratory mill**. A 10g sub-sample from each of the samples of flour was placed in the mixograph bowl mixer. After adding 6 ml of water and mixing the dough, the qualitative assessment of dough strength, time to the development of maximum dough strength and breakdown of dough properties were measured.

The procedure involves placing a pen on paper and swinging the pen arm to and fro, marking the commencement on the minute line. The timer is set to seven minutes to start mixing. When the machine has come to rest, the end of the graph is again marked by swinging the arm to and fro. The output from the Mixograph is a plot of a curve indicating changes in resistance of the dough mix overtime.

3.4 Statistical Analysis

The data from the three experimental sites (Maseru, Leribe and Mafeteng) were analysed independently as well as across sites. This was done so as not to mask the treatment effects at each site.

The data were subjected to the analysis of variance (ANOVA), mean separation and regression and correlation analysis using an MSTAT C statistical computer programme. The Duncan Multiple Range Test was also used to compare the means.

CHAPTER FOUR

RESULTS

4.1 Grain Yield and Yield Components

Selected properties of the soils used in the field trials sites are given in Table 1. The rainfall pattern during the growth of the crop at the three sites is presented in Figure 1. Notable from the soil properties is the extreme soil acidity at Leribe and Mafeteng. Rainfall amounts and distribution varied a great deal among the three sites, Mafeteng having been the driest (143.3 mm total rainfall for the period compared to 176.2 mm and 306.7 mm at Maseru and Leribe respectively).

These environmental conditions at site are expected to have confounded the crop yield obtained between sites. A presentation of the results from each trial site follows.

Table 1: Mechanical and chemical analysis of soils at the three experimental sites in Lesotho

						Available					
Site	**Soil Type**	**Depth (cm)**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**NO_3^+ -N (mg/kg)**	**NH4+ -N (mg/kg)**	**P (mg/kg)**	**K (mg/kg)**	**pH**	**Textural classes**
Maseru	Sofonia (fluventic Hapludolls)	0 – 25	20.0	19.0	61.0	2.7	20.3	8.9	73.9	5.1	Sand Loam
		25 – 50	32.0	12.0	56.0	1.3	17.1	34.6	46.7	5.3	Sandy Clay Loam
Leribe	Leribe (Typic Hapludolls)	0 – 25	18.0	31.8	50.2	3.4	14.1	123.3	64.1	4.4	Loam
		25 – 50	27.3	27.6	45.1	2.2	15.8	37.5	51.9	4.7	Clay Loam/Clay
Mafeteng	Patsa (Typic Natraqualfs	0 – 25	12.0	30.0	58.0	12.3	21.6	9.4	128.5	4.4	Sandy Loam
		25 – 50	49.1	21.8	29.1	9.9	20.4	15.3	60.0	4.6	Loam

Sources: (i) Soil surveys of Lesotho Report, 1976

(ii) The chemical analysis report of mineral nutrients taken from the sites March, 1997; analysis by Small Grain Institute, Soil Analysis Laboratory.

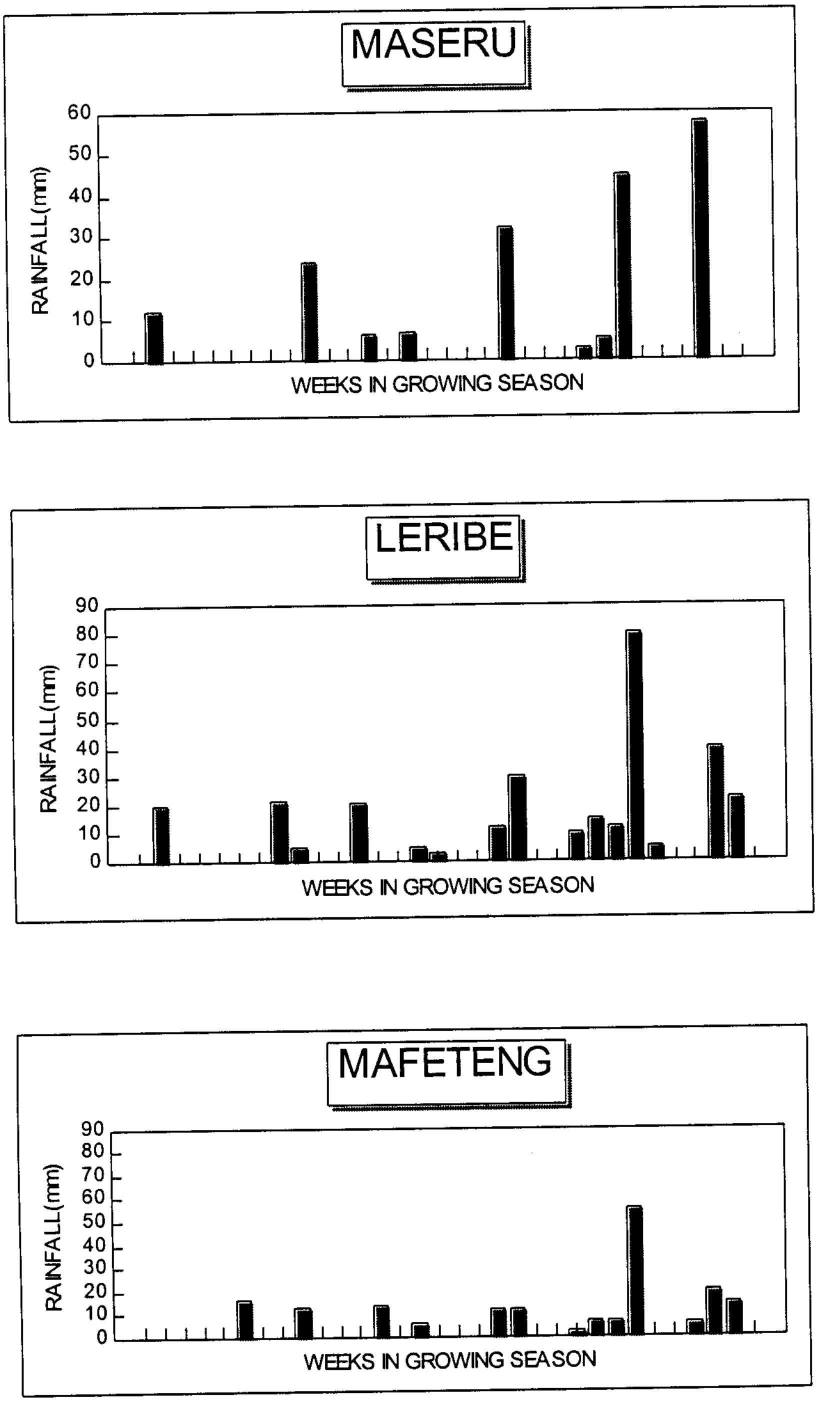

Fig. 1 Changes in total weekly rainfall at experimental sites during wheat growing season (June -December 1997)

4.1.1 Maseru Experimental Site

The yield data for the Maseru site are given in Table 2a. The average wheat yield was 1000 kg ha^{-1}, which is more than the 600-800 kg ha^{-1} average for this area. The data show that there was no significant effect of applied N up to 80 kg ha^{-1}.

The 1000 kernel weight (TKW) decreased significantly ($P<0.05$) with application of N fertiliser above 20 kg ha^{-1}. These data show that smaller kernels were obtained with higher rates of N. On the other hand, N application over 20 kg ha^{-1} significantly increased the number of heads per square meter (NHSM), indicating more productive tillers at high N rates. However, the effect of added N on the grain number per head (GNH) showed no logical pattern. There was no significant effect of N on the harvest index. This result shows that regardless of the increase in density of productive tillers at high N fertiliser rates, the NHSM alone was not sufficient to influence biological yield and hence the harvest index.

There were no significant differences in grain yield among the four varieties (Tugela DN, Betta DN, SST 124 and Caledon) at this location. The observed trend was that Betta DN gave a yield of 1195 kg ha^{-1} compared to Tugela DN (1188 kg ha^{-1}), Caledon (1168 kg ha^{-1}), and SST 124 (1140 kg ha^{-1}). Under commercial practices a farmer is expected to obtain at least 2000 kg ha^{-1} to break-even (Lesotho Agricultural Situation Report 1983/1984–1994/1995).

Table 2a. Effects of nitrogen application on grain yield and yield components of wheat grown at Maseru in 1997.

Nitrogen applied (kg ha^{-1})	Grain yield (kg ha^{-1})	1000 Kernel wt (g)	Grain number per head	Number of heads per m^2	Harvest index (%)
0	878a	35.6a	20.0b	90.0b	26.9a
20	1189a	35.1ab	24.0a	95.0b	25.8a
40	1221a	33.4b	24.0a	119.0a	26.2a
60	1266a	33.9b	23.0ab	123.0a	26.1a
80	1308a	33.5b	26.0a	129.0a	27.8a
C.V %	21.8	6.4	14.0	21.0	18.4

Means in a column followed by the same letter are not significantly different at 0.05% level of significance, according to Duncan's Multiple Range Test.

4.1.1a The Genotype by Nitrogen Fertiliser Interaction on Grain Yield – Maseru Site

Table 2b shows the interaction between N fertiliser and wheat variety. A significant (P<05) difference in grain yield occurred in variety Caledon only when N fertiliser was applied at the rate of 40 kg ha^{-1} and at the rate of 80 kg ha^{-1} for Betta DN. The best variety by N fertiliser combination was Caledon with 40 kg N ha^{-1} as less amount of N fertiliser was used to obtain high yields.

Table 2b: **Interaction between genotypes and nitrogen fertiliser on grain yield of wheat at Maseru Experimental Station in 1997.**

	Nitrogen Rates (kg ha^{-1})					
Genotype Tested	**0**	**20**	**40**	**60**	**80**	**Means**
Tugela DN	1149.00b-ev-y	1106.00a-du-x	1079.00a-eu-y	1207.00a-eu-y	1398.00abuv	1188.00u
Betta DN	743ey	1100.00a-eu-y	1242.00a-eu-y	1388.00abuv	1501.00au	1195.00u
SST 124	797dexy	1353.00a-cu-w	1140.00a-eu-y	1346.00a-cu-w	1063.00a-eu-y	1140.00u
Caledon	823c-ew-u	1198.00a-eu-y	1423.00au	1124.00a-eu-y	1270.00a-du-x	1168.00u
Mean	878.00a	1189.00a	1221.00a	1266.00a	1308.00a	1173.00a
C.V.%	21.8					

Means followed by the same letter in a row (a.b.c.d.e.f) or in column (u,v,w,x,y,z) do not differ significantly at 0.05 level of significance, according to Duncan's Multiple Range Test.

4.1.2 Leribe Experimental Station

Table 3a shows the yield data for Leribe. The average wheat yield at this site (3000 kg ha^{-1}) was nearly three times that obtained at Maseru. This compared favourably with commercial yields of 1500 – 2000 kg ha^{-1} for the area (Lesotho Agricultural Situation Report 1983/1984 – 1994/1995). The data show that application of N fertiliser up to 80 kg ha^{-1} significantly ($P<0.05$) increased grain yield at the site. A significant response to applied N was obtained up to 40 kg ha^{-1}, in which range the incremental yield was 30.4 kg grain per kg of N.

Contrary to the result obtained at Maseru, application of N had no significant effect on the GNH. However, there was a significant ($P<0.05$) effect of N on TKW, NHSM, as was also observed at Maseru. The data show that there were more heads per m^2 with increasing N application, reaching 300 at the highest rate of N (80 kg ha^{-1}). The harvest index was significantly ($P<0.05$) increased with application of N, which indicates an increase in grain yield with increasing N rate. In this case, like at Maseru, the high number of heads per m^2 was the major contributor to high yields at high N application rates.

As at Maseru, there was no significant difference in grain yield among the four varieties tested. The trend observed was that Tugela DN gave a yield of 3560 kg ha^{-1} followed by SST124 with 2936 kg ha^{-1}, Betta DN with 2858 kg ha^{-1} and the least was Caledon with 2854 kg ha^{-1}. The latter variety ranked first at Maseru site. Under commercial production Tugela DN is the preferred variety as it yields better in addition to its resistance to wheat Russian aphids (*Diuraphis noxia*).

Table 3a: Effect of nitrogen application on grain yield and yield components of wheat grown at Leribe in 1997

Nitrogen applied (kg ha^{-1})	Grain Yield (kg ha^{-1})	1000 Kernel Wt (g)	Grain Number Per head	Number of Heads per m^2	Harvest Index (%)
0	2298b	37.6a	36a	165c	32.6b
20	2980ab	36.7ab	40a	214b	35.4ab
40	3297a	36.0ab	44a	236b	34.4ab
60	3311a	35.8b	40a	272a	35.4ab
80	3373a	35.1b	43a	293a	35.6a
C.V.%	16.7	4.84	22.19	14.32	9.2

Means in a column followed by the same letter are not significantly different at 0.05% level of significance, according to Duncan's Multiple Range Test.

4.1.2a Genotype by Nitrogen Fertiliser Interaction on Grain Yield - Leribe Site

For Leribe the results of interaction between wheat genotypes and nitrogen fertiliser are shown in Table 3b. Only wheat variety Tugela DN showed significant ($P<0.05$) difference when N was applied at the rate of 40 kg ha^{-1} to 80 kg ha^{-1}. The highest variety interaction with N fertiliser was between Tugela DN and 80 kg N ha^{-1} giving a mean yield of 3600 kg ha^{-1}. However, this variety x N interaction was not significantly different from that at 40 kg ha^{-1}. Therefore, Tugela DN by 40 kg ha^{-1} appears the best combination because less nitrogen was applied to produce grain yield of 3700 kg ha^{-1} compared to 4200 kg ha^{-1} with 80 kg ha^{-1} N application.

Table 3b: Interaction between genotypes and nitrogen fertiliser on grain yield of wheat at Leribe Experimental Station in 1997.

	Nitrogen Rates (kg ha^{-1})					
Genotype Tested	**0**	**20**	**40**	**60**	**80**	**Means**
Tugela DN	2792.00d-fx-z	3036.00a-du-x	3755.00a-cu-w	4006.00abuv	4210.00au	3560.00u
Betta DN	2082.00efyz	3034.00b-ev-y	3057.00b-ev-y	3069.00b-ev-y	3049.00b-ev-y	2858.00u
SST 124	1866.00fz	3268.00a-du-x	3251.00a-du-x	3255.00a-du-x	3039.00a-du-x	2936.00u
Caledon	2206.00d-fx-z	2826.00c-fw-z	3125.00-ev-y	3132.00ev-y	2979.00c-ew-y	2854.00u
Mean	2298.00b	2980.00a	3297.00a	3311.00a	3373.00a	3052.00
C.V.%	16.7%					

Means followed by the same letter in a row (a.b.c.d.e.f) or in column (u,v,w,x,y,z) do not differ significantly at 0.05 level of significance, according to Duncan's Multiple Range Test

4.1.3 Mafeteng State Farm

At Mafeteng the average wheat yield was 2900 kg ha^{-1} (Table 4a), which is similar to that obtained at Leribe. The data show that there was no significant effect of applied N up to 80 kg ha^{-1} on yield. In fact yield decreased with application of N above 20 kg ha^{-1}. The unexpected result could be explained by moisture stress during growth of the crop.

Under the droughty conditions such as was prevailing in Lesotho during the 1997 growing season there was no effect of applied N on TKW. Kernels were small and light probably indicating low content of carbohydrates in the grain. On the other hand, N application significantly ($P<0.05$) increased GNH, showing that there were more grains with high N applications. However, there was a significant ($P<0.05$) decrease in NHSM with N application above 20 kg ha^{-1}, indicating that nitrogen fertiliser had no effect on NHSM when moisture was limiting during the growing season. The data also show that there was no effect of N on the harvest index, which is consistent with the decreases in NHSM and TWK.

As at the other two sites, there were no significant differences in grain yield among the four varieties at Mafeteng. However, the trend in yield was Tugela DN › Caledon › SST 124 › Betta DN.

Table 4a: Effect of nitrogen application on grain yield and yield components of wheat grown at Mafeteng in 1997.

Nitrogen applied (kg ha^{-1})	Grain Yield (kg ha^{-1})	1000 Kernel Wt (g)	Grain Number Per head	Number of Heads per m^2	Harvest Index (%)
0	3142a	31.1a	34d	247a	30.7a
20	2950a	30.1a	38cd	253a	29.3ab
40	2588a	29.9a	39bc	235ab	27.6b
60	2805a	29.9a	44a	233ab	30.0ab
80	2946a	30.4a	43ab	209b	30.5ab
C.V%	14.3	4.5	14.1	14.6	11.0

Means in a column followed by the same letter are not significantly different at 0.05% level of significance, according to Duncan's Multiple Range Test.

4.1.3a Genotype by Nitrogen Fertiliser Interaction on Grain Yield – Mafeteng Site

The yield results for the Mafeteng State Farm are shown in Table 4b. The data show that there was no significant interaction between wheat variety and nitrogen fertiliser. Unlike at the other two locations, grain yield decreased with N application above 20 kg ha^{-1}. Nitrogen fertiliser applied at this site in the dry weather conditions of 1997 had no effect on grain yield.

Table 4b: The interaction between genotypes and nitrogen fertiliser on grain yield of wheat at Mafeteng State Farm in 1997

	Nitrogen Rates (kg ha^{-1})					
Genotype Tested	**0**	**20**	**40**	**60**	**80**	**Means**
Tugela DN	3386.00abuv	3491.00au	3197.00a-cu-w	3126.00a-cu-w	3355.00abuv	3311.00u
Betta DN	3010.00a-eu-y	2859.00a-eu-y	1958efyz	2274.00efyz	2682.00b-ev-y	2557.00u
SST 124	3048.00a-du-x	2548.00c-fw-z	2398.00a-eu-y	2748.00a-eu-y	2879.00a-e-u-y	2724.00u
Caledon	3128.00a-du-x	2903.00a-eu-y	2799.00a-eu-y	2940.00a-eu-y	3001.00a-eu-y	2954.00u
Mean	3143.00a	2950.00a	2588.00a	2772.00a	2979.00a	2886.00
C.V.%	14.3					

Means followed by the same letter in a row (a.b.c.d.e.f) or in column (u,v,w,x,y,z) do not differ significantly at 0.05 level of significance, according to Duncan's Multiple Range Test.

4.1.4 Yield Results across Three Sites

The combined yield data across three sites is given in Table 5. The average wheat yield was 2300 kg ha^{-1}, which is much higher than the national average of 500 – 800 kg ha^{-1}. The data show that there was a significant increase in grain yield when N was applied only at 80 kg ha^{-1}.

The 1000 kernel weight (TKW) decreased significantly ($P<0.05$) with application of N fertiliser from 20kg ha^{-1}. This data show that smaller kernels were obtained with higher rates of N application. On the other hand, N application over 20 kg ha^{-1} significantly increased the number of heads per square meter (NHSM), indicating more productive tillers at high N rates. The effect of added N on the grain number per head (GNH) was not significant with application of N up to 80 kg ha^{-1}. However, the trend showed an increase in GHN with N application from 20 kg ha^{-1} up to 80 kg ha^{-1}. There was no significant effect of N on the harvest index. Although there was a significant increase in grain yield and density of productive tillers across the three locations with increasing N fertiliser application, these two components (Grain yield and NHSM) were not large enough to influence a significant effect on the harvest index.

There was no significant difference in grain yield among the four varieties across the three locations. The trend is that Tugela DN gave an average yield of 2685 kg ha^{-1} compared to Caledon 2325, Betta DN 2303 and SST 124 with the lowest average yield of 2266 kg ha^{-1}.

Table 5: Effect of nitrogen application on grain yield and yield components of wheat across three sites

Nitrogen applied (kg ha^{-1})	Grain Yield (kg ha^{-1})	1000 Kernel Wt (g)	Grain Number Per head	Number of Heads per m^2	Harvest Index (%)
0	2106b	34.8a	30a	166b	30a
20	2369ab	33.6ab	34a	187ab	30.2a
40	2373ab	33.2ab	36a	197ab	30.4a
60	2470ab	32.1b	37a	209a	30.5a
80	2667a	30.0c	38a	210a	31.3a
C.V.%	17.6	5.2	16.2	16.0	12.6

Means in a column followed by the same letter are not significantly different at 0.05% level of significance, according to Duncan's Multiple Range Test.

4.2 Effects of Nitrogen Application on Protein Content of Wheat

Protein is an important constituent of food and feed crops from the standpoint of nutritive value. In wheat, the quantity and quality of protein are major factors in determining the quality of wheat flour and its suitability for making various bakery products (Terman, 1978; Hanson *et al*, 1982). The protein content of wheat is greatly influenced by environmental factors, particularly by nitrogen. Genetic factors also influence protein content as some wheat varieties characteristically contain higher protein content than others when grown under comparable environmental conditions (Rao *et al*, 1992).

4.2.1 Maseru Research Station

The data on grain protein content (GPC) for wheat grown at the Maseru site is given in Table 6a. The average protein content was 11.00%, which is normal for wheat grown in the area. The data show that there was no significant effect of applied N on protein content up to 80 kg ha^{-1}.

There were also no significant differences in GPC between the four varieties at this location. According to the Lesotho Flour Mills grading standards, wheat varieties should contain at least 12% protein, or higher to be graded Class A, or 10 to 11.9% for B Class. Varieties containing less than 9% GPC are regarded as feed grade, or are recommended for blending with wheats of high protein content (Leisanyane, K. Personal Communication).

Table 6a: Effect of nitrogen on protein content of wheat grown at 3 locations in 1997.

Nitrogen Applied (kg ha^{-1})	Grain Protein Content %		
	Maseru	Leribe	Mafeteng
0	11.21a	8.18c	14.68a
20	10.38a	8.48c	15.60a
40	10.84a	9.27b	15.84a
60	11.25a	10.33a	15.70a
80	11.33a	10.99a	15.63a
C.V.%	9.66	9.73	5.90

Means followed by the same letter in a column are not significantly different at the 0.05% level of significance, according to Duncan's Multiple Range Test.

4.2.2 Leribe Research Station

The data on wheat GPC at these locations are presented in Table 6a. The mean wheat GPC was 9.5% which is 14% lower than that obtained at the Maseru site, and 21% lower than what is expected from a commercial farmer in order to achieve grade A on the market. However, there was a significant ($P<0.05$) effect of applied N up to 60 kg ha^{-1} on GPC.

The average protein contents of the four varieties were not significantly different at this site. Under commercial production SST 124 with 10% protein content is the only variety which performs better than the other varieties which are down-graded to C because of low protein content (less than 9%).

4.2.3 Mafeteng State Farm

Table 6a also gives the data on the grain protein content of wheat grown in Mafeteng. The average GPC of wheat at this site was 15.50%, comparatively higher than the averages of GPC obtained at Maseru by 29% and at Leribe by 39%. The 15.50% GPC obtained at this location is one of the highest mean protein contents ever measured in Lesotho. The normal GPC average from most of the commercial farmers is 11 – 12%. Despite the high GPC observed at this site, application of N fertiliser up to 80 kg ha^{-1} had no significant effect on protein content of the grain. As at Maseru and Leribe there was no significant difference is GPC among the four varieties tested at this location.

4.3 Protein and Dough Properties of Wheat

Mixograph development times curves, are plots, or graphs of dough consistency as a function of time. They give qualitative measurements that describe dough properties. These include, height of a curve which is a measure of protein content, time taken to reach a peak of the curve or maximum consistency and breakdown curve after four minutes, which are all associated with dough strength (Finney *et al*, 1967; Kosmolak and Crowler, 1980).

4.3.1 Wheat from the Maseru Site

The data on mixograph development time (MDT) for wheat from the Maseru site are given in Table 6b. The average MDT was three minutes, which is within the acceptable time allowed for the flour to mix into dough. The data show that there was a significant ($P < 0.05$) increase in dough mixing times with application of N up to 80 kg ha^{-1}. This result suggests greater dough strength at higher N rates. On the other hand there was greater height of the curves when protein content increased from 9.5% to 11.8%. This result according to Bushuk *et al* (1968) indicates an increase in loaf volume (Fig. 2 and 3).

The four varieties tested in this experiment were significantly ($P<0.05$) different in their values of MDT (Table 6c). This result indicated that irrespective of the non significant increase in GPC with N fertiliser application (Table 6a), varieties can have significantly different MDT. Under commercial practice, 2.5 - 3 minutes is the allowed standard time for the wheat flour to mix and develop into acceptable dough.

Table 6b: Effects of nitrogen on Mixograph development times of Wheat flour at three locations in 1997.

Nitrogen Applied (kg ha^{-1})	Mixograph Development Times Minutes		
	Maseru	Leribe	Mafeteng
0	2.80b	2.89a	3.10a
20	2.99b	2.93a	3.18a
40	3.13ab	2.91a	3.27a
60	3.17ab	3.01a	3.28a
80	3.19a	3.13a	3.33a
C.V.%	13.96	13.18	9.13

Means followed by the same letter in a column are not significantly different at the 0.05% level of significance, according to Duncan's Multiple Range Test.

4.3.2 Wheat from the Leribe Site

Table 6b also shows the data on the mixograph development time (MDT) for wheat grown at Leribe. The average MDT for wheat from this site was 2.98 minutes, comparable to that obtained for wheat from Maseru. The data also show that application of N fertiliser up to 80 kg ha^{-1} had no significant influence on MDT at this site.

Contrary to the results obtained at Maseru, Tugela DN showed a significant ($P<0.05$) effect on the MDTs among the four varieties tested. The mixograph development times were higher, 3.67 minutes for Tugela DN with a protein content of 9.25% (Table 6a and 6b). This result shows that GPC had significant influence on the MDT of the different varieties. As at Maseru, greater height of the curves was obtained with increasing grain protein content (Fig. 4 and 5).

4.3.3 Wheat from the Mafeteng Site

The data for the mixograph development times (MDT) for wheat grown at Mafeteng site are also given in Table 6b. The average MDT was 3.23 minutes (Fig. 6 and 7), greater than those obtained for wheat grown at Maseru and Leribe by 7 and 8% respectively. There was no significant effect of applied N up to 80 kg ha^{-1} on MDT for this site.

There was a significant ($P<0.05$) difference in mixograph development times among the four varieties tested at this location (Table 6c). As at the other two locations, the curve heights were higher with increasing protein content, indicating an increase in loaf volumes

Table 6c: Effects of genotypes on Mixograph development times of Wheat flour at three locations in 1997.

Genotype	Mixograph Development Times Minutes		
	Maseru	Leribe	Mafeteng
Tugela DN	4.03a	3.67a	4.31a
Betta DN	2.79b	2.65b	2.83c
SST 124	2.92b	2.94b	3.36b
Caledon	2.33c	2.86b	2.42d
C.V.%	13.96	13.18	9.13

Means followed by the same letter in a column are not significantly different at the 0.05% level of significance, according to Duncan's Multiple Range Test.

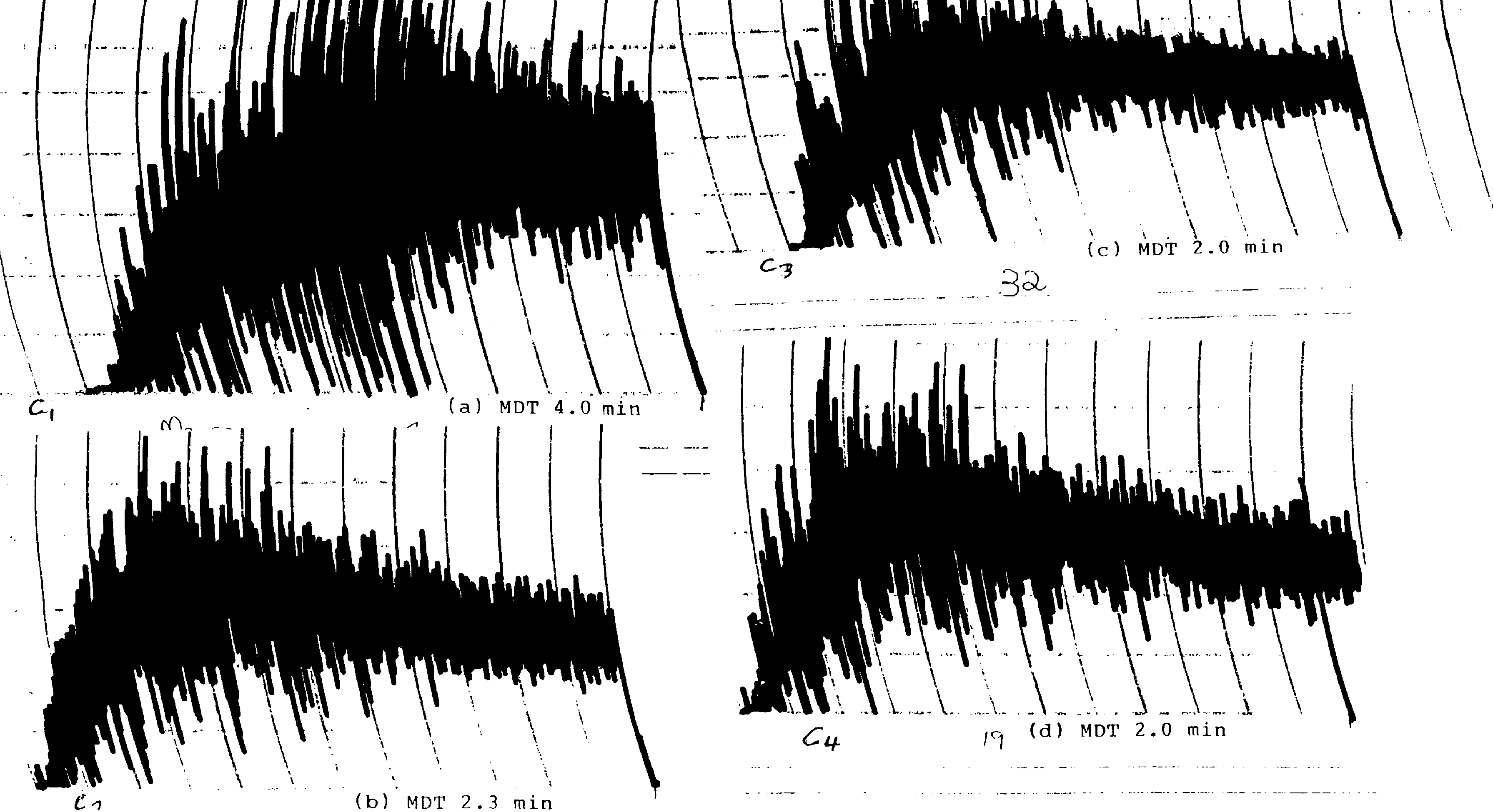

Fig 2: Mixing curves of wheat flour from four varieties (Maseru site) (a) Tugela DN (b) Betta DN, SST 124 and Caledon when no N was applied.

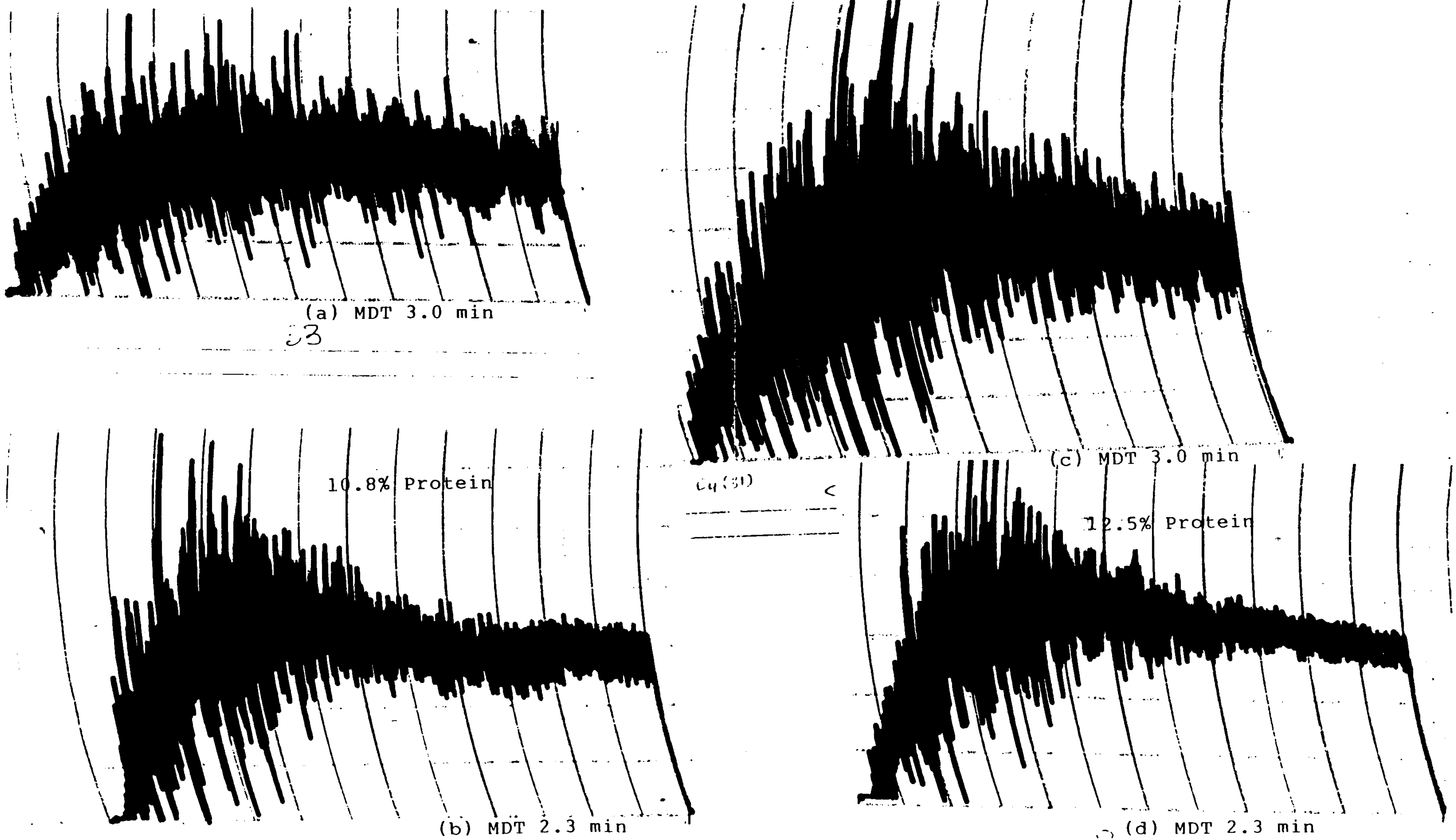

Fig 3: Mixing curves of wheat flour at different protein contents (a) 8.4% (b) 10.8% (c) 11.2% and (d) 12.5%, corresponding to N application rates of 0, 20, 40, and 60 kg ha^{-1} respectively at Maseru.

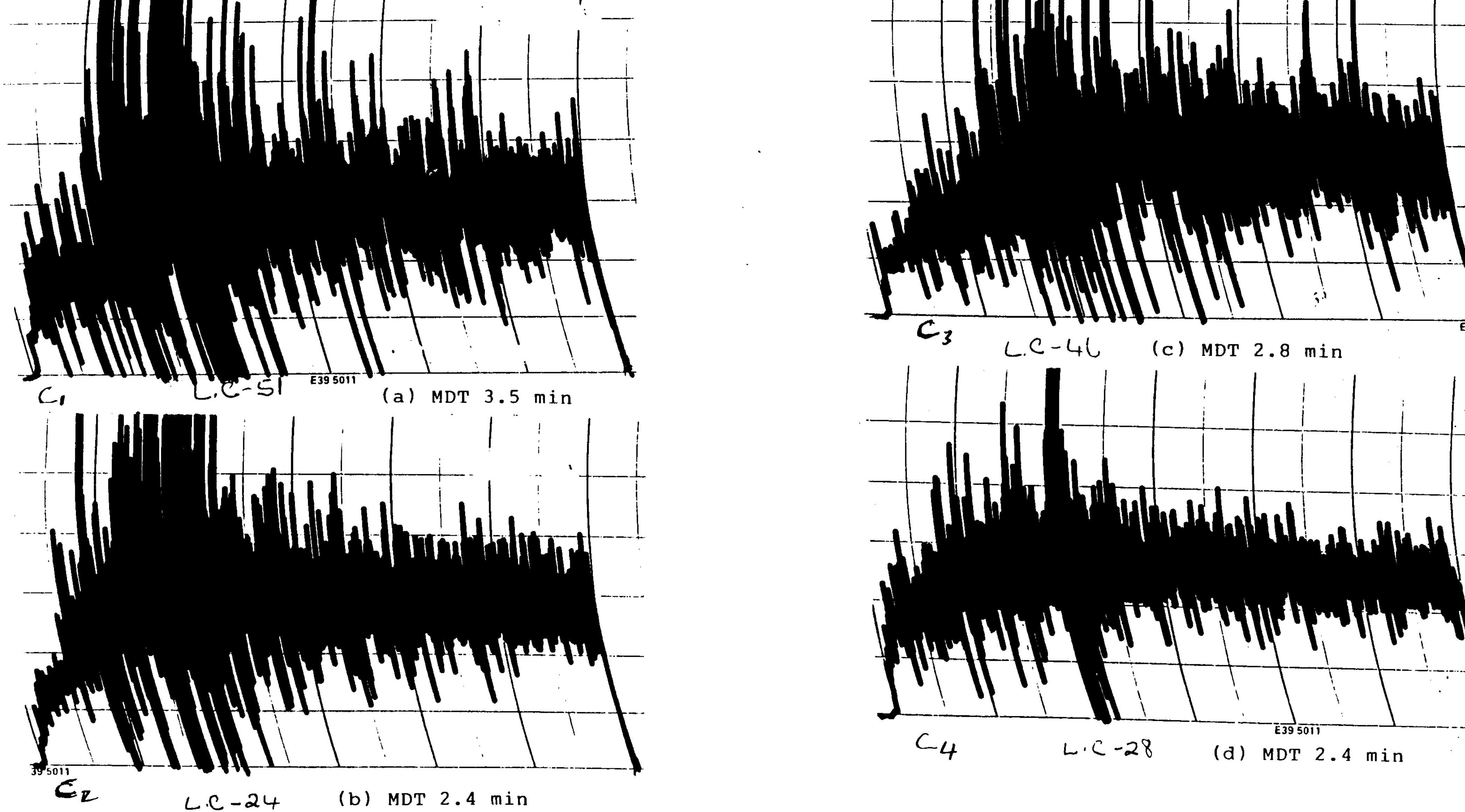

Fig 4: Mixing curves of wheat flour from the four varieties (Leribe site): (a) Tugela DN, (b) Betta DN, (c) SST 124 and Caledon when no N was applied.

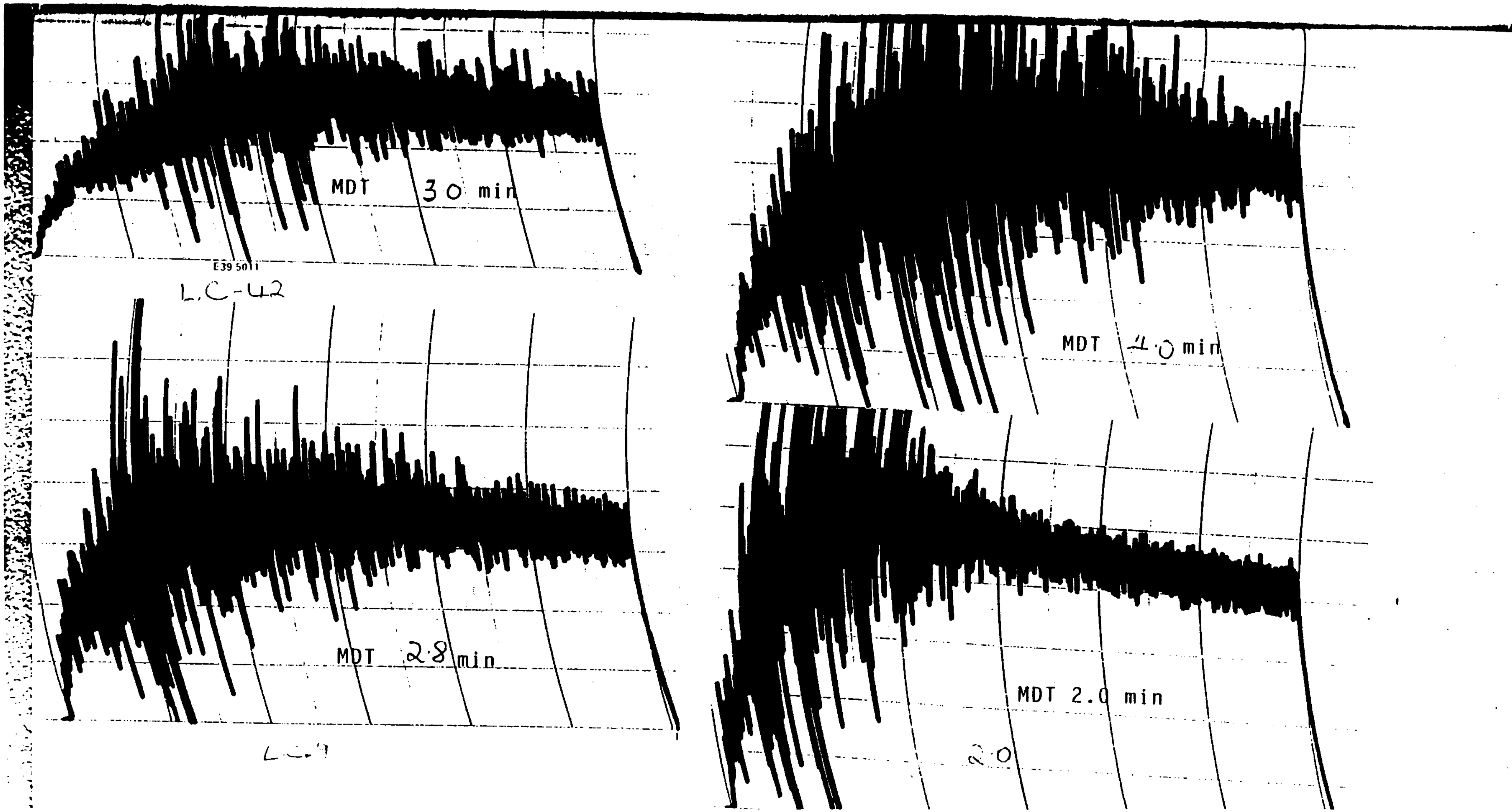

Fig 5: Mixing curves of wheat flour at different protein contents (a) 7.9% (b) 9.1% (c) 11.1% and (d) 14.1% corresponding to N application rates 0, 20, 40 and 60 kg ha^{-1} respectively at Leribe.

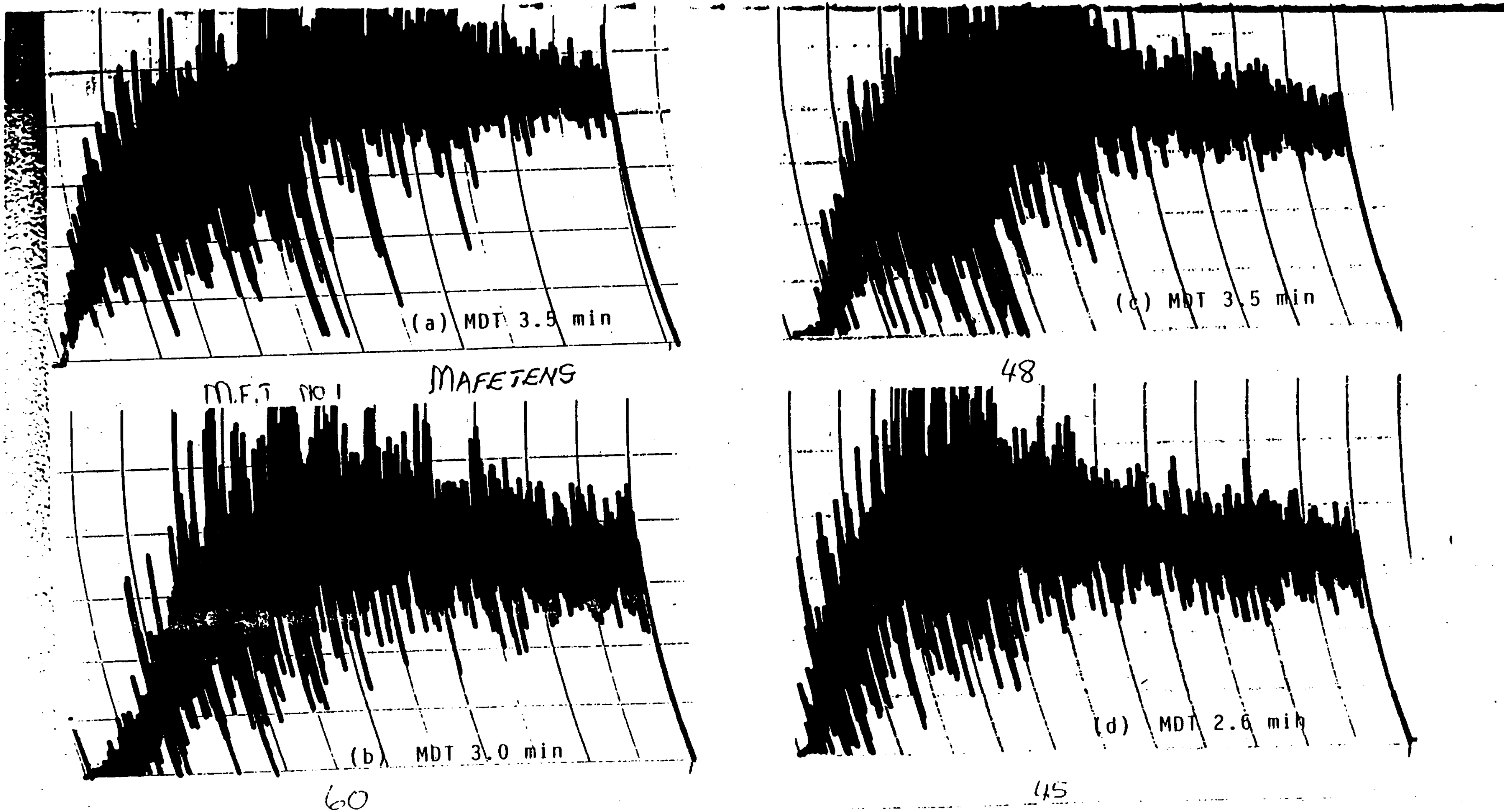

Fig 6: Mixing curves of wheat flour from the four varieties (Mafeteng site) (a) Tugela DN, (b) Betta DN, (c) SST 124 and Caledon when no N was applied.

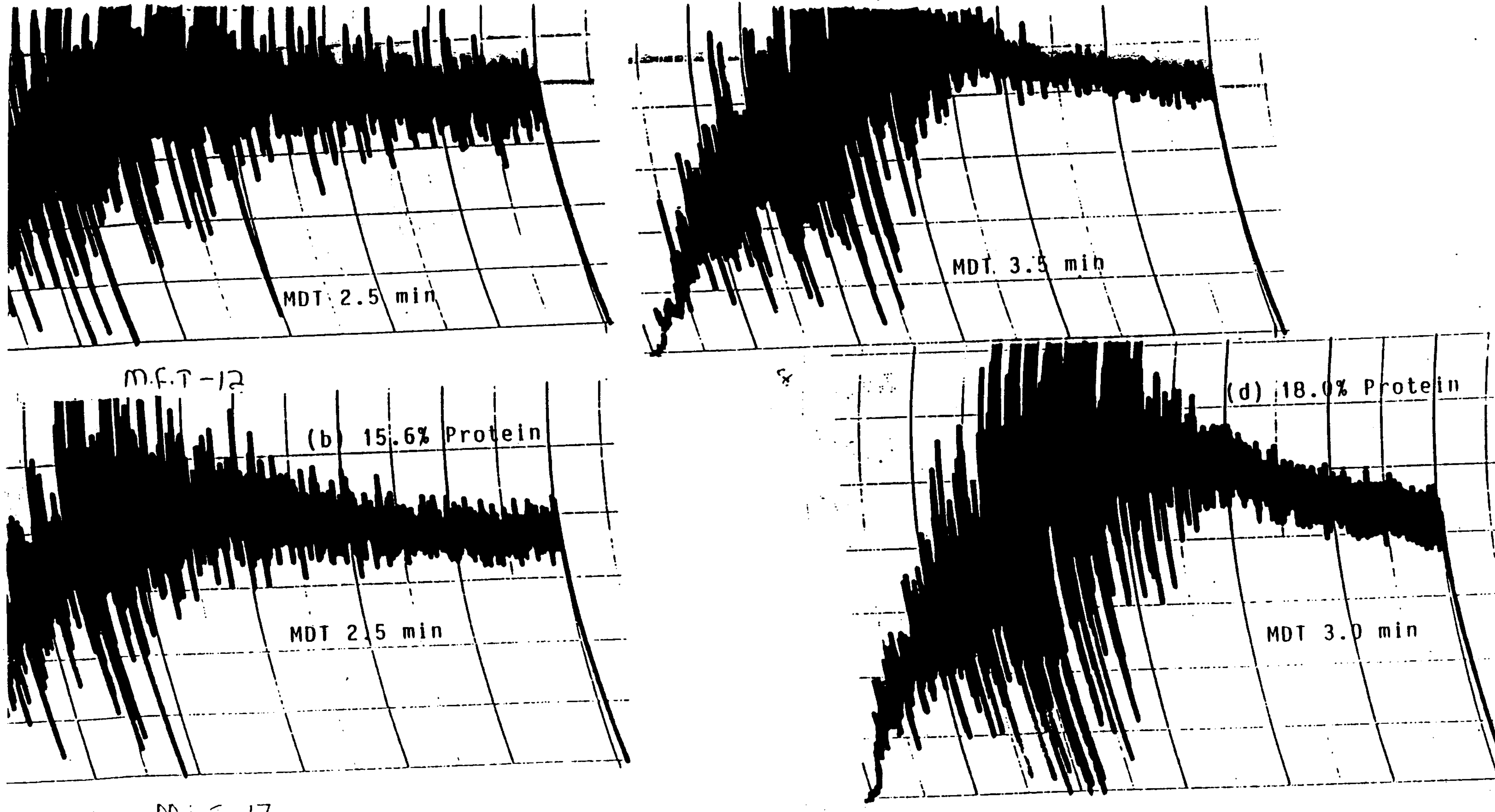

Fig 7: Mixing curves of wheat flour at different protein contents (a) 14.3% (b) 15.6% (c) 16.1% and (d) 18.0% protein content when N was applied at the rates of 0, 20, 40, 80 kg ha^{-1} respectively at Mafeteng.

CHAPTER FIVE

DISCUSSION

In Lesotho wheat yields on farmer's fields are generally low (<1000 kg ha^{-1}) compared to yields of 3000 kg ha^{-1} under similar conditions in neighbouring Orange Free State in South Africa (Small Grain Institute,1997). Furthermore, the quality of the wheat is poor, and this is why it is normally down graded by millers who can only use it for blending with high quality wheats. It is therefore desirable for farmers to increase yields and improve the quality of the wheat as well. The objective of this study was, therefore, to evaluate the effect of N application and genotype on yield and quality.

5.1 Effect of Nitrogen on Grain Yield

Nitrogen application up to 80 kg ha^{-1} significantly increased yield at only one of the three sites. At this site (Leribe) yields increased by 35% while across the locations yields increased by 21% compared to the control. With the application of the high N rate of 80 kg ha^{-1}, the yield was 3373 kg ha^{-1} at Leribe (Table 3a), and 2667 kg ha^{-1} across the three sites (Table 5) which is comparable to what is normally obtained in Orange Free State in South Africa. Such yields are obtained with application of 50 kg N ha^{-1} in South Africa (Small Grain Institute, 1997).

At Leribe, soil fertility is low, therefore, application of 80kg N ha^{-1} is justified (Appendix A). The rainfall at this site is adequate (Appendix B). Therefore, it appears that the limitation to high yields in commercial practice at Leribe is due to low N application, which is currently 30 kg N ha^{-1}.

At both Maseru and Mafeteng sites, there was no significant yield response to N application (Tables 2a and 4a). At Maseru, the rainfall was 176mm, which was lower than the normal years. While in the normal years, the minimum rainfall should be 300mm. The rainfall distribution was also erratic. The data in Fig. 1 and Appendix B show that rainfall was only 3.3mm during the critical stage of grain-filling. The crop suffered moisture stress as is borne out by the reduction in the value of the thousand kernel weight (TKW), which is an indication of smaller kernels, and suggesting lower accumulation of carbohydrates in the grain (Table 2a).

There was an increase in the number of productive tillers per square meter (NHSM) and grain number per head (GNH) at higher N rates (Table 2a). The increase in the values of these yield components indicate that there is potential for obtaining high grain yields with increasing N application. However, the increase in the values of these components w not large enough to mask the reduction in TKW because there was an increase in NHSM only at 40 kg N ha^{-1}. Thus, the increase in NHSM and GNH can increase grain yield when rainfall or soil-stored moisture during post-anthesis is sufficient to supply the crop through the process of grain-filling.

At Mafeteng there was a non significant effect of applied N on yield. This result is not unusual for the area. Dr. Purchase at the Agricultural Research Council (ARC) in Bethlehem, South Africa has made similar observations in the drier areas of the Orange Free State (Personal Communication). The explanation for the tendency of yields to decline with N application is that applied N at higher rates early in the growing season stimulates excessive early vegetative growth, which causes rapid depletion of soil moisture before the crop can go through the critical stages of flowering and grain-filling. This explanation is consistent with the low kernel weight at Mafeteng (Table 4a), compared to that of Leribe at higher N rates. Furthermore, Adjetey (1991) found a similar result in the drier areas of Australia where application of 50 kg ha^{-1} reduced yield by 13%.

As at Maseru, there was drought during the growing season at Mafeteng where only 176mm of rain was received (Appendix B). The distribution was also poor, giving only 13mm during the grain-filling period (Fig. 1). The resulting moisture stress could have contributed to the low yields that were obtained.

The NHSM was significantly decreased as a result of poor seedling emergence at high N application. Although there was tillering, it probably was not enough to compensate for the decrease in this yield component. This may be due to the fact that soils at this site are sandy in the top (0 – 25cm), and there is a clay pan at around 50cm, meaning that there is probably poor moisture storage in this soil. In drought years, such as during this study, moisture stress would reduce yields, thereby nullifying even the effect of added nitrogen.

The Central and Southern Districts of Lesotho, for example (Maseru and Mafeteng respectively), are characterised by low and erratic distribution of rainfall. The average rainfall in these areas was only 160mm, which was 49% less than that obtained at Leribe during the 1997 growing season. In order to avoid yield losses under such dry conditions, there is the need to develop N management strategies that achieve the balance between vegetative growth and moisture use before the crop goes through the critical stages of anthesis and grain-filling.

5.2 Effect of Added Nitrogen on Quality of Wheat

The grain protein content (GPC) and the mixograph development time (MDT) were used as indicators of wheat quality. Good quality wheat for bread should contain at least 10% GPC and the MDT of between 2.5 – 4 minutes (Finney and Yamazaki, 1967; Kosmolak and Crowler, 1980).

Nitrogen application significantly increased GPC only at Leribe (Table 6a). The GPC increase was 2.8% with N application compared to the control. Although nitrogen application increased grain protein, the average GPC of 9% which was obtained at this site is low compared to the 10% minimum requirement for bread wheat. This low value may be due to the fact that substantial increases in grain protein can be obtained when the maximum yield potential is achieved and the excess N is then available to increase grain protein. These results are consistent with those of Pierre *et al*, (1979); Adjetey and Yankey, (1995) and Campbell *et al*, (1996), who reported 1 to 2% increase in protein content in the high rainfall areas of United States, Ghana and Canada. As shown in Table 3a, there is no evidence that grain yield had reached a peak yield. Thus it appears that under the conditions of this study, rates of N higher than 80 kg ha^{-1} may be required to give substantial grain protein increases.

At Mafeteng and Maseru, there was no significant effect of nitrogen on GPC and MDTs (Tables 6a and 6b). At Maseru the GPC were greater than 10%, but there was no significant response to N application. However, at Mafeteng the GPC were all over 15%, though the result was not significant. This is probably a result of a concentration effect on protein content. Under drought conditions, such as those experienced at Maseru and Mafeteng, the kernel weights were smaller, as indicated by the small TKW (Table 2a and 4a) at higher N rates, resulting in low content of carbohydrates, and consequently the GPC were very high. This observation and explanation was also reported by Langer and Liew (1973) and Campbell *et al*, (1993).

5.3 The Nitrogen by Genotype Interaction on Yield

Four commercial wheat varieties (Tugela DN, Betta DN, SST 124 and Caledon) were evaluated at five rates of N. There was no significant yield response to N application by any of the varieties at the three sites (Tables 2b, 3b, and 4b). Therefore, given adequate rainfall as occurred at Leribe, yields of any of the four varieties could be increased to at least 3000 kg ha^{-1} with high N application. In practice, however, farmers prefer variety Tugela DN because of its resistance to Russian wheat aphids and tolerance to soil acidity. As indicated in Appendix A and Table1, most of Lesotho soils are acidic, as also observed in this study.

5.4 Effect of Genotype on Grain Yield

The four local varieties of wheat assessed in this study gave similar yields at all three sites. This result is probably due to the fact that there was no evidence of attacks by Russian wheat aphid (*Diuraphis noxia*) or any adverse effect of aluminium toxicity noted during the growing season. Susceptibility to the Russian wheat aphids and aluminium toxicity are the only two major basis for any differences in yield among the varieties of wheat grown in Lesotho and neighbouring Orange Free State (Small Grain Institute, 1997).

5.5 Effects of Genotype on Quality

The four varieties showed no significant differences in grain protein content (GPC) with increasing rates of N application. All the varieties contained at least 10% GPC, which is the minimum required for bread wheat. The only explainable variation observed could be attributed to site factors. Thus at Maseru and Mafeteng, where rainfall was low during grain-filling period (end of October to Mid-November) kernels were small and protein contents were high among the varieties, averaging 11% to 15% respectively. At Leribe where rainfall was almost double that at Maseru and Mafeteng, kernels were large and protein contents were in the region of 10% for all four varieties. Reports from other researchers (Terman, 1978; Rao *et al*, 1992) suggest that the role of rainfall and temperature in influencing protein content in wheat is higher when compared to cultivars in influencing the protein content. Pushman and Bingham (1976) reported that cultivars differed significantly in their protein content.

There were significant differences in measured mixograph development times (MDT) among varieties. The desirable MDT for bread wheat is 2.5 to 4 minutes (Finney *et al*, 1967). The MDT was not significantly reduced by application of N. Greater MDT are not desirable for various uses of wheat, and so wheat varieties with long MDT (more than 4 minutes) are not preferred by bakers and millers as more energy is required to develop their flour into dough than with flour from varieties with medium to medium-long mixing requirements (2.5 – 4 minutes). On the other hand, varieties with short mixing requirements of less than 2 minutes are also not preferred because their water absorption is low, resulting in small loaf volume. In this study, Tugela DN was only a few seconds above the preferred MDT, but this may be corrected by blending with Caledon which is also a few seconds below 2.5 minutes in order to produce required MDTs.

CHAPTER 6

CONCLUSION

The data from the three sites in this study show that grain yield increased with increasing rates of N application only at Leribe where rainfall was above 300 mm during the growing season. In contrast, at Maseru and Mafeteng where only 176 mm of rainfall was received, there was no response to applied N. Increasing N application resulted in greater grain protein content. However, at only one site Leribe, there was significant difference with increased N application. Thus N application greater than 80 kg N ha^{-1} may be required in order to increase grain protein content and therefore improve the quality of wheat in this area.

The four varieties evaluated in the study did not significantly differ in grain yield and protein content at all the three sites as well as across the locations. However, where there are signs of aluminium toxicity, or previous infestation of Russian wheat aphids, resistant cultivars such as Tugela DN would be recommended. The Mixograph Development Times were different for all the four varieties, which is an indication that the wheat varieties differ in dough strength. Some varieties need more time and others less time to develop into acceptable dough (2.5 – 4 minutes being ideal time).

The results reported here are only from one growing season (1997/98), and therefore no conclusive recommendations can be made. There is need for further research to determine the optimum N application especially under such dry conditions as encountered at Maseru and Mafeteng in order to establish a balance among grain yield, water use during anthesis and grain-filling period and wheat quality.

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Appendix A: Soil Analysis Results (values of nutrient elements in mg/kg)

Parameter	Maseru		Leribe		Mafeteng	
	Value	Rating	Value	Rating	Value	Rating
pH	5.1	Low	4.4	Very low	4.4	Very low
$No_{-3}^{-}N$	2.7	Very low	3.4	Very low	12.3	Low
$NH^{+}_{4}{}^{-}N$	14.1	Low	20.3	Moderate	21.1	Moderate
Phosphorus	8.9	Very low	23.3	Low	9.4	Very low
Potassium	73.9	Low	64.1	Low	128.5	Moderate
Calcium	1500.0	High	244.0	Moderate	424.0	Moderate
Magnesium	385.2	High	26.5	Moderate	89.7	Moderate
Sodium	21.4	Moderate	6.5	Low	12.3	Low

Rating based on Lesotho Survey Report, 1976. Samuel L. Tisdale, Wemer L. Nelson and James D. Beaston: Soil Fertility and Fertilizers. Fourth edition, 1984. Analysis done on Small Grain Institute, Soil analysis laboratory. March 1997.

Appendix B: Rainfall across three locations during growing season 1997

Rainfall in mm			
Month	Maseru site	Leribe site	Mafeteng site
June	11.9	25.2	15.8
July	0.0	21.2	16.6
August	30.0	26.4	12.7
September	6.6	16.2	3.7
October	32.2	48.7	15.5
November	39.9	119.2	39.9
December	45.5	61.8	39.1
Total	176.2	309.7	143.3

Data supplied by: Lesotho Meteorology Services

Planting dates:
Maseru = 17th June, 1997
Leribe = 19th June, 1997
Mafeteng = 18th June, 1997

Harvesting dates:
Maseru = 21st December, 1997
Leribe = 29th December, 1997
Mafeteng = 23rd December, 1997

Appendix C: Analysis of variance for grain yield – Maseru site

Source of variation	Df	SS	Ms	F.Value
Replication	2	88686.233	44343.117	
Varieties (V)	3	27393.733	9131.244	0.04^{ns}
Error (a)	6	1162472.167	193744.361	
Nitrogen levels (N)	4	1441435.167	360358.792	6.51^{ns}
V x N	12	1067897.100	88991.425	1.14^{ns}
Error (b)	32	3876595.100	102015.661	
Total	59	6502007.333		
CV = 21.8%				

^{ns} = Not significant

Appendix D: Analysis of variance for grain yield – Leribe site

Source of variation	Df	SS	Ms	F.Value
Replication	2	8893031.700	4446515.850	
Varieties (V)	3	4913740.000	1637913.333	5.2^{ns}
Error (a)	6	1298630.933	216438.489	
Nitrogen levels (N)	4	10222538.833	2555634.708	8.13^{*}
V x N	12	3391511.833	282625.986	0.50^{ns}
Error (b)	32	11949579.633	314462.622	
Total	59	39370402.000		
CV = 16.7				

^{ns} = Not significant
* = Significant at 5% level

Appendix E: Analysis of variance for grain yield – Mafeteng site

Source of variation	Df	SS	Ms	F.Value
Replication	2	8855757.700	4427878.850	
Varieties (V)	3	3995430.533	1331810.178	6.38^{ns}
Error (a)	6	2697026.000	449504.467	
Nitrogen levels (N)	4	2261564.100	565391.025	2.71^{ns}
V x N	12	1866952.300	155579.358	0.75^{ns}
Error (b)	32	7931190.967	208715.552	
Total	59	24910895.600		
CV = 14.3				

^{ns} = Not significant

Appendix F: Analysis of variance for grain yield – Across the three sites

Source of variation	Df	SS	Ms	F.Value
Location	2	134898419.344	67449209.672	216.8698
Replication	6	19197611.100	3199601.850	10.2877
Varieties (V)	3	5126052.200	1708684.067	
L x A	6	2959875.900	493312.650	
Nitrogen levels (N)	4	5867234.056	1466808.514	
L x N	8	9105503.211	1138187.901	
V x N	12	3184128.967	265344.081	
L x V x N	24	7319675.100	304986.462	
Total		223113918.444		
CV = 23.28%				

ns = Not significant

Appendix G: Analysis of variance for protein content – Maseru site

Source of variation	Df	SS	Ms	F.Value
Replication	2	57.510	28.755	
Varieties (V)	3	12.434	4.145	2.60^{ns}
Error (a)	6	9.550	1.592	
Nitrogen levels (N)	4	7.592	1.898	1.68^{ns}
V x N	12	6.777	0.565	0.50^{ns}
Error (b)	32	36.147	1.130	
Total	59	130.010		
CV =	9.66%			

^{ns} = Not significant

Appendix H: Analysis of variance for protein content – Leribe site

Source of variation	Df	SS	Ms	F.Value
Replication	2	30.386	15.193	
Varieties (V)	3	10.871	3.624	1.47^{ns}
Error (a)	6	14.760	2.460	
Nitrogen levels (N)	4	68.718	17.179	20.30^{*}
V x N	12	6.694	0.558	0.65^{ns}
Error (b)	32	27.080	0.846	
Total	59	158.509		
CV =	9.73%			

* = Significant at 5% level

ns = Not significant

Appendix I: Analysis of variance for protein content – Mafeteng site

Source of variation	Df	SS	Ms	F.Value
Replication	2	16.023	8.012	
Varieties (V)	3	21.515	7.172	7.54^{ns}
Error (a)	6	5.703	0.951	
Nitrogen levels (N)	4	10.376	2.594	3.11^{ns}
V x N	12	11.210	0.934	1.11^{ns}
Error (b)	32	26.723	0.835	
Total	59	91.554		
CV =	5.93%			

^{ns} = Not significant

Appendix J: Analysis of variance for Mixogram development times – Maseru site

Source of variation	Df	SS	Ms	F.Value
Replication	2	0.772	0.386	
Varieties (V)	3	23.442	7.814	33.98*
Error (a)	6	1.380	0.230	
Nitrogen levels (N)	4	1.112	0.278	1.57ns
V x N	12	2.082	0.174	0.98ns
Error (b)	32	5.681	0.178	
Total	59	34.470		
CV =	13.96%			

ns = Not significant

* = Significant at 5% level

Appendix K: Analysis of variance for Mixograph development times – Leribe site

Source of variation	Df	SS	Ms	F.Value
Replication	2	3.049	1.525	
Varieties (V)	3	10.371	3.371	5.67^{*}
Error (a)	6	3.569	0.595	
Nitrogen levels (N)	4	0.393	0.098	0.58^{ns}
V x N	12	3.064	0.255	1.50^{ns}
Error (b)	32	5.435	0.170	
Total	59	25.623		
CV =	13.81%			

^{ns} = Not significant
* = Significant at 5% level

Appendix L: Analysis of variance for Mixograph development times – Mafeteng site

Source of variation	Df	SS	Ms	F.Value
Replication	2	0.361	0.180	
Varieties (V)	3	30.139	10.046	122.10^{*}
Error (a)	6	0.491	0.082	
Nitrogen levels (N)	4	0.398	0.099	1.14^{ns}
V x N	12	1.329	0.111	1.27^{ns}
Error (b)	32	2.785	0.087	
Total	59	35.503		
CV =	5.93%			

^{ns} = Not significant
* = Significant at 5% level