

THE EFFECT OF SPLIT APPLICATION OF TOP DRESSING NITROGEN
ON GRAIN YIELD AND BAKING QUALITY OF FOUR WHEAT VARIETIES
IN ZAMBIA

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FRANK NOAH SICHONE

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A DISSERTATION SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN
PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRONOMY (CROP SCIENCE)

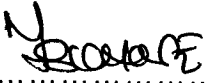
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DECLARATION

I, Frank Noah Sichone, hereby declare that this dissertation represents my own work and that it has not previously been submitted for a degree at this or another university.

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APPROVAL

This dissertation of Frank Noah Sichone is approved as fulfilling the requirements for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

Signature:

Date:

Prof. Prof. Obed Lungu

25/03/2002

Deo K. M. M. M. M. M.

28/03/2002

Dr. M. M. M. M. M.

25/03/2002

DEDICATION

I dedicate this work to my late brothers Maxwell and Justine Sichone for their support to my family. May their souls rest in peace.

ABSTRACT

An experiment was conducted to evaluate the effect of split application of top dressing nitrogen fertiliser on grain yield and baking quality of four wheat varieties. The recommended top dressing fertiliser of 115 kg N/ha normally added at the 3-leaf stage was split in application. It was applied at the 3-leaf stage and at anthesis. The treatments consisted of applying the whole amount at once and 75%, 50% and 25% at the 3-leaf stage and the remainder later at anthesis. The four test varieties were Loerie II, Nkwazi, Pwele and Nkanga. The treatments were replicated four times and arranged in a split plot of a randomised complete block design. The four varieties were assigned main plots with split top dressing nitrogen as subplot treatments. Grain yield, protein content, gluten content, flour yield, flour ash, falling number, test weight, number of heads/m², 1000-grain weight, harvest index, grain moisture content, days to heading, days to maturity, disease score, lodging score, and plant height were recorded for each plot. Split application of nitrogen resulted in no significant difference in days to maturity, disease score, lodging score, grain yield, test weight, harvest index, gluten content, and grain moisture content. The split top dressing nitrogen fertiliser improved the protein content compared to the control. The results for protein content, however, showed that the application of 25% of nitrogen at the 3-leaf stage and 75% at anthesis gave the highest protein content of 14.1% compared to 13% for the control (applying all the N at once). The total N of 115 kg of N/ha for top dressing application can improve the protein content if it is split in application of 25% of nitrogen at the 3-leaf stage and 75% at anthesis.

Nkwazi variety gave the highest protein content (14.6%). On the basis of these results high yields of wheat and protein content can be obtained when top dressing nitrogen is applied in a split of 25% at the 3-leaf stage and 75 % at anthesis. Application of 115 kg of N/ha can increase the protein content in the wheat grain. The application of 25% of nitrogen at the 3-leaf stage and 75% at anthesis gave the largest seed size of 44.3 grams for 1000-grain weight compared to 42.9 grams for the control.

ACKNOWLEDGEMENTS

I would like to thank Dr D. N. Mbewe and Dr D. Lungu who spent long patient hours going through the drafts and making this work a reality through patience and unequalled guidance.

Special thanks to my sponsors Maize and Wheat Improvement Research Network (MWIRNET) for Southern African Development Community (SADC) under International Maize and Wheat Improvement Centre (CIMMYT) and Government of the Republic of Zambia (GRZ) for their financial support.

Sincere gratitude to my wife, children, brothers, sisters and parents for their encouragement while away, on study leave.

The workers of Food Technology and Research Unit at the National Institute of Scientific and Industrial Research (NISIR), especially Dr Rodah Zulu, Technicians and the Head of the unit Dr M. Kaputo.

Lastly, but not the least, to Rabby Samana Banda for his assistance.

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1.0 INTRODUCTION.

Wheat (*Triticum aestivum* L.) is the world's most important food crop in terms of tonnes of grain produced each year (Gooding and Davies, 1997). It provides more nourishment for the people of the world than any other food source. It contributes more calories and more protein to the world's diet than any other food crop. Wheat provides a major source of energy, protein and dietary fibre in human nutrition. Hundreds of millions of people throughout the world depend on food made from the kernels of the wheat plant. The kernels are ground into flour to make bread, cakes, cookies, and other foods. The raised bread loaf is possible because the wheat contains gluten, which is an elastic form of protein. Only in certain areas of developed countries, primary in times of surplus, are some kinds of wheat used directly for animal feed. Also in highly developed countries, nearly 28% of wheat-milled products, bran and shorts go into mixed feeds (Gooding and Davies, 1997; Martin, 1992; Haldore *et al.*, 1982; Inglet, 1974).

World trade in wheat exceeds trade in all other grains combined and its production and utilisation has been intimately linked with the development of both agriculture and civilisation over at least the last 12,000 years. (Gooding and Davies, 1997; Haldore *et al.*, 1982).

In the Eastern, Central and Southern African countries region (i.e. Ethiopia, Sudan, Kenya, Tanzania, South Africa, Zimbabwe, Zambia, Burundi, Uganda,

Malawi, and Angola), the total wheat importation and production stands at between 2.57 and 4.80 million tonnes, respectively, on a corresponding total wheat area of 281 million hectares (CIMMYT 1999). These eleven countries include the six nations with the largest areas of wheat production in the region, namely Ethiopia, Sudan, Kenya, Tanzania, South Africa and Zimbabwe (Appendix 1). Areas sown to wheat have increased significantly in Zambia. There has been a 45% increase in area sown to wheat from 1990 to 1994 (CIMMYT, 1999).

Wheat was first introduced to Zambia in the 1940s. At that time, domestic production was sufficient to meet the local demand that was confined to the small urban population. With increasing rural-urban migration since the 1960s, demand for wheat increased and in no time outstripped local production. To meet the short fall, wheat had to be imported. By 1985, domestic wheat production accounted for about 10% of national consumption of 94,000 tonnes per annum. The bulk of domestic production was produced by commercial farmers under irrigation (Mooleki and Hill, 1992).

Although wheat is not a traditional staple food in Zambia, the increased popularity of bread as a convenience food has led to an increasing demand for wheat over the last three decades, making it one of the most important cereals in the country, second only to maize (Mooleki 1995; Payne, 1996,).

According to the annual report of the Ministry of Agriculture, Food and Fisheries (MAFF) Research Branch, agricultural statistics indicated that

during 1995/96 season, per capital wheat consumption was 11.7 kg/year. The gross harvest for the season was 50,000 metric tonnes. Commercial imports and food aid accounted for 50,000 metric tonnes each, while domestic utilisation was in the range of 107,000 metric tonnes (MAFF, 1996; Appendices 2-4)

In September, 1993 a priority setting exercise that was under-taken by the Ministry of Agriculture, Food and Fisheries, wheat was ranked the second most important cash crop after maize both in agro-ecological regions II and III. This ranking means that wheat does not only provide household food security to the growers, the marketing of the commodity also provides an important source of income to farmers.

In 1995 the National Milling Company of Zambia observed that there was an increase of low protein wheat grown the previous year (1994) with protein levels of about 9%, while their minimum specification is 11% from some farmers growing the recommended variety of Loerie II. The farmers were using the same variety and recommended agronomic practices. This meant that the farmers lost money due to their low quality wheat and risked losing the entire crop if the National Milling Company rejected their wheat.

Since good quality wheat was produced from the same area with neighbouring farms using the same variety and recommended agronomic practices, the problem could not have been caused by the variety. Some of the major environmental factors affecting wheat quality are nitrogen and grain

moisture content at harvesting and grain moisture content in storage (Phiri and Mwale 1995). Considering the harvesting time, there is more likelihood of having the nitrogen deficiency as a problem rather than grain moisture content at harvesting since the irrigated wheat is harvested in September and October, which are the hottest months. In other studies, Dampney and Salmon (1990); Haldore *et al.* (1982) found that grain protein content in wheat can be manipulated to some extent by the amount of fertiliser applied and the timing of application. Applying nitrogen to the soil early during crop development generally resulted in high grain yield and applying nitrogen at flowering time or a little later generally produced more protein in the grain. Ayoub *et al.* (1994) found that splitting the nitrogen application increased flour protein content concentration and bread loaf volume.

If Zambia has to export its wheat then the baking quality will need to be improved for the crop to be accepted on the regional market. In particular, uniformity in protein content and other quality factors within the desirable tolerance limits for the regional market is helpful (Gilles and Sibbit, 1974).

1.2 Objective

This study was aimed at establishing the effect of split application of the recommended top dressing nitrogen fertiliser (115 kg N/ha) on the grain yield, baking quality and milling quality of four varieties of wheat.

1.3 Hypothesis

This study is based on the premise that split application of top dressing nitrogen fertiliser does influence grain yield, milling and baking quality of wheat.

Dampney and Salmon (1990) found that application of the second split of top dressing nitrogen fertiliser at flowering or later had little effect on grain yield.

Mercedes *et al.* (1993) found that grain yield increases were achieved with split applications of nitrogen fertiliser when nitrogen fertiliser was top dressed at GS 4 or GS 6 as compared with applying all pre-plant. Split nitrogen application at GS 10 produced greater grain yield than application at GS 4 or GS 6 in 1990. By split applying fertiliser nitrogen, plant nitrogen availability apparently better matched crop needs during the growing period. Split applying nitrogen in three or four applications in 1989 yielded more grain than just two splits, apparently due to greater grain weight per spike. Grain yield was also higher when the second half of two split fertiliser applications was supplied at GS 4 or 6 than at GS 10. Splitting 75 kg N/ha into four applications yielded more grain than splitting into three applications.

2.2 Effect of split nitrogen fertilisation on wheat bread making quality

Splitting the nitrogen application increases flour protein content and bread loaf volume according to Ayoub *et al.* (1994); Djoke and Denic (1985) observed that the crude protein increase by 35% on average for all varieties when nitrogen is fed to the leaves at anthesis stage.

Phiri and Mwale (1995) suggested a continuous and adequate supply of nitrogen which can be achieved by split applications of the top dressing fertiliser. The first dose may be applied at about 6 weeks (full tiller stage) and

the second at anthesis. The proportion of split application of top dressing should be about 75% of the recommended rate as the first and 25% as the second dose at anthesis for higher protein content.

Other studies by Olson et al. (1964) showed that the later the vegetative stage at which nitrogen is applied up to the bloom stage the less the effect on the vegetative growth weight and the greater the increase in grain protein. Liu et al. (1997) concluded that late nitrogen application was only useful at high soil fertility, and most of the nitrogen translocated was used for the synthesis of residual proteins. Grignani and Reyneri (1990) also found that grain protein content was higher with the later than earlier nitrogen applications and increased with increase in nitrogen rate.

Protein content in wheat can be manipulated to some extent by the amount of fertiliser applied and the timing of application. Applying nitrogen to the soil early during crop development will generally result in high grain yield and applying nitrogen at flowering time or a little later will generally produce more protein in the grain but will have little effect upon yield (Dampney and Salmon, 1990; Haldore et al., 1982). Pelton (1992) found that nitrogen added at pollination mainly increased the kernel weight and bread making quality.

2.3 Significance of wheat baking quality

The basic definition of wheat quality usually varies from one class of wheat to another and is dependent on the wheat's suitability for a given product. For

example, the quality of a soft winter or white wheat variety is defined in terms of its suitability for soft wheat milling and for the production of cakes, cookies and crackers. The quality of durum wheat is defined in terms of suitability for semolina and macaroni production. Hard red winter wheat and spring wheat quality is defined in terms of specific milling and baking properties that determine the suitability of a wheat for hard wheat milling and bread production (Finney and Yamazaki, 1967).

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Quality of wheat is as critical as the quantity produced. The usefulness of wheat can only be described in terms of its quality. The quality of hard spring wheat and winter wheat for bread making is directly related to gluten protein content (Tanner *et al.*, 1990; Finney and Yamazaki, 1967).

A flour of good quality for bread baking should have high water absorption, a medium to medium-long mixing requirement, a small to medium oxidation requirement, satisfactory mixing tolerance and dough-handling properties and good loaf volume. Subnormal bread-baking properties are associated with high temperatures (>32.2°C) and low relative humidity during the last 15 days before harvest. Varieties showed differences in quality parameters like crude protein content, sedimentation value (Zeleny), gluten content, and alveograph W value. Varieties with longer mixing times, however, are more tolerant or resistance to detrimental effects of these climatological factors than those with shorter mixing times. The most important baking qualities can be determined by test baking, and they include flour water absorption, mixing requirement, mixing tolerance, dough handling characteristics, oxidation

requirement, loaf volume considering flour protein content, crumb grain and crumb colour. Many tests have been developed in the past to study wheat quality. They include simple chemical, physical and physico-chemical tests (Finney and Yamazaki, 1967; Loch *et al.*, 1998).

Opportunities exist to improve the quality and market value of wheat grain at all stages of production, storage and transport. An essential prerequisite is a thorough knowledge of market requirements, both for the approaching crop season and well into the future in the case of breeding programmes and research planning. Elucidation of the molecular basis of grain quality is an important part of the overall strategy of quality improvement (Wrigley, 1994). It is imperative that quality must be considered not on the basis of what it once might have been, but rather on the basis of the actual quality characteristics of the wheat at the time a decision must be reached for a quality evaluation (Gilles and Sibbit, 1974).

For a given species or variety of wheat there is often a positive relationship between grain nitrogen content and loaf quality (Gooding and Davies, 1997; Peterson *et al.*, 1992). When grain yield increases and grain protein concentration decreases, the milling and baking quality of bread flour can be adversely affected (Costa and Kronstad, 1990; Koekemoer *et al.*, 1999).

2.4 Milling quality or Flour yield

Flour for bread making is obtained mainly from hard wheat belonging to *T. aestivum*. Flour from soft wheat, belonging to the same species, is used mainly for making cakes, biscuits, pastry and other articles. Wheat is made into many breakfast foods. Coarsely ground wheat is known as semolina (Purseglove, 1972).

Wheat hardness may be defined in terms of the way in which the endosperm behaves on a roller mill in which hard wheat produce a coarser flour with higher levels of starch damage than soft wheat (Osborne, 1991). In the production of white flour, the pericarp and the embryo are removed during milling and the bran is used mainly for feeding to livestock (Purseglove, 1972).

Gaines *et al.* (1997) took nine cultivars which were separated into large, medium, and small kernels that had no shrivelling and eleven cultivars which were separated into sound, moderate, and severely shrivelled kernels and tested them for milling quality. Shrivelling greatly decreased the amount of flour produced during milling. It adversely affected all other milling quality characteristics (ash content, endosperm separation index, and friability). Shrivelled kernels produced flour that had inferior soft wheat baking qualities (smaller cookie diameter and higher alkaline water retention capacity). In contrast, test weight and milling qualities were independent of kernel size. Small, non-shrivelled kernels had slightly better baking quality (larger cookie diameter) than larger non-shrivelled kernels. Small kernels were softer than

large kernels (measured by break flour yield, particle size index, and flour particle size). Small non-shrivelled kernels did not have diminished total flour yield potential or other reduced flour milling characteristics. Those observations suggest a possibility of separating small sound kernels from small shrivelled kernels to improve flour yield, and Gibson *et al.* (1998) found that flour yield correlated positively with kernel weight, kernel diameter, test weight and proportion of large kernels.

2.4.1 Flour Ash.

The flour ash of wheat is usually related to the variety and to the environment under which the wheat was grown. In general, the flour ash of wheat ranges from 1.1 to 2.0%, calculated on a 14% moisture basis. In certain areas, the flour ash of the wheat is inversely related to quality. This is particularly true where millers employ the cumulative ash curve technique to determine flour yield (Gilles and Sibbit, 1974).

Douglas and Dyson in 1985, examined the relationship between mineral composition and baking quality of wheat grain in 35 samples. Baking score was positively correlated with nitrogen content and negatively correlated with 1000-grain weight.

2.4.2 Test weight (Hectolitre weight)

The test weight is a measure of bulk density of grain, i.e. the weight of grain that can be contained in a unit volume packed in a standard way. It is one of the first determinations made preliminary to experimental milling, but kernel

density has an important influence on test weight. It is a crude measure of grain shrivelling. Badly shrivelled wheat may have low test weights because shrivelled grain contains proportionately more bran than endosperm of well filled grain, hence used as a rough guide of expected flour yield by millers. In general, higher test weight is expected to give higher flour returns (Gooding and Davies, 1997). Although Troccoli *et al.* in 1999 found that there was no correlation between the test weight and 1000-grain weight, CIMMYT in the same year found that there was a positive correlation.

Neither flour ash nor flour yield can be properly assessed or evaluated without a knowledge of kernel plumpness which is usually indicated by the test weight. When the test weight is increasing, flour yield increases while flour ash decreases (Finney and Yamazaki, 1967).

2.5 Factors Affecting Quality of Wheat

2.5.1 Protein content

Wheat compares well with other cereals in nutrient values. Its protein content is higher than that of rice, maize, sorghum and is about equal to that of other cereals like oats, barley and rye (Haldore *et al.*, 1982). The protein content of commercial wheat ranges from 6-16%. The composition of wheat protein provides an efficient source of protein if balanced by other foods that supply certain amino acids such as lysine which are low in wheat protein and therefore important in determining the nutritional status of millions of human beings. Grain protein content is a major contributor to nutritional quality of

wheat (Hammonds, 1981; Koekemoer *et al.*, 1999).

In general, grains of higher protein content have more economic value for bread making purposes. In other areas, grains of low protein content may be preferable for use in cakes and cookies. Beyond the quantitative aspect, however, protein has two major areas of interest. When flour is mixed with water and sufficiently blended, a gluten matrix will form. This is the unique characteristic of wheat flour that most people associate with the ability of dough to form envelopes that enclose the gas liberated by yeast during baking process. This is responsible for making yeast-leavened bread, particularly attractive to those people who like the texture of open grained, relatively light bread types (Gilles and Sibbit, 1974).

According to Cygankiewicz (1998), correlation coefficients confirmed that sedimentation value and protein content are good preliminary indicators of baking quality which can be utilised in selection of materials, particularly at the early stages of breeding programmes. Hubik (1995), found a positive correlation between protein content and wet gluten content with nitrogen fertiliser rate.

2.5.2 Gluten content

Gluten is an elastic, sticky substance that helps make dough rise. It forms when certain proteins in flour are moistened in dough. The flour forms a dough when mixed with water, which upon leavening and baking produces a porous bread due to the gluten which holds the carbon dioxide produced by

the fermenting yeast. The unique dough-forming properties of wheat flour are primarily due to its protein constituents, especially the gluten proteins. Thus, protein content is the most important compositional attribute determining wheat's market value and processing quality. However, protein content is only one of many means of examining wheat quality. As a single window, it provides an adequate picture, but it can be augmented by knowledge of the variety and growing conditions (Martin, 1992; Purseglove, 1972; Wrigley *et al.*, 1997).

Gluten content is an important factor in assessing flour quality. In another study, 40 samples of hard red winter and 17 samples of hard red spring wheat flours were analysed for wet and dry gluten. Statistical analysis showed high correlation coefficient (0.92-0.97, P less than 0.05) between wet and dry gluten values and protein content (Kulkarni *et al.*, 1987). Gluten quality is measured primarily for two parameters: quality for baking purposes and quality for nutritional purposes (Gilles and Sibbit, 1974).

2.5.3 Falling number

There are two major starch-degrading enzymes that affect the quality characteristics of wheat. These are alpha-amylase and proteinase, and the Hagberg falling number measures them.

Proteinase (which is induced by insect attack injected in the kernel) plays a key role in the reduction of polymeric protein structure and also in the initial mobilisation of the main reserve of protein in the starch endosperm. This is

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not preferred as it depends on insect attack for activation of the proteinase (Stevens *et al.*, 1988; Szof and Zelazowska, 1975; Gilles and Sibbit, 1974).

The alpha-amylase (which arises from sprout grain) reduces the viscosity of starch-water suspensions. Consequently, this reduces the ability of the ground product to thicken, or to form a gel of rigid structure, which is essential in the manufacture of products such as bread, cake and soup thickeners. The required alpha-amylase activity can be achieved by blending flours. If this cannot be done, more fermentation, higher additions of salt, increase of heat at the start of baking, or using the flour to make small products containing little or no sugar are recommended (Stevens *et al.*, 1988; Szof and Zelazowska, 1975; Gilles and Sibbit, 1974).

Perhaps the most convenient method for detecting alpha-amylase activity is the "falling number test", devised by Hagberg (1961) and improved by Perten (1964). The falling number is the measure of the viscosity of a mixture of water and ground wheat mixed in a tube and placed in a water bath at 100 °C. The falling number is the time in seconds required for stirring (60 seconds) plus the time taken for the stirrer to fall through the flour suspension while it is being liquified by the enzyme. Alpha-amylase breaks down starch to produce a mixture of glucose and maltose and, therefore, reduces viscosity. Generally, falling number values in excess of 250 seconds indicate an acceptable level of alpha-amylase activity (Gooding and Davies, 1997; Medcalf *et al.*, 1966).

A high falling number indicates low alpha amylase activity and low falling number indicates high alpha amylase activity. A high alpha amylase concentration in bread flour will attack the starch and give a sticky bread crumb. On the other hand, wheat with low alpha amylase will produce dry bread (Szof and Zelazowska, 1975).

Practical tests confirmed the existence of a relationship between the Hagberg falling number and the quality of bakery products. The optimum Hagberg number for all types of wheat flour is in the limits 200-300. For bakery products containing sugar, the flour can have a higher Hagberg number. For wheat flour with a low Hagberg number (less than 185), any defects of the crumb are intensified (e.g. poor elasticity) (Szof and Zelazowska, 1974).

2.5.4 Temperature

The effect of high temperature on the grain characteristics, milling quality, and flour quality of hard red winter wheat during maturation was investigated by CIMMYT (1999) and Gibson *et al.* (1998). They found that flour yield decreased as temperature increased and increased temperature correlated negatively with hardness index and proportion of small grains.

Wrigley *et al.* (1994), found that as growth temperatures increase up to 30°C, there is a general increase in dough strength, and increasing temperatures during grain filling produced grain with a higher protein content although not as consistent and marked as the effects on dough strength in field and glass house experiments. Uhlen *et al.* (1998) also found that the protein content

increased as temperature increased. Rao *et al.* (1993) found that maximum temperature during grain-filling stage influenced the protein content at 9 out of 10 locations. Generally a rise in temperature resulted in higher protein contents.

2.5.5 Moisture content

Moisture is one of the most important factors affecting the quality of wheat. Since the amount of dry matter is the important economic attribute of the kernel, moisture content is directly related to economic value. Composition of protein or starch are inversely related to the grain moisture content (Gilles and Sibbit, 1974; Gooding and Davies, 1997).

Correl *et al.* (1994) observed that high grain moisture content was associated with decreased wheat grain protein and more importantly the number of days above 30 degrees centigrade were positively associated with an increase in wheat grain protein levels. The same study also revealed that even the analysis data from malting barley varieties from 1982-1991 also showed that increased grain moisture content was associated with decreased protein content. However, the dominating influence was the number of days in a row above 35°C that was consistently associated with increased protein content.

Wheat that is excessively dry, in the 8 or 9% moisture range, will tend to be brittle and to break during post harvest handling operations (Gilles and Sibbit, 1974) and wheat that contains an excess of 13.5% moisture is graded "tough" according to the Official Grain Standards of the United States of America (1970)

3.0 MATERIALS AND METHODS

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3.1 *Experimental Site*

The experiment was carried out under irrigation in 1997 at Golden Valley Agricultural Research Trust (GART), 80 km north of Lusaka. This farm is located in Chisamba, Central Province of Zambia. Its altitude is 1125 meters above sea level. The latitude is 14°53'S and the longitude is 28°28'E (de Milliano, 1983). The average annual rainfall is 800 mm.

The principal soils of Golden Valley Agricultural Research Trust are Makeni series clay loam, a deep soil (>160 cm) with dark reddish brown to very dark grey clay surface horizon (Spaargaren, 1969). The soil is of high fertility and is suitable for wheat and a wide range of other crops (De Milliano, 1983). The soil analysis showed that the soil texture where the experiment was conducted is clay loam. It had a pH of 7.7 in 0.01M CaCl₂, 0.03% total nitrogen, 9 ppm available phosphorus, 0.64 cmol kg⁻¹ potassium, 10.1 cmol kg⁻¹ calcium and 5.2 cmol kg⁻¹ magnesium at the time of planting. Golden Valley Agricultural Research Trust up to now grows commercial wheat and there are experiments on wheat.

3.2 *Treatments and experimental design*

The trial was planted on 8th May 1997 in a dry seedbed. The experimental design was a split plot in a randomised complete block arrangement with four

replications. The four varieties, Loerie II, Nkwazi, Pwele and Nkanga were assigned to the main plots with split top dressing nitrogen as subplot treatments. These varieties selected are the ones currently recommended for production under irrigated conditions in Zambia. The recommended top dressing nitrogen fertiliser applied as urea (46% N) of 115 kg/ha was split in application and applied as the following treatments:-

1. The control where 115 kg N/ha is applied at the 3-leaf stage and 0 kg N at anthesis.
2. 86.25 kg N/ha is applied at the 3-leaf stage and 28.75 kg N/ha is applied at anthesis.
3. 57.5 kg N/ha is applied at the 3-leaf stage and 57.5 kg N/ha is applied at anthesis.
4. 28.75 kg N/ha is applied at the 3-leaf stage and 86.25 kg N/ha is applied at anthesis.

The two stages of top dressing nitrogen fertiliser application used were from the recommendations by Raemaeckers and Little (1986) at 3-leaf stage and Phiri and Mwale (1995) recommended the second application at anthesis.

3.3 Management

The research involved two stages. The field trials to obtain agronomic data and laboratory analyses to determine quality in the four wheat varieties.

Seed was treated with Baytan (200g/100 kg of seed) as a preventive measure against seed borne diseases like smuts. The seed was sown in rows to a depth of 4-5 cm with a planter. The seed rate of 100 kg/ha was used as recommended by Raemaekers and Little (1987). A basal dressing fertiliser of 500 kg/ha 'C' compound (30kg N/ha, 90kg P₂O₅/ha and 60kg K₂O/ha) was applied at planting to all the plots.

The first irrigation after planting was done on 18th May 1997 ten days after planting (DAP). The irrigation interval was ten days. Seven hours were used per cycle, giving 25 mm. In total, 15 cycles were used resulting in about 375 mm of water being applied during the growing period. The recommended amount of water is from 250 to 450 mm during the growing period (Raemaekers and Little, 1987).

The top dressing nitrogen fertiliser of 115 kg/ha was applied according to the different treatments at the 3-leaf stage and at anthesis. The total nitrogen applied to all plots after 3 split application times was 145 kg N/ha (i.e. 30 kg N/ha from basal and 115 kg/ha from top dressing split application).

There were five rows per plot and one meter between the plots. The plot width was one meter while the length was six meters and the plot area was 6m². There was one guard plot of 6m² on each end of each replicate. One-metre pathways separated the replications. Hand hoeing was used to control the weeds when necessary.

3.4 Records taken

Records were taken for each plot from the harvesting area i.e. 3 m². Fifty centimetres were trimmed from both ends of the plot and 2 outside rows were also trimmed leaving 3 middle rows for harvesting. After harvesting, the seed was threshed, cleaned before post harvest data collection as outlined below.

The following field data were taken from each plot;

Days to maturity was assessed from a visual estimate of the day on which 50% of the peduncles are ripe i.e. turned yellow in colour. These were calculated as the days from the first irrigation to physiological maturity (CIMMYT, 1979).

The number of heads/m² was obtained by counting the total number of heads in each of two 1-metre lengths of row selected at random in each harvest area of the plot. The data is reported as heads per m².

$\text{Heads/m}^2 = (\text{count 1} + \text{count 2}) / 2 \times \text{spacing between rows (0.2 m)}$

Grain yield (g/plot) is the grain yield obtained from the harvest area of 3 m² and reported as kg/ha. A 1000-grain weight (gm) was obtained by counting two lots of 200 grains. These two lots were then weighed. The average weight of the two lots was multiplied by 5 to get 1000-grain weight.

To get the test weight (hectolitre weight), one pint of seed was weighed in grams. The weight of one pint was then converted to a hectolitre weight. The conversion factor of 0.182 was used to change this measurement to kilograms per hectolitre (kg/hl).

Flour ash (AACC Method 08-01). A flour sample weighing 5 grams was put in an ashing dish and was placed in a muffle furnace heated at 590 °C. It was incinerated until it turned into a light grey ash. It was then cooled in a dessicator and then weighed when it reached room temperature. The % ash was calculated as weight of residue/sample weight X 100.

Crude protein (AACC Method 46-11A). A flour sample weighing 1 gram was put in a digestion flask where a catalyst (copper sulphate) and 20 millilitre of concentrated sulphuric acid were added. The flask was heated until white fumes cleared the bulb of the flask. After cooling, 25 millilitre of standard sulphuric acid and methyl red indicator was added. The mixture was boiled until all ammonia was distilled. Titration was done with sodium hydroxide solution to neutrality, using methyl red indicator as an indicator. The % protein was calculated from the formular:

$$(B-S) \times N \times 1.4007 \times 5.7 / \text{sample weight}$$

where B= millilitre alkali back-titration of blank

S= millilitre alkali back-titration of sample

N= normality of alkali.

Crude gluten (AACC Method 38-10). A flour sample weighing 25 grams was placed in a porcelain cup and sufficient water added to form a firm dough ball. The dough was kept in water at room temperature for one hour. Then it was kneaded gently in a stream of tap water until starch and all soluble matter were removed, leaving gluten. This gluten was again left to stand in water for one

hour. Then it was pressed between hands so as to remove excess moisture, rolled into a ball and placed in a weighed flat-bottom dish. The weight obtained was recorded as wet gluten.

Falling number (AACC Method 56-81B). A flour sample weighing 7 grams was put into a dry falling number tube, and 25 millilitre of water was added. After inserting a rubber stopper on the tube, the contents were shaken in an upright position until the sample was thoroughly mixed. Then the tube and viscometer-stirrer were put into the apparatus immediately. The time in seconds for the stirrer to fall was measured in seconds as the falling number.

Grain moisture content (AACC Method 44-15A, one stage). A flour sample of 3 grams was weighed in a moisture dish. It was heated for one hour at 103 °C and then weighed when it reached room temperature. The % moisture was calculated as the difference of the original weight of sample in grams from the oven dried sample/ original weight of sample X 100

To obtain flour yield a 100-gram wheat sample (sample moisture taken into consideration) was put in glass jars, and a standard table was used to determine the amount of moisture content required to temper the wheat to 14% moisture basis. The tempered grain was milled to separate the bran from the flour. A 60 GG hand-sifter was used to separate the bran from the flour. The flour yield was calculated from the formular:

$$\% \text{ flour yield} = \text{weight flour} / (\text{total flour} + \text{bran}) * 100$$

3.5 Analysis of data

The analysis of the data was done on the Mstatc version 4 software. Analysis of variance (ANOVA) for a split plot design was performed on the data and the means were separated using the LSD procedure to test the effects of split top dressing nitrogen application and variety on grain yield, flour yield, flour ash, test weight, protein content, gluten content, falling number, 1000-grain weight, number of heads per m², and days to maturity.

The Statistical Model used in the data analysis was:

$$Y_{ijk} = \mu + M_i + B_j + \xi_{ij} \cdot T_k + (MT)_{ik} + \epsilon_{ijk}$$

where Y = Parameters

μ = Mean

M = Main plots

B = Replications

T = Subplots

ξ = Error for main plots

ϵ = Error for subplots and interaction

4.0 Results and Discussion

4.1 Grain yield

The split application of top dressing nitrogen treatments did not result in any significant differences in grain yield (Table 1 and Appendix 6). There were also no significant differences among the four varieties of wheat (Table 2). This indicates that the split top dressing nitrogen fertiliser did not affect the yield. This is in line with the results of Dampney and Salmon (1990), who found that application of nitrogen fertiliser at flowering time or later increased protein in the grain but had little effect on grain yield.

The varieties used have a yield potential of over 6 tonnes per hectare (Raemaekers and Little, 1987). In this trial, the average yield for the varieties ranged from 2798 to 3586 kg/ha. These yields are therefore lower than expected. This could be due to the poor water distribution during irrigation in the fourth replication that was receiving less water leading to poor plant growth in this replication. This replication was also attacked more by rats due to its proximity to the Eucalyptus plantation adjacent to it.

4.2 Flour Yield.

There were no significance differences due to varieties, split top dressing nitrogen fertiliser and interaction between split application of top nitrogen and varieties (Appendix 7). The different varieties did not affect the flour yield. There was no difference on flour yield in this experiment. This indicates that

split top dressing nitrogen fertiliser did not affect the flour yield. Flour yield is correlated positively with 1000-grain weight and test weight according to Gibson *et al.* (1998), but in this experiment the flour yield was not affected by the split top dressing nitrogen fertiliser application.

Table 1. Effect of split application of nitrogen fertiliser on grain yield and other parameters.

Split top dressing nitrogen (kg N/ha)	Grain yield (kg/ha)	Flour yield (%)	Flour ash (%)	Test weight (kg/hl)	Protein content	Gluten content	Falling number	Number of heads/m ²	1000 grain weight (g)	Days to maturity
28.75+86.25	3224.0	84.9	1.642	80.5	14.1	42.4	350.4	321.9	44.3	121.8
86.25+28.75	3172.0	84.2	1.438	80.8	13.5	42.1	340.0	321.3	44.1	121.8
57.50+57.50	3240.0	84.7	1.503	80.9	13.6	42.4	350.0	328.8	43.7	121.8
115.00+0.00	3152.0	85.1	1.587	81.2	13.0	42.4	343.3	334.1	42.9	121.8
CV (%)	9.9	2.6	12.3	0.9	7.4	2.6	7.0	11.6	2.0	0.0
Significance	NS	NS	*	NS	*	NS	NS	NS	**	NS
LSD	210.4	1.56	0.036	0.5	0.7154	0.78	17.4	27.2	1.583	0.0

Note: NS = Non significant

* = Significant at 5% level

** = Significant at 1% level

Table 2. Effect of variety on grain yield and other parameters.

Variety	Grain yield (kg/ha)	Flour yield	Flour ash (%)	Test weight (kg/hl)	Protein content	Gluten content	Falling number	Number of heads/m ²	1000 grain weight (g)	Days to maturity
Loerie II	3586.0	86.1	1.7	78.9	13.0	43.0	318.2	323.1	41.3	118.0
Nkwazi	2798.0	84.1	1.7	83.1	14.6	42.1	315.2	313.4	42.9	123.0
Pwele	3191.0	85.6	1.3	79.5	13.4	42.8	366.6	304.4	47.1	123.0
Nkanga	3215.0	82.9	1.5	81.9	13.1	41.5	383.6	365.0	43.6	123.0
CV (%)	12.2	2.5	5.6	1.6	2.4	2.4	7.1	10.2	1.7	0.0
Significance	NS	NS	**	**	**	NS	*	NS	**	NS
LSD	579.5	3.26	0.1385	2.093	0.5296	1.63	48.84	53.7	1.166	5

Note: NS = Non significant

* = Significant at 5% level

** = Significant at 1% level

4.2 Flour Yield.

The analysis showed that there were no significance differences due to varieties and split application of nitrogen fertiliser. There was also no significant interaction between split application of nitrogen fertiliser and varieties (Appendix 7). The different varieties did not affect the flour yield. There was no difference on flour yield in this experiment. This indicates that split top dressing nitrogen fertiliser did not affect the flour yield.

4.3 Flour ash.

There was a significance difference ($P \leq 0.05$) on flour ash from the effect of split application of nitrogen fertiliser. There were also significant difference ($P \leq 0.01$) among varieties for flour ash. The interactions between the split top dressing nitrogen application and the varieties resulted in a significance difference ($P \leq 0.01$) on the flour ash (Appendix 8).

Looking at split application of nitrogen fertiliser, flour ash content for 25% N at 3-leaf stage and 75% N at anthesis (1.642%) was not significantly different from 100% N at 3-leaf stage and 0% N at anthesis (1.587%) but it was significantly higher than 75% N at 3-leaf stage and 25% N at anthesis (1.438%) and 50% N at 3-leaf stage and 50% N at anthesis (1.503%) of recommended rate (Table 1).

Table 3. Effect of split top dressing nitrogen management and interactions on flour ash content.

Genotype	split top dressing nitrogen (% ratio)				Mean
	100/0	75/25	50/50	25/75	
Loerie II	1.725	1.637	1.625	1.750	1.684
Nkwazi	1.735	1.863	1.750	1.563	1.728
Pwele	1.475	1.052	1.200	1.302	1.259
Nkanga	1.412	1.200	1.438	1.950	1.500
Mean	1.587	1.438	1.503	1.642	1.543

Note: Ash content is a mean of four replications. To compare means in a column, $LDS_{0.05} = 0.135$; and in a row, $= 0.372$

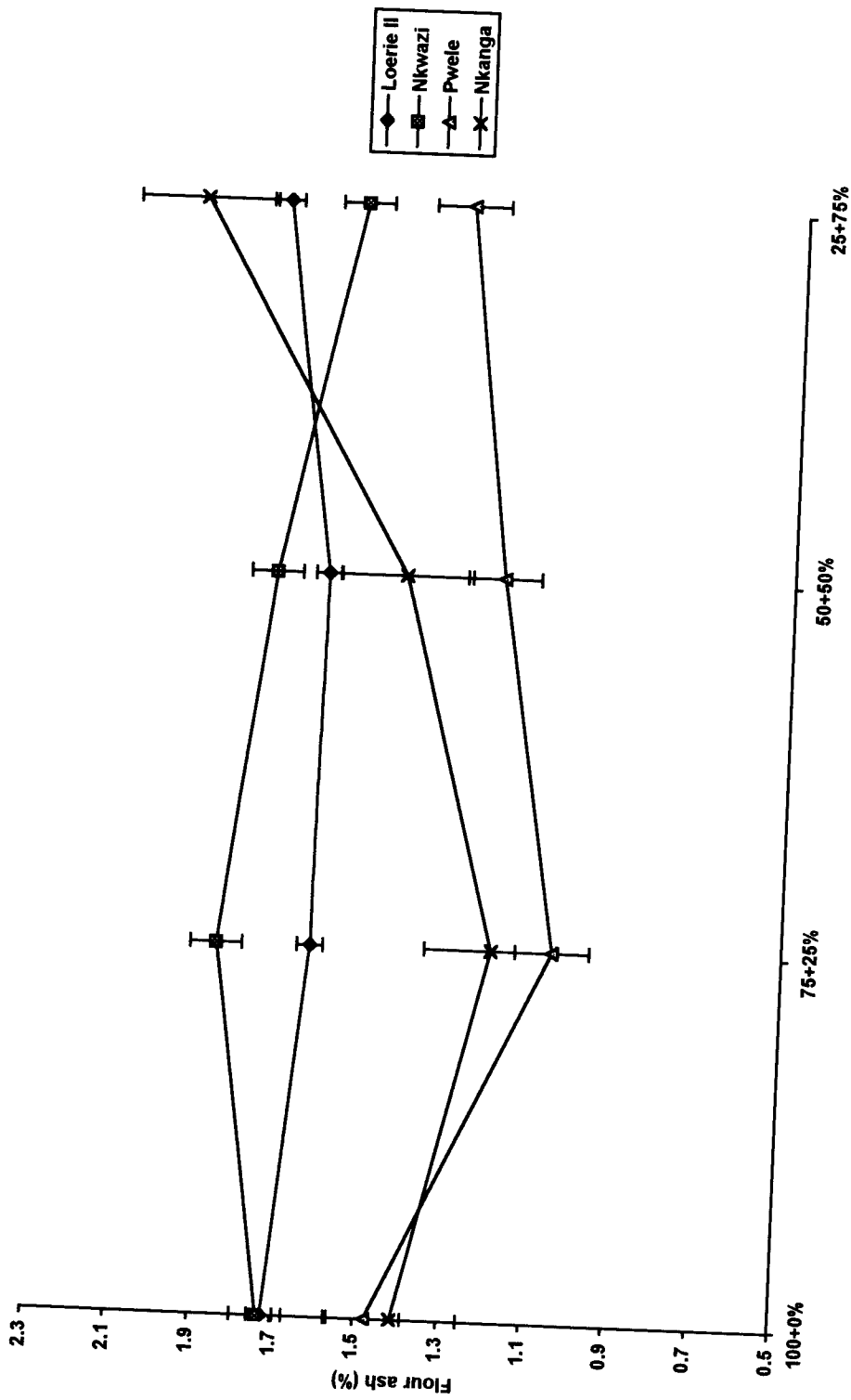


Figure 1: The effect of split top dressing nitrogen fertilizer application management on flour ash.

Nkwazi had the highest flour ash content (1.73%) followed by Loerie II (1.68%). However, these varieties were not significantly different. Nkwazi and Loerie II produced higher flour ash content than Nkanga (1.5%) and Pwele (1.26). Nkanga's flour ash content was higher than that of Pwele (Table 2).

There were differences on interactions with split application of nitrogen fertiliser and varieties for Nkanga with 25% N at the 3-leaf stage and 75% N at anthesis. The combination of Nkanga with 25% of N at 3-leaf stage and 75% of N at anthesis produced the highest ash content (1.95g) (Table 3 and Figure 1). It is significantly ($P \leq 0.01$) higher from the combinations of Pwele with 75%+25%, 25%+75%, 50%+50% and 100%+0%. It is significantly ($P \leq 0.01$) higher from the combinations of Nkanga with 75%+25%, 25%+75%, 50%+50% and 100%+0%. It is also significantly ($P \leq 0.01$) higher from the combinations of Nkwazi with 25%+75%. The flour ash of wheat ranges from 1.1 to 2.0% (Gilles and Sibbit, 1974). Douglas and Dyson (1985) examined 35 wheat samples and observed that baking score was positively correlated with nitrogen content and negatively correlated with 1000-grain weight. Looking at the results Loerie II and Nkwazi should give good baking score than Pwele and Nkanga.

4.4 Test weight.

The split application of nitrogen fertiliser did not affect the test weight (Appendix 9). However, the only significant difference ($P \leq 0.01$) was on the test weight for varieties. The test weight for Nkwazi was the highest among

the varieties and it was higher than Loerie II and Pwele. Loerie II and Pwele were not significantly different. Nkanga was the next but not significantly different from Nkwazi (Table 2). According to Gooding and Davies (1997), varieties of wheat can vary significantly with respect to test weight. The split top dressing nitrogen fertiliser did not affect the test weight in this experiment, hence it could not affect the flour returns although Taniguchi et al. (1995) found that the test weight was increased when wheat was top dressed at booting stage.

Hlynka and Bushuk (1959) found that in general, higher test weight resulted in higher flour yield returns. In this experiment, Nkwazi and Nkanga are expected to yield higher flour returns. Sharp (1927) reported that kernel density is directly related to protein content and in this trial Nkwazi and Nkanga protein content was significantly higher than other varieties thus confirming this relationship.

Flour yield increases and flour ash decreases with increasing test weight according to Finney and Yamazaki (1967). In this trial there was no difference in flour yield, but flour ash for Nkanga was significantly lower than for Nkwazi and Loerie II. Pwele also gave significantly lower flour ash than Nkanga while Nkwazi and Loerie II were not significantly different in their flour ash content.

4.5 Number of heads/m²

The analysis showed that there were no significance differences due to varieties and split application of nitrogen fertiliser. There was also no significant interaction between split application of nitrogen fertiliser and varieties (Appendix 10). The optimum number of heads per metre squared is 450 to 550 (Raemaekers and Little, 1987). In the trial the range was from 280 to 389 heads which was below the average. This result could have even contributed to the lower yields obtained this experiment. Splitting the application of top dressing nitrogen fertiliser did not affect the number of heads/m² in this trial.

4.6 1000-grain weight (g)

The 1000-grain weight was significantly ($P \leq 0.01$) affected by the split application of nitrogen fertiliser and the 1000-grain weight was also significantly ($P \leq 0.01$) affected by the varieties. The interaction between split top dressing nitrogen and varieties was also significantly ($P \leq 0.01$) affected (Appendix 11).

The split of 25% N at the 3-leaf stage and 75% N at anthesis gave highest 1000-grain weight value of 44.3 grams. However, the value was not significantly different from the values of 75% N at the 3-leaf stage and 25% N at anthesis and 50% N at the 3-leaf stage and 50% N at anthesis. It was significantly different to the split of 100% N at the 3-leaf stage and 0% N at anthesis which is the control (Table 1). The results suggest that split top

dressing nitrogen fertiliser can be used as one of the ways to increase seed size.

The Pwele variety had the highest 1000-grain weight, followed by Nkanga. Nkanga and Nkwazi had similar size of seed. Nkwazi and Loerie II was also not significantly different (Table 2). According to the results Pwele had the biggest seed size followed by Nkanga and Nkwazi which were more or less the same. Loerie II had the smallest seed size.

The combination of Pwele with 75% N at the 3-leaf stage and 25% N at anthesis gave the highest 1000-grain weight and it was significantly higher than all other combinations. This was followed by the combinations of Pwele with 50% N at the 3-leaf stage and 50% N at anthesis and Pwele with 100% N at the 3-leaf stage and 0% N at anthesis which were significantly different from the interactions of Nkwazi, Nkanga and Loerie II with different applications of N fertiliser. Pwele and split top dressing nitrogen fertiliser interactions increased the seed size more than other varieties (Table 4 and Figure 2).

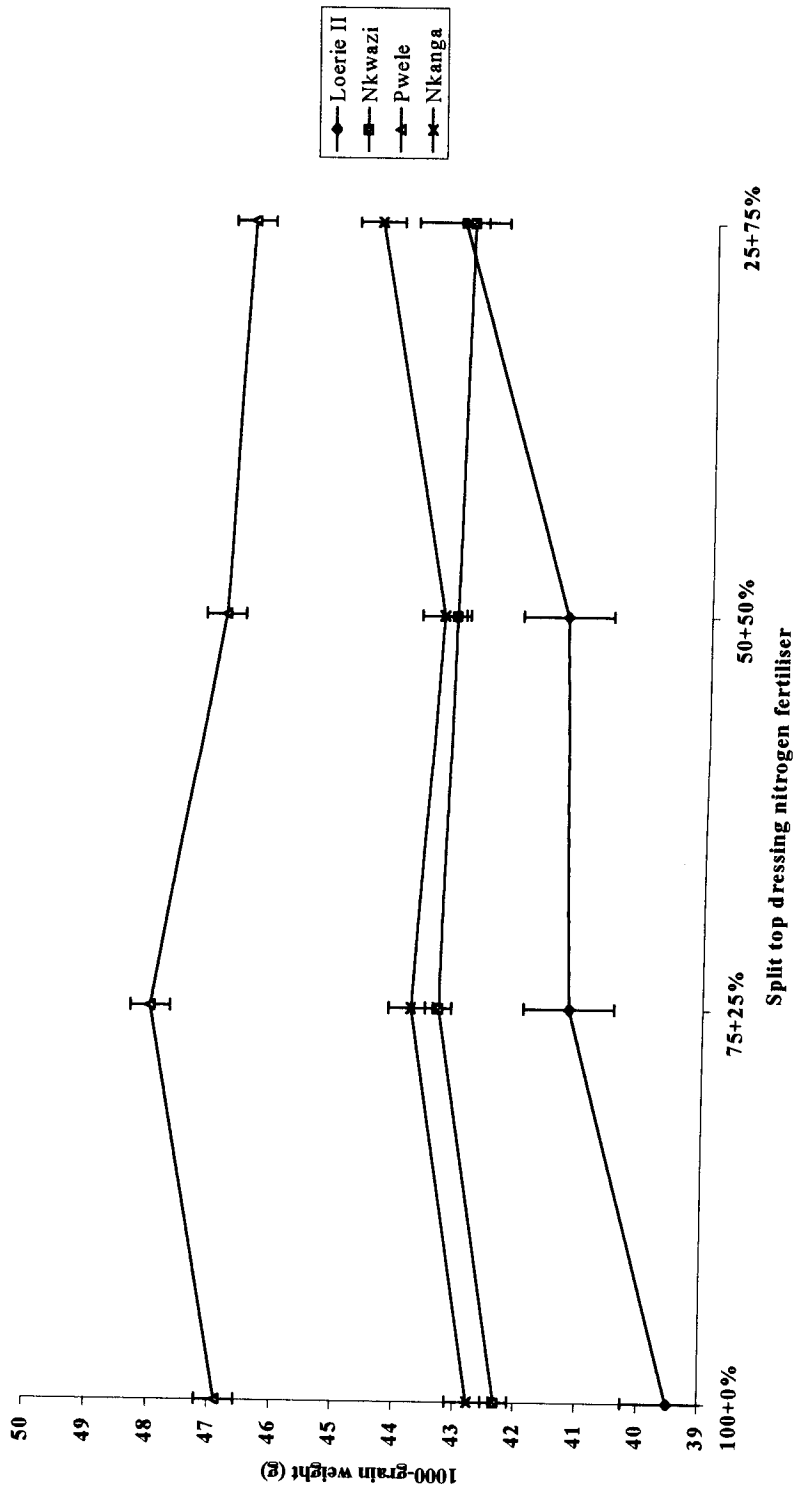


Figure 2: The effect of split top dressing nitrogen fertilizer application management on 1000-grain weight.

Gooding and Davies (1997) found that the 1000-grain weight could also give an indication of flour yield on the basis that large, well-filled, dense grain will contain greater amounts of endosperm compared with bran. If 1000-grain weight can indicate the flour yield, the split top dressing nitrogen application of 25% N at the 3-leaf stage and 75% N at anthesis, and 75% N at the 3-leaf stage and 25% N at anthesis in this experiment, were expected to give higher flour yield than 50% N at the 3-leaf stage and 50%N at anthesis and the control (100% N at the 3-leaf stage and 0% N at anthesis). The variety, Pwele was supposed to give more flour yield than other varieties because it had the highest 1000-grain weight, which can also give an indication of flour yield according to Gooding and Davis (1997). However, in this experiment there was no significance difference on flour yield for the varieties.

Table 4. Effect of split top dressing nitrogen management and interactions on and 1000-grain weight.

Genotype	split top dressing nitrogen (% ratio)				Mean
	100/0	75/25	50/50	25/75	
Loerie II	39.506	41.188	41.338	43.137	41.292
Nkwazi	42.319	43.325	43.163	42.963	42.924
Pwele	46.887	48.025	46.944	46.550	47.102
Nkanga	42.762	43.775	43.375	44.481	43.598
Mean	42.869	44.078	43.705	44.283	43.734

Note: 1000-grain weight is a mean of four replications. To compare means in

a column, $LDS_{0.05} = 0.621$ grams; and in a row, = 1.583 grams

4.7 Days to maturity

Loerie II took 118 days to reach physiological maturity while Nkwazi, Pwele and Nkanga took 123 days. The split top dressing nitrogen did not affect the maturity date for all the four varieties. The results indicate that maturity date will not be changed if N is applied as split top dressing. Nirala and Jha (1996) found that days to maturity were associated with grain yield, which was not observed in this experiment.

4.8 Protein content.

There was a significant difference ($P \leq 0.05$) in protein content due to split application of nitrogen fertiliser. There was also a significant difference ($P \leq 0.01$) in protein content due to varieties. The interactions between split top dressing nitrogen and with varieties was not significant (Tables 1, 2 and Appendix 12).

Only applying 25% N at the 3-leaf stage and 75% N at anthesis gave higher protein content than the control (100% N at the 3-leaf stage and 0% N at anthesis (Table 1). Although Phiri and Mwale (1995), suggested a proportion split of 75% as first dose and 25% as a second dose, in this experiment it was the 25% as first dose and 75% as a second dose which was significantly different to the control. According to Ayoub *et al.*, 1995, splitting nitrogen application increased protein concentration and bread loaf volume. This means that from these results the loaf volume of bread will be increased with

split top dressing nitrogen fertiliser. In terms of protein content, Nkwazi was significantly different from Loerie II, Nkanga and Pwele while Loerie II, Nkanga and Pwele were not significantly different from each other (Table 2). All the varieties had protein contents of above 13%. This shows that they were well above the minimum requirement for acceptable standards for local wheat in Zambia (Appendix 5).

4.9 Gluten content.

The analysis showed that there were no significance differences due to varieties and split application of nitrogen fertiliser. There was also no significant interaction between split application of nitrogen fertiliser and varieties (Appendix 13). This result indicates that the split top dressing nitrogen application had no effect on gluten content in this experiment. Although Kulkarni (1987) found that there is a high correlation coefficient between gluten and protein content, there was no indication of this relationship in this experiment.

4.10 Falling number

The analysis showed that there were no significance differences due to varieties and split application of nitrogen fertiliser. There was also no significant interaction between split application of nitrogen fertiliser and varieties (Appendix 14). The falling number was significantly different ($P \leq 0.05$) among varieties only. Nkanga and Pwele had significantly higher falling number than with Loerie II and Nkwazi. Nkanga and Pwele were not significantly different between themselves as Loerie II and Nkwazi were also

not significantly different (Table 2). However, the falling numbers for varieties were within the range of acceptable levels for alpha-amylase enzyme (Appendix 5).

5.0 Conclusion

This study has shown that applying the recommended rate of top dressing nitrogen in two splits (at 3-leaf stage and at anthesis) does not influence grain yield, flour yield, test weight, gluten content, falling number, number of heads/m² and date of maturity. The four test varieties responded similarly for grain yield, flour yield, gluten content and falling number.

However, split top dressing N significantly ($P \leq 0.05$) gave higher protein content in the wheat grain than the application of top dressing N fertiliser all at once at the 3-leaf stage (control). The total N of 115 kg of N/ha for top dressing application can improve the protein content if it is split in application of 25% of nitrogen at the 3-leaf stage and 75% at anthesis. The control (100% N applied at the 3-leaf stage and 0% N at anthesis) had 13.0% protein content while the highest protein content was obtained with a split of 25% N applied at the 3-leaf stage and 75% N applied at anthesis which had 14.1% protein content. The results show that splitting of top dressing nitrogen fertiliser at 25% N at the 3-leaf stage and 75% N at anthesis is recommended in order to obtain highest protein content. The split top dressing nitrogen fertiliser application increased the protein content and this can result in increasing the bread loaf volume. The split top dressing N fertiliser of 25% N applied at the 3-leaf stage and 75% N applied at anthesis increased the seed size by 3.6% and 2.8% respectively than the control. This means that the desirable large seed size of wheat grain can be got by splitting the top

dressing N fertiliser at 25% N applied at the 3-leaf stage and 75% N applied at anthesis.

The split application of the top dressing nitrogen fertiliser improves the baking quality of wheat. This study has shown that splitting application of top dressing nitrogen fertiliser at the ratio of 25% applied at the 3-leaf stage and the remaining 75% at anthesis resulted in higher protein content than other splits of 75% applied at the 3-leaf stage with the remaining 25% at anthesis and 50% applied at the 3-leaf stage with the remaining 50% at anthesis. Looking at the acceptable standards for local wheat in Zambia, the following quality factors were improved by the split application of N fertiliser at the ratio of 25% applied at the 3-leaf stage and the remaining 75% at anthesis, protein content up to 14.6% (11% minimum) and falling number up to 350.4 (250 minimum) see Appendix 5.

The variety Nkwazi had higher protein content (14.6%) than Pwele (13.4%), Nkanga (13.1%) and Loerie II (13.0%). Pwele (47.1g) had the biggest seed size than Nkanga (43.6g), Nkwazi (42.9g) and Loerie II (41.3g). Nkwazi had the highest ash content (1.73%) followed by Loerie II (1.68%) then Nkanga (1.5%) and lastly Pwele (1.26).

The interaction of Pwele and 86.25+28.75 (N kg/ha) resulted in increasing seed size (48.03 grams). The smallest seed size was got from the combination of Loerie II and control, which had 39.51 grams. The interaction of Nkanga and 28.75+86.25 (N kg/ha) yielded more ash content (1.95 grams)

while the combination of Pwele and 86.25+28.75 (N kg/ha) resulted in lowest ash content of 1.053 grams. The combination of Nkwazi and 28.75+86.25 (N kg/ha) resulted in higher moisture content (6.94%) than the combination of Nkwazi and 115+0 (N kg/ha) (5.63%).

The treatment that gave the desirable attributes of high protein content, flour ash and 1000-grain weight was 25% N applied at the 3-leaf stage and 75% N applied at anthesis. Since this study was done at one location and for one season only, it is recommended for it to be done at other locations to find out if the genetic by environment interactions can affect the results.

6.0 REFERENCES

- AACC 1995. Approved Methods of the American Association of Cereal Chemists. 9th Edition. American Association of Cereal Chemists, Salem, Maine, U.S.A.
- ANON. 1970. Official Grain Standards of the United States. U. S. Dep. Agr. Marketing Ser., Grain Div., Washington, D. C.
- Ayoub M.; S. Guertin; J. Reid Fregeau and D. L. Smith. 1994. Nitrogen fertilizer effect on bread-making quality of hard red spring wheat in Eastern Canada. Crop Science (USA). (Sep-Oct 1994). v. 34(5) 1346-1352.
- CIMMYT. 1979. Wheat Training Manual. Mexico. D.F. CIMMYT.
- CIMMYT. 1999. The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia: CIMMYT.
- Correl R.; J. Butler; L. Spouncer and C. Wrigley. 1994. The relationship between grain protein content of wheat and barley and temperature during grain filling. Australian Journal of Plant Physiology vol 21(6) 869-873.
- Costa J. M.; and W. E. Kronstad. 1990. Association of grain protein concentration and selected traits in hard red winter wheat populations in the Pacific Northwest. Crop Science (USA). (Sep-Oct 1994). v. 34(5) 234-239.
- Cygankiewicz A. 1998. Efficacy of preliminary evaluation of grain quality of winter and spring wheat forms and cultivars based on sedimentation value and protein content in comparison to results of complete

evaluations. Biuletyn Instytutu Hodowli i Aklimatyzacji Roslin. 1997, publ. 1998, No. 204, 237-243.

Dampney P. M. R; and S. Salmon. 1990. The effect of rate and timing of late nitrogen application to bread-making wheats as ammonium nitrate or foliar urea-N, and the effect of foliar sulphur application. I. Effect on yield, grain quality and recovery of nitrogen in grain. Aspects of Applied Biology. 1990, No.25, 229-241.

De Milliano W. A. J. 1983. Improvement of wheat in Zambia using incomplete resistance against rusts. Laboratorium voor Fytopathologie. Wageningen.

Djoke D. and M. Denic. 1985. Influence of foliar application of N on protein content of dryland wheat in northern New South Wales. Australian Journal of Experimental Agriculture. 31:1 85-92.

Douglas J. A. and C. B. Dyson. 1985. Preliminary investigation of concentrations of minerals and nitrogen in wheat grain and their relationship with baking quality and 1000-grain weight. New Zealand Journal of Agricultural Research. Vol 28:1 81-85.

Doyle A. D. and R. A. Shapland. 1991. Effect of split N applications on the yield and protein content of dryland wheat in northern New South Wales. Australian Journal of Experimental Agriculture. 31:1 85-92.

Finney K. F. and W. T. Yamasaki. 1967. Quality of hard, soft and durum wheats. In Wheat and Wheat Improvement. 471-503. Agronomy #13. American Society Agronomy. Madison. Wisconsin.

Gaines C. S.; P. L. Finney and L. C. Andrews. 1997. Influence of kernel size and shrivelling on soft wheat milling and baking quality. Cereal Chemistry. 74:6 700-704.

- Gibson L. R.; P. J. McCluskey; K. A. Tilley; G. and M. Paulsen. 1998. Quality of hard red winter wheat grown under high temperature conditions during maturation and ripening. *Cereal Chemistry*. 75:4 421-427.
- Gilles K. A. and L. D. Sibbit. 1974. in *Wheat: Production and Utilization*, AVI, Westport, Connecticut, U.S.A.
- Gooding M. J. and W. P. Davies. 1997. *Wheat Production and Utilization*. CAB International. Wallingford. UK.
- Grignani C. and A. Reyneri. 1990. Effects of nitrogen fertilizer applications and of phytosanitary control on soft wheat quality. *Informatore Agrario*. 1990, 46:41 45-49.
- Haldore H.; N. E. Borlaug and R. G. Anderson. 1982. *Wheat in the third world*. Westview. Boulder, Colorado.
- Hammonds D. H. 1981. *Wheat proteins: Their chemistry and nutritional potential*. In *Wheat Science To-day and Tomorrow*. Cambridge University Press. London.
- Hlynka I. and W. Bushuk. 1959. The weight per bushel. *Cereal Science Today*. 4:439-240
- Hubik K. 1995. The effect of fertilizer application and year on bread wheat quality. *Rostlinna Vyroba*. 1995, 41:11 521-527.
- Inglet G. E. 1974 *Wheat: Production and Utilization*, AVI, Westport, Connecticut
- Koekemoer F. P.; M. T. Labuschagne and C. S. van Deventer. 1999. A selection strategy for combining high grain yield and high protein content in South African wheat cultivars. *Cereal Research*

Communications. 1999, 27:1-2 107-114.

Kulkarni R. G.; J. G. Ponte Jr and K. Kulp. 1987. Significance of gluten content as an index of flour quality. *Cereal Chemistry*; 64:1 1-3.

Liu XiaoBing; Li WenXiong; X. B. Liu and W. X. Li. 1997. Effects of late nitrogen application on nitrogen translocation and protein fractions of wheat genotypes differing in protein content. *Journal of Northeast Agricultural University English Edition*. 1997, 4:2 89-94.

Loch J.; Z. Gyori and P. Pepo. 1998. Assessment of wheat quality in Hungary. Einfluss von Erzeugung und Verarbeitung auf die Qualität landwirtschaftlichen Produkte. Vorträge zum Generalthema des 110 VDLUFA-Kongresses, 14-18 September 1998, Giessen, Germany. 1998, 135-138; VDLUFA-Schriftenreihe 49.

MAFF. 1996. Wheat Research Annual Report for 1994/95. Research Branch. Mount Makulu Research Station, Chilanga, Zambia. 60pp.

MAFF. 1997. 1995/96 Agricultural Statistics Bulletin. Policy and Planning Division. Lusaka.

Malloch J. C. and R. Neton. 1934. The relationship between yield and protein content of wheat grain. *Canadian Journal of Research* 10:774-779.

Martin M.; F. Miceli; G. Mosca and G. Zerbi. 1990. Influence of nitrogen level and timing of application on the yield of winter wheat varieties. *Agricoltura Mediterranea*. 1990, 120:2 129-137.

Medcalf D. G.; K. A. Giles and L. D. Sibbitt. 1966. Detection of sprout damage in wheat. *Northwest. Miller* 5, 16-18.

- Metzger W. H. 1935. The residual effect of alfalfa cropping periods of various lengths upon yield and protein content of succeeding wheat crops. *Journal American Society Agronomy* 27:653-659.
- Mooleki P. 1995. Wheat and Barley (*Triticum aestivum* (L.) and *Hordeum vulgare* (L.) Sensulo). In Muliokela Stephen W ed. *Zambia Seed Technology Handbook*. Ministry of Agriculture Food and Fisheries. Zambia.
- Mooleki P. and H. Hill. 1992. Wheat Production by Small-Scale farmers in Zambia: Reality or Myth? In Tanner, D.G., and W. Mwangi, eds. 1992. *Seventh Regional Wheat Workshop for Eastern, Central and Southern Africa*. Nakuru, Kenya, CIMMYT 313-320.
- Nirala R. B. P. and P. B. Jha. 1996. Association of certain quantitative characters with grain yield in inter-varietal crosses of wheat. *Journal of Applied Biology*. 1996, 6:1-2 22-24.
- Olson R. A.; F. Dreuer; C. Thompson; K. Frank and P. H. Grabouski. 1964. Using fertilizer effectively on grain crops. *Nebraska Agricultural Experimental Station Research. Bulletin SB 479*.
- Osborne B. G. 1991, Measurement of the hardness of wheat endosperm by near infrared spectroscopy. *Post harvest News and Information*. 2:5, 331-334.
- Payne T. S.; D. G. Tanner, and O. S. Abdella. 1996. Current Issues in Wheat Research and Production in Eastern, Central and Southern Africa: Changes and Challenges In: Tanner D. G., T. S. Payne, and O. S. Abdella eds. 1996. *The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa*. Addis Ababa, Ethiopia. CIMMYT 1-7.

- Peltonen, J. 1992. Ear developmental stage used for timing supplemental nitrogen application to spring wheat. *Crop Science (USA)*. (Jul-Aug 1992). v. 32(4) 1029-1033.
- Peterson, C. J.; R. A. Graybosch; P. S. Baenziger and A. W. Grombacher. 1992. Genotype and environment effects on quality characteristics of hard red winter wheat. *Crop Science (USA)*. (Jan-Feb 1992). v. 32(1) 98-103.
- Phiri B. K. and S. Mwale. 1995. *Wheat: How to achieve high baking quality*. Mount Makulu Research Station.
- Purseglove J. W. 1972. *Tropical crops: Monocotyledons*, Longman, London.
- Raemaekers R. 1986. *Diseases and Pests of Rainfed Wheat in Zambia*. Department of Agriculture. Belgium Development Cooperation. Lusaka.
- Raemaekers R. and D. Little. 1987. *Wheat In: Mc Philips J. K. ed. 1976. Commercial Crop Production Recommendations*. Department of Agriculture. Lusaka. 3-17.
- Rao A. C. S.; J. L. Smith; V. K. Jandhyala; R. I. Tapendick and J. F. Parr. 1993. Cultivar and climatic effects on the protein content of soft white winter wheat. *Agronomy Journal* Vol. 85(5) 1023-1028.
- Schlehuber A. M. and B. B. Tucker. 1959. Factors affecting protein content of wheat. *Cereal Science Today* 4:240-242.
- Sharp P. F. 1927. *Wheat and Flour Studies IX*. Density of wheat as influenced by freezing, stage of development and moisture content. *Cereal Chemistry*. 4:14-46.

Spaargaren W. T. 1969. Republic of Zambia Office of the President. NCDP, Lusaka 139-212

Spaargaren, W. T. 1969. Report on the Detailed Soil Survey of Golden Valley, Farm No. 631/10. Mount Makulu Research Station, Department of Agriculture. Lusaka.

Stevens D.; B.; L. V. Vaidyanathan; J. H. Baldwin; D. J. Stevens; B. A. Stewart; S. C. W. Hook; A. G. Morgan; R. J. Cook; G. L. Jones; K. A. McLean; M. D. Gale; J. E. Flintham and C.M. Duffus. 1988. Hagberg falling number and breadmaking quality. HGCA Research Review. 1988, No. 2, 90 pp

Szof A and Z. Zelazowska Major. 1974. [Requirements for flour quality; determination for the purpose of flour standardization for bakery use. II. Determination of Hagberg falling number.]. Zagadnienia Piekarstwa ZBPP; No. 2, 1-8.

Szof A and Z. Zelazowska Major. 1975. [Proposed Hagberg falling numbers for flour, determined with reference to technological quality.]. Zagadnienia Piekarstwa-ZBPP; 20 (2) 23-29

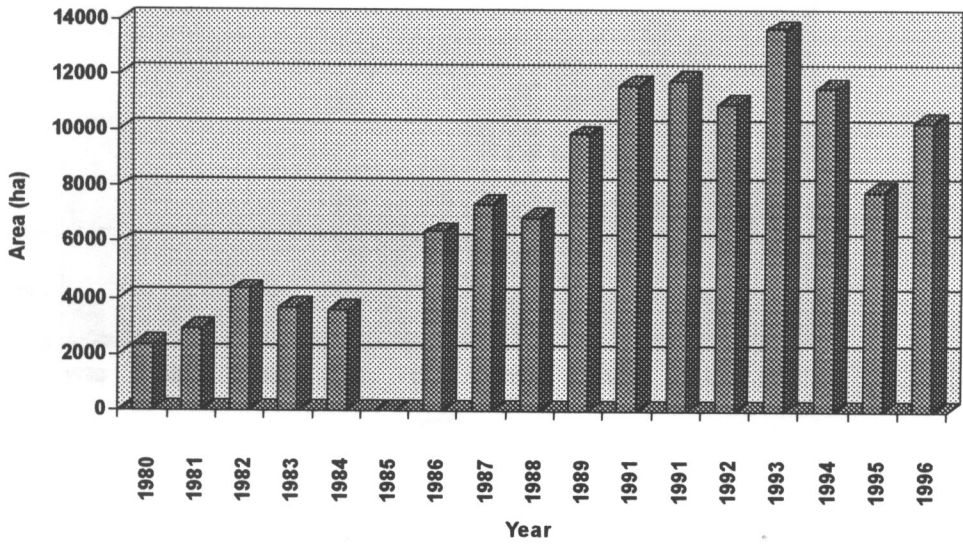
Szof A. and Z. Zelazowska Major. 1974. [Standardization of flour quality for bakeries. I. Quality of bakery products in relation to falling number and other flour quality characteristics.]. Zagadnienia Piekarstwa ZBPP; No. 1, 41-55.

Szof A. and Z. Zelazowska Major. 1975. [Assessment of Hagberg falling number for characterizing the processing quality of flour]. Przegląd Piekarski I Cukierniczy; 23 (8/9) 176-179.

- Taniguchi Y.; M. Fujita and A. Sasaki. 1995. The effects of black point on flour yield and quality of wheat. Report of the Kyushu Branch of the Crop Science Society of Japan. 1995, No. 61, 36-38.
- Tanner D. G.; M. van Ginkel and W. Mwangi. eds. 1990. Sixth Regional Wheat Workshop for Eastern, Central and Southern Africa. Mexico. D.F. CIMMYT
- Terman G.; L. R. E. Ramig; A. F. Dreier and R. A. Olson. 1969. Yield protein relationship in wheat grain as affected by N and water. *Agronomy Journal* Volume 61:755-759
- Trocchi A. and N. di Fonzo. 1999. Relationship between kernel size features and test weight in *Triticum durum*. *Cereal Chemistry*. 1999, 76:1 45-49.
- Uhlen A. K.; R. Hafskjold; A. H. Kalhovd; S. Sahlstrom; A. Longva; E. M. Magnus. 1998. Effects of cultivar and temperature during grain filling on wheat protein content, composition, and dough mixing properties. *Cereal Chemistry*. 1998, 75:4 460-465.
- Wrigley C. W. 1994. Developing better strategies to improve grain quality for wheat. *Australian Journal of Agricultural Research*. 1994, 45:1 1-17.
- Wrigley C. W.; C. Blumenthal and E. W. R. Barlow. 1994. Temperature variation during grain filling and changes in wheat grain quality. *Australian Journal of Plant Physiology* vol 21(6) 875-885.
- Wrigley C. W.; G. L. Lookhart; J. L. Steele (ed.) and OK Chung. 1997. Wheat protein as a quality determinant. Proceedings of the International Wheat Quality Conference, Manhattan, Kansas, USA, 18-22 May 1997. 1997, 51-59

Xu YangChun; Jiang TingHui; Zhang ChunLan; Wang YiBing; Cai DaTong;
Y. C. Xu; T. H. Jiang; C. L. Zhang; Y. B. Wang; D. T. Cai. 1998.
Responses of grain yield and protein content of bread-making wheat
cultivars to nitrogen application rate. *Acta Agronomica Sinica*. 1998,
24:6, 731-737.

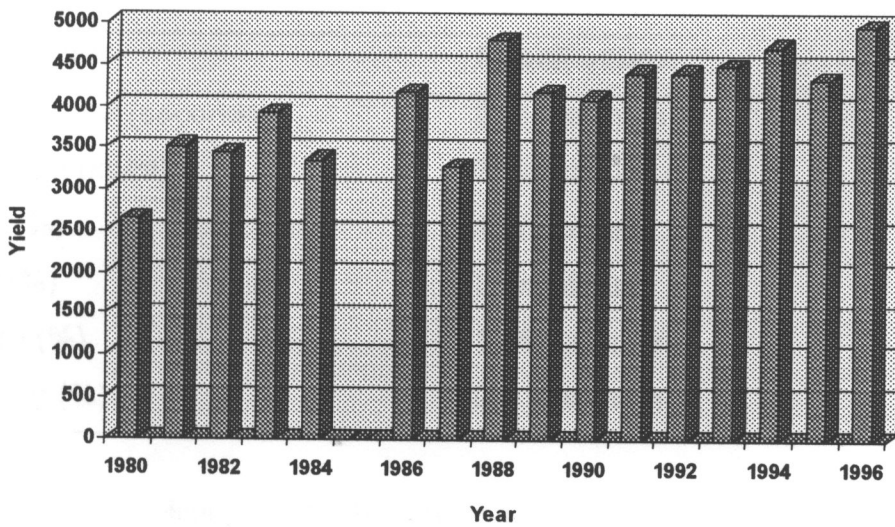
Appendix 2. Area under irrigated wheat production in hectares in Zambia from 1980-1996.



Source: MAFF. 1995/96 Agricultural Statistics Bulletin, 1997.

Note: There was no survey done in 1985

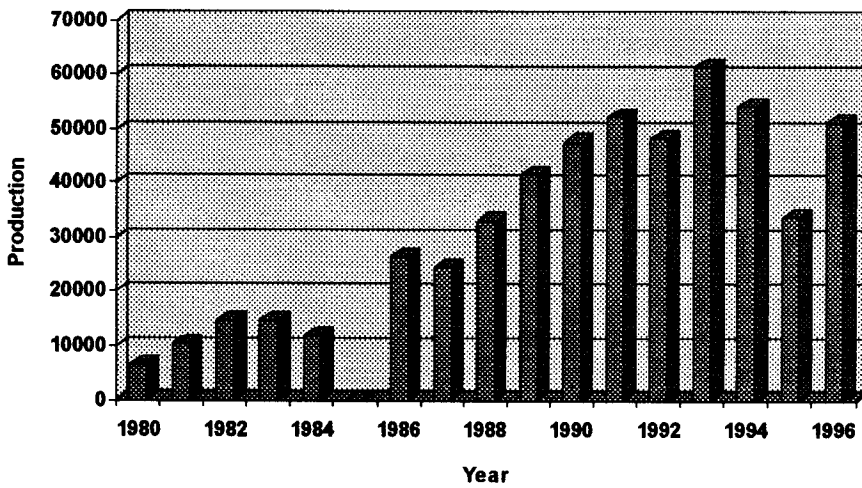
Appendix 3. Irrigated wheat yield per hectare in Zambia from 1980-1996.



Source: MAFF. 1995/96 Agricultural Statistics Bulletin, 1997.

Note: There was no survey done in 1985

Appendix 4. Irrigated wheat production in tonnes in Zambia from 1980-996.



Source: MAFF. 1995/96 Agricultural Statistics Bulletin, 1997.

Note: There was no survey done in 1985

Appendix 5. Acceptable standards for local wheat (Zambia).

Quality factor	Specification
Falling number (seconds)	250 minimum
Test weight (kg/hl)	75 minimum
Protein (%)	11 minimum
Gluten (%)	35 minimum
Moisture (%)	12.5 maximum
Screening (%)	0.5 maximum

Source: National Milling Company, Lusaka.

Appendix 6. Analysis of variance for grain yield

Source of variation	d.f.	s.s.	m.s.	F Value	F-Prob.
Replication	3	25890000	8629312		
Variety	3	4245498	1415165	2.70	0.110
Main plot Error	9	4725037	525004		
Nitrogen	3	63281	21093.7	0.24	0.841
VarietyxNitrogen	9	1257607	139734	1.62	NS
Error	36	3100681	86130.031		
Total	63	39280000			

CV (Main plot) 12.19

CV (Subplot) 9.87%

NS=Non significant

Appendix 7. Analysis of variance for flour yield

Source of variation	d.f.	s.s	m.s	F-Ratio	F prob.
Replication	3	68.399	22.800		
Variety	3	97.923	32.641	1.96	NS
Main plot Error	9	149.635	16.626		
Nitrogen	3	8.079	2.693	0.57	0.675
VarietyxNitrogen	9	47.005	5.223	1.10	0.511
Error	36	170.623	4.740		
Total	63	527.264			

CV (Main plot) 2.41%

CV (Subplot) 2.57%

NS=Non significant

Appendix 8. Analysis of variance for ash content

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob
Replication	3	0.1225	0.04084		
Variety	3	2.192	0.7308	24.19	<0.001
Main plot Error	9	0.2719	0.03021		
Nitrogen	3	0.3927	0.1309	3.67	0.021
VarietyxNitrogen	9	1.439	0.1599	4.48	<0.001
Error	36	1.285	0.03569		
Total	63	5.703			
CV (Main plot)		5.63%			
CV (Subplot)		12.25%			

Appendix 9. Analysis of variance for test weight

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob
Replication	3	4.806	1.602		
Variety	3	178.008	59.336	8.66	0.005
Main plot Error	9	61.649	6.850		
Nitrogen	3	3.115	1.038	2.06	0.055
VarietyxNitrogen	9	1.619	0.180	0.36	0.954
Error	36	18.141	0.504		
Total	63	276.338			
CV (Main plot)		1.62%			
CV (Subplot)		0.88%			

Appendix 10. Analysis of variance for heads per m²

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob.
Replication	3	10719.922	3573.307		
Variety	3	34460.547	11486.849	2.55	0.121
Main plot Error	9	40609.766	4512.196		
Nitrogen	3	1779.297	593.099	0.41	0.745
VarietyxNitrogen	9	13575.391	1508.377	1.05	0.422
Error	36	51739.062	1437.196		
Total	63	152884.			
CV (Main plot)	10.29				
CV (Subplot)	11.61				

Appendix 11. Analysis of variance 1000-grain weight

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob.
Replication	3	11.412	3.804	1.80	
Variety	3	287.172	95.724	45.04	<0.001
Main plot Error	9	19.129	2.125		
Nitrogen	3	18.706	6.235	8.34	<0.001
VarietyxNitrogen	9	21.209	2.357	3.15	0.007
Error	36	26.928	0.748		
Total	63	384.556			
CV (Main plot)	1.67%				
CV (Subplot)	1.98%				

Appendix 12. Analysis of variance for protein

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob.
Replication	3	3.844	1.281	2.92	
Variety	3	26.690	8.897	20.29	<0.001
Main plot Error	9	3.496	0.438		
Nitrogen	3	8.787	2.929	2.94	0.046
VarietyxNitrogen	9	6.879	0.7643	0.77	0.646
Error	36	35.831	0.995		
Total	63	85.976			
CV (Main plot)		2.44%			
CV (Subplot)		7.36%			

Appendix 13. Analysis of variance for gluten content

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob.
Replication	3	16.878	5.626		
Variety	3	24.029	8.010	1.92	0.160
Main plot Error	9	37.497	4.166		
Nitrogen	3	1.872	0.654	0.53	0.638
VarietyxNitrogen	9	11.893	1.321	1.12	0.434
Error	36	42.573	1.183		
Total	63	134.736			
CV (Main plot)		2.41%			
CV (Subplot)		2.57%			

Appendix 14. Analysis of variance for falling number

Source of variation	d.f.	s.s.	m.s.	F-Ratio	F-Prob.
Replication	3	2571.375	857.125		
Variety	3	55715.500	18571.833	7.72	0.006
Main plot Error	9	21637.125	2404.125		
Nitrogen	3	1569.375	523.125	0.89	0.347
VarietyxNitrogen	9	4086.125	454.014	0.77	0.781
Error	36	21101.500	586.153		
Total	63	106681			
CV (Main plot)	7.06%				
CV (Subplot)	6.97%				