UNIVERSITY OF ZIMBABWE

EFFECTS OF FOLIAR FERTILIZER APPLICATION DURING THE SEED FILLING PERIOD ON SOYABEAN (*Glycine Max* (L) Merr.) GRAIN YIELD AND SEED QUALITY

BY

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ABSTRACT

One major factor that prevents widespread adoption of soyabean (*Glycine Max* (L) Merr.) has been attributed to low yields. A research study focusing on the development of technologies to increase soyabean productivity and improve seed quality through use of foliar fertilizer during the reproductive stages was conducted at Thornpark Farm (UZ Farm) during the 2006/2007 cropping season. The response of soyabean variety Solitaire to OmniBoost and Folifert Molibor was evaluated. The effect of OmniBoost and Folifert Molibor on Solitaire seed quality was determined through foliar and grain nutrient analysis. Compound D (7% N: 14% P_2O: 7% K_2O) was used as a basal fertilizer. Foliar fertilizer was applied at three different growth stages during the pod-filling stage, that is, during the 7^{th}, 8^{th} and 9^{th} week after crop emergency. Different applications rates were evaluated as follows; rate I was the control (no foliar fertilizer applied), rate 2 (0.5kg OmniBoost + 0.5L Folifert Molibor, rate 3 (1kg OmniBoost + 1L Folifert Molibor, rate 4 (1.5kg OmniBoost + 1.5L Folifert Molibor), rate 5 (2kg OmniBoost + 2 kg Folifert Molibor) and rate 6 (2.5 kg OmniBoost + 2.5L Folifert Molibor), There was the standard rate recommended by the fertilizer manufacturers (2kg OmniBoost + 2L Folifert Molibor) which was applied at 4 weeks after crop emergency. The experimental design was a 3 x 6 incomplete factorial arranged in an Randomised Complete Block Design (RCBD) with three replications. There was a significant difference ($P<0.05$) in grain yield and yield components, such as the weight of 1000 seeds and the number of branches per plant. The control, where no foliar fertilizer was applied, was significantly lower than the other treatments. There was also a significant difference ($P<0.05$) in phosphorus (P) and molybdenum (Mo) content in the grain. The content of P and Mo increased with increase in the rate of foliar fertilizer applied. However, there were no significant differences in the other yield components, which are the number of pods, seeds and barren pods per plant. There was no significant effect of application time, interaction of rate and time on the foliar and grain nutrients (N, P, K, Mg, Ca, Mn, Zn, Fe, Cu). Evaluation of effect of these fertilizers on net income showed that it was only profitable to apply 0.5kg OmniBoost + 0.5L Folifert Molibor. The comparison of how well the crop used supplied nutrients under the respective treatments (Nutrient Use Efficiency) was done using the Agronomic Efficiency (AE) and the Partial Factor Productivity (PFP). Fertilizer use efficiency of N, P, Mg, Mo, B was calculated and it was observed that Agronomic Efficiency and Partial Factor Productivity (PFP) decreased with increase in the rate of foliar fertilizer applied. Germination tests were carried out to determine the viability of the seeds. There was no definite trend, which was established, but some significant differences were observed amongst the treatments. The control was significantly lower than all the other treatments and rate 3 where 1kg OmniBoost + 1L Folifert Molibor was applied during the 9^{th} week after crop emergency was significantly higher than all the other treatments. The other treatments were comparable. It can be concluded that foliar fertilizer application during the pod-filling stage can result in yield increases and grain phosphorus and molybdenum content. It was recommended that farmers use foliar fertilizer at rate 1 (0.5kg 0mniBoost + 0.5L Folifert Molibor) because it was found to be cost effective and farmers would realize less costs.

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God Bless You All!

DEDICATION

This research study is dedicated to my mother, Rosina Nyabadza, who has been growing soyabean since time immemorial and has now joined the Soyabean Taskforce in Zimbabwe.

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LIST OF ABBREVIATIONS

N	Nitrogen
P	Phosphorus
K	Potassium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Zn	Zinc
Fe	Iron
Ca	Calcium
Cu	Copper
B	Boron
OB	OmniBoost
FM	Folifert Molibor
UZF	University Of Zimbabwe Farm
ZW$	Zimbabwean Dollar
WACE	Weeks After Crop Emergence
Kg	Kilogram
Ha	Hectare
L	Litre
AE	Agronomic Efficiency
PFP	Partial Factor Productivity
RCBD	Randomized Completely Block Design
AOSA	Association Of Official Seed Analysis

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Soyabean (*Glycine max* (L) Merr.) has generally been described by many responsible and authoritative people as one of mankind's most remarkable foods. This description comes from the recognition that there are few other crops that have been found to have multi-purposes in both human and animal nutrition, as soyabean is a valuable source of human food and livestock feed. In developing countries like Zimbabwe, these uses have not been fully developed, yet the potential for a meaningful and significant contribution to agriculture and human nutrition is enormous (Javaheri, 1986).

Although, there is a great scope for the greater use of soyabeans as human food in Zimbabwe, and Southern Africa in general, the soyabean production system is not without its problems. The problems include soyabean productivity challenges that emanate from soil fertility, lack of suitable cultivars under harsh climatic conditions, lack of seed storage, and lack of processing facilities. One major factor that prevents widespread adoption of soyabean has been attributed to low yields (less than 900 kg/ha) (Whingwiri, 1986). In addition, high demand for labour, pod shattering, difficulties in harvesting, weed pressure, poor rains and low soil pH, were cited as major limiting factors in the production of soyabean (Mabika and Mariga, 1996). Investments in research over the years have made little impact on production of soyabean by smallholder farmers in Zimbabwe, who until recently accounted for only 2% of the crop (Rusike, Sukume, Dorward, Mpepereki and Giller, 2000). Much research has been focused on the use of soil applied fertilizers, yet very little research has been conducted to study the feasibility of foliar applied nutrients during pod–filling period of grain crops.

There are various processes that occur in soyabean plants that indicate a potential impact on yield of foliar fertilization during the seed-filling period. Research has indicated that as seeds fill they become dominant sink for carbohydrates being produced in the leaves (Giller, 2001). The soluble carbohydrate content in the stems and roots decrease. On the other hand, nodules stop fixing nitrogen, die and slough off, and sometimes root growth stops and uptake of some nutrients slows and eventually stops at this stage of grain filling (Wein, 1973). Thus, in order to supply foliar nutrients required by the developing seeds, nutrients are translocated from the leaves and other vegetative parts to the seeds (Vincent, 1970). This nutrient depletion of the leaves results in a decreasing rate of photosynthesis and in soyabean, the leaves turn yellow and fall off the plant.

It is therefore imperative to carry out a research on how to increase soyabean productivity in the smallholder farming sector. Research results produced elsewhere have shown that some opportunity exists for improving soyabean productivity if foliar fertilizer application with N, P, K and S during the seed-filling period is done (Vincent, 1970). Such foliar applications could be used to avoid depletion of these nutrients in the leaves. The resulting reduction in photosynthesis rate during this period due to poor nutrient uptake from the soil and translocation of these elements from the leaves to the developing seeds.

Efforts are being made to improve soyabean production in Zimbabwe smallholder farming sector, but no studies have been reported on the effects of foliar application of fertilizer nutrients on grain crops in Zimbabwe. Results from limited studies of soil applied nitrogen and phosphorus on soyabean grain yield generally have not been encouraging (Singh and Rashiell, 1987). This study aims to determine the effect of foliar fertilizer applications during the seed-filling period on soyabean yield and seed quality.

1.2 Objectives

The overall objective was to determine the efficacy of foliar fertilizer application during the seed-filling period of soyabean on grain yield and seed quality. Specific objectives were to:

(i) Determine grain yield and nutrient composition of soyabean sprayed with six rates of a combination of Omniboost and Folifert Molibor foliar fertilizers at three different stages during pod filling.

(ii) Compare the germination response of soyabean seed grown under the above treatments.

(iii) Determine possible interaction between foliar fertilizer application time and application rate on soyabean grain yield and seed quality.

1.3 Hypotheses

It was generally hypothesized that time and rate of application of foliar fertilizer during the seed filling period has no effect on soyabean grain yield, nutrient composition and germination response. Specific hypotheses were that:

(i) No significant differences exist among the grain yields and nutrients composition of soyabean sprayed with six rates of a combination of Omniboost and Folifert Molibor foliar fertilizers at three different stages during pod filling.

(ii) The germination response of soyabean seed grown under the above treatments is comparable.

(iii) Interaction between the time and the rate of application of the above foliar fertilizers during the seed-filling period has no significant effect on soyabean grain yield and seed quality.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Impact Of Research On Soyabean Performance In Zimbabwe

Soyabean production in Zimbabwe has mainly been confined to the large scale commercial farmers using highly capitalized production systems (Giller, 2001). In the smallholder farming sector, production started in the 1960s mainly in Hurungwe and Guruve Districts in the northern Zimbabwe where a variety called “Local” has been used up to recent times (Mpepereki, Javaheri, Davies and Giller, 2000).

According to Tattersfield (1986), the first soyabean breeding programme in Zimbabwe was carried out in 1960 by Mr H.C Arnold at Harare Research Station. There was interest in soyabean production among farmers and researchers in 1961 at Harare Research Station. Subsequently, Seed Co. established its own breeding programme in 1982, which has worked closely with the national programme (Seed Co., 2002)

The research areas that have been significantly contributing to increased soyabean production in Zimbabwe are breeding, agronomy, inoculation and pest control. Breeders have been seeking to develop genotypes that are high yielding, resistant to the major diseases and pests of their target environment, resistant to pod shattering, using conventional procedures (Singh and Rashiell, 1987). The first cultivar to be released was Oribi in 1973. Thereafter a number of cultivars have been released. Each new cultivar has had yield or agronomic advantages over its predecessors (Tattersfield, 1997). Agronomic studies into optimum planting dates, fertilization, plant populations and row widths have all contributed to improved yields

(Madhanzi, 2004), Inoculation studies have revealed generally poor nodulation, where the appropriate *Rhizobium spp* were not available or were poorly handled in application (e.g., improper storage and application) (Singh,*et al,* 1987). However, research on *rhizobium* led development of very effective legume inoculants for farm use, a pre-requisite for high yield in soyabean.

The disease complex includes bacterial, viral, fungal organisms, as well as nematodes and parasites, e.g., striga. An increase in pests and diseases can be expected as production intensifies, especially in new regions. Most worrisome are insects attacking new flowers, developing pods and maturing seeds. Considerable progress has been made in controlling semi-looper caterpillars, which can be a serious pest of soyabean using a naturally occurring virus, Nuclear Polyhydrolysis Virus (NPV) (Poole, Randall and Ham, 1983).

Zimbabwe has in recent decades developed a successful soyabean research programme, which has, provided an excellent production technology for the large scale commercial farming sector. As a result, the country is now the largest soyabean production country in Africa (Waddington, 2002). The output of soyabean is estimated at about 80 000 tonnes whilst domestic consumption is about 130 000 tonnes annually (Mpepereki *et al*, 2000), leaving a deficit of 50 000 tonnes that may be settled through importation. It is therefore important to promote the crop in all farming sectors, particularly the smallholder sector where growth potential is good as a result of resettlement of smallholder farmers into previously commercial land beginning the 1980s (Mpepereki *et al*, 2000).

However, the limited support received by smallholder farmers in Zimbabwe from extension prior to 1996 was partly due to inadequate information on soyabean production technologies under smallholder conditions. As noted, the success of the crop in the large- scale commercial sector is centred on the use of *rhizobia* inoculants and improved seed varieties. A lot of research work is done in Zimbabwe to develop more suitable soyabean cultivars for small scale farming systems. Increasing the quality and quantity of soyabean in Zimbabwe involves more than just developing new cultivars and introducing new agronomic practices. It requires the introduction of viable crop management packages capable of maximizing economic returns within the ecological environments of small farmers who at present face numerous other constraints (Mudita, 2004).

2.2 Benefits Of Soyabean Production In The Smallholder Farming Sector

Studies have shown that soyabean has potential in the smallholder as a food crop and for soil fertility improvement through biological nitrogen fixation (Waddington, 2002). A major attribute of soyabean is the versatile and multifarious nature of its potential and alternative uses, which, apart from the production of edible oil and cake for animal feed, include meal for direct human consumption, soyamilk, weaning foods for children, drinks, biscuits, soup dishes and several high protein health foods. Such foods would greatly assist in meeting the needs of the growing nation and for institutional markets as schools and hospitals especially with the advent of HIV/AIDS in the country.

Soyabean has potential to fix atmospheric nitrogen biologically and gives benefit to the soyabean crop and subsequent crops (Mpepereki *et al*, 2000). Compared to other legumes like groundnuts (*Arachis hypogeae)*, common bean (*Phaseolus vulgaris*), and cowpea (V*igna* *unguiculata*), soyabean has a low susceptibility to pests and diseases, high vegetative production and better seed storage. In Zambia, soyabean adoption succeeded because soyabean fetched better prices on the market than other crops (Mpepereki *et al,* 2000).

2.3 Foliar Fertilization

Foliar fertilization entails the application-via spraying-of nutrients to plant leaves and stems and their absorption at those sites (Garcia and Hanway, 1976). Used in both conventional and alternative production systems, it is a viable means of enhancing crop nutrition. Foliar feeding has been used as a means of supplying supplementary doses of minor and major nutrients, plant hormones, stimulants, and other beneficial substances. Observed effects of foliar fertilization include yield increases, resistance to diseases and insect pests, improved drought tolerance and enhanced crop quality (Faust, 1996).

2.3.1 Benefits Of Foliar Fertilization

Foliar applications are often timed to coincide with specific vegetative or fruiting stages of growth, and the fertilizer formula is adjusted accordingly. Applications may also be used to aid plants recover from transplant shock, hail damage or the results of other weather extremes. In terms of nutrient absorption, foliar fertilization can be from eight to twenty times as efficient as ground application (Arnon, 1995). However, this efficiency is not always achieved in actual practice. Often, failures result from inattention to the principles of foliar feeding. Other causes of failure include application at the wrong time (Arnon, 1995). Judging what foliar materials to apply and at what plant stage to spray them appears to be an art.

Because of the variability in research results and practical field experience with foliar feeding, opinions on its usefulness vary in both conventional and alternative agriculture circles (Faust, 1996). There is general consensus however that foliar fertilization should not be considered a substitute for a sound soil-fertility program (Omnia, 2006).

One of the benefits of foliar fertilization is the increased uptake of nutrients from the soil. This notion is based on the belief that foliar fertilization causes the plant to pump more sugars and other exudates from its roots into the rhizosphere. Beneficial microbial populations in the root zone are stimulated by the increased availability of these exudates. It is this rationale, in good part, that reinforces the use of foliar fertilization is organic agriculture, where the philosophy of “feed the soil, not the plant” prevails (Kuepper, 1998).

While foliar fertilization is being used on a wide variety of crops, its economic value is generally deemed greater for horticultural than for agronomic crops. This is because horticultural crops are of higher value and their nutrient status is more carefully monitored.

In areas where crop production has continued for some time and where the interactions of particular crops and soil have been well studied, certain nutrient deficiencies are predictable. Where these deficiencies involve secondary nutrients and micronutrients, foliar feeding often becomes the preferred means of correction. For example, foliar feeding is routinely used in some regions to manage zinc deficiencies on pecan crops (Kuepper, 1998). Likewise, calcium sprays have often been recommended as one means to prevent blossom end rot in tomatoes. The decision to spray in such cases is basically the result of past experience, often bolstered with soil test information and or observation of symptoms in the field (Kuepper, 1998).

Some proponents of foliar fertilization consider it an especially effective means of stimulating the natural defence mechanisms of plants. Studies to date are rather limited but have shown some positive results. Israeli research on corn (*Zea mays*) using foliar sprays of phosphate and of trace nutrients demonstrated induced resistance to several diseases (Zimmer, 2000).

2.3.2 Foliar Fertilization At Podfill Stage In Soyabean Production

There is no sharply defined transition from flowering to the pod and seed-formation stage. Pods, withered flowers, and newly opened buds may be found on the same plant, often at the same node. The first pods appear ten days to two weeks after the first flowers appear. Pod set, once started, proceeds at about the same speed as flowering. Under normal conditions it will be essentially complete in three weeks. The rate of pod growth and seed enlargements relatively slow at first, but picks up rapidly as flowering come to a halt (Wein, 1973).

The seed- filling period is the most critical time in the life of the soyabean plant. Anything that interferes with plant functions during this time can reduce grain yield. For example, if a hail storm causes a 100 % leaf loss when the beans are beginning to fill, there can be more than an 80 % reduction in yield. While the maximum number and size of seed is controlled genetically, the actual number and size produced is largely determined by conditions prevailing during the seed-filling period. Dry weather during seed-filling will not only reduce seed size, but may also reduce the number of seeds per pod. The plant actively accumulates nutrients from the soil during most of the pod and seed formation period. The plant draws about 30 % of its potassium and 40 % of its phosphorus and nitrogen from the soil after the seed-filling stage begins. It is at this stage where foliar application of nutrients is of paramount importance, as it places nutrients at the right place where almost all of it is accessible to the plants. Applying these nutrients to the soil, therefore, does not usually relieve the deficiency as absorption from the soil will not be adequate (Arnon, 1975). Some of the nutrients applied to soil are taken up by weeds, some are lost from the root zone by leaching, denitrification or volatilization, and some react with the soil to become less available.

Soyabeans are better efficient users of residual fertilizer phosphorus than any other field crops (Seed Co., 2002). A significant amount of potassium is removed with the crop, and there is a period in early growth when nitrogen must be available in the soil. As a result, fertilizer nitrogen, phosphorus and potassium must be applied to ensure the attainment of economic yields and the maintenance of productivity, unless soil analysis indicates otherwise.

Similarly, it is said that as soyabeans are legumes, they require no fertilizer nitrogen if inoculation is successful. Again this statement must be interpreted against the background of the situation under which soyabeans are grown. There is sufficient nitrogen within the seed to keep the plant growing for 2 to 3 weeks after emergence but the *rhizobia* only reach a level of activity from which the plant benefits from the fixed nitrogen some 5 to 6 weeks after germination (Seed Co., 2002). There is therefore a time gap, which if not bridged by soil available nitrogen, can adversely affect the final yield. If the soil has little natural available nitrogen, then some fertilizer nitrogen must be applied to sustain the plant through this period.

Extensive research addressed foliar fertilization of soyabeans at reproductive stages during the 70s and 80s. The soyabean plant has been characterized by markedly reduced root activity during late seed development and increased translocation of nutrients and metabolites from other tissue into the seed (Boote, Gallagher, Robertson, Hinson and Hammond, 1978). This depletion of nutrients from leaves could result in decreased photosynthesis's, leaf senescence, and lower grain yields.

2.4 Factors That Affect Soyabean Seed Quality

There are several factors that affect soyabean seed quality. In general, seed quality is a function of four major factors which are, climatic conditions, the soil upon which the crop is grown, type of fertilizer and method of application used and the management practices followed. Seed quality in soyabean encompasses several important attributes which include genetic purity, physical purity, germination and vigour (Delouche, 1975).

The quality of soyabean seed is routinely evaluated by standard tests procedures (ADSA, 1970). These procedures include a purity analysis, germination test, and usually a moisture test. A germination test determines the percentage of the number of seeds capable of producing "normal" seedlings. In many ways, the standard germination test appears to admirably serve the needs and interests of seed analysts, seed control officials, and seed producers (Nandju, 1986). However, the germination test has several deficiencies which should be recognized. One of them is that it focuses primarily on the final and does not adequately take into account the very substantial loss in performance potential that can occur before the germination capacity is lost.

2.5 Fertilizer Use Efficiency

Fertilizer utilization efficiency is dependent on the way in which fertilizers are applied to crops, the time of fertilizer application and the type fertilizer used. The fertilizer should be placed in the right place where almost all of it is accessible to the plants and should be applied at the right time when it is needed by the plants. Such an approach would improve use efficiency in crop production, which is an important agronomic, economic and environmental goal (Liang and MacKenzie, 1994).

There is need for application of foliar applied fertilizers in some cases for example where soil applied fertilizer results in immobilization of nutrients, when nutrients are required quickly by the plants, when there is leaching problem and as a supplement when absorption from the soil is not adequate. One of the ways in which the utilization efficiency can be enhanced is by applying the fertilizer where it can all be utilized by the plants quickly like with foliar applied fertilizers. (Seed Co., 2002)

It is important to utilize nutrients as efficiently as possible. However, accomplishing this goal or even defining it is difficult to achieve. In general, getting as much of a nutrient as possible into the harvested portion of a crop is the concept of efficient nutrient use. Tracking the recovery of applied nutrients is a key component to measuring nutrient efficiency (Broadbent and Carlton, 1978).

CHAPTER 3

3.0 GENERAL MATERIALS AND METHODS

3.1 Study Site

The research study was carried out at the University of Zimbabwe Farm located 31° East and 17° 30" South. The Farm is in Natural Region lla, which is an area of very high yield potential. The area that comprises University of Zimbabwe Farm lies in Mazowe District in Mashonaland Central Province, of Zimbabwe. The highest point on the farm is 1480 metres above sea level with a fall of 60 metres to the lowest point. The terrain is flat with a slope of 2 % or less and suitable for crop cultivation (Kwela, 1998). This simulates smallholder farming situation as most smallholder farmers are now situated in such soils after the land redistribution programme.

The soils at University of Zimbabwe Farm are classified in Zimbabwe as the Harare 5E. 2 (Tyoic or Kandic Rhodustalf (U.S.D.A) Taxonomy). The soils are described as Chromic Luvisoils using the F.A.O classification (Nyamapfene, 1991). The soils of deep to moderately deep well drained granular clay soils derived from epidiorite with some intrusions of banded ironstone. Soil colour changes from red in the well drained areas to grey and black in the vleis. These black soils are deficient in phosphate and potash (Kwela, 1998).

The area has a mean annual rainfall of about 815 mm for 50 years up to 1987 with a range of 444 mm to 1270mm (Kwela, 1998). Most of the rainfall falls from November to March. The mean monthly maximum temperature ranges from 22°C in June and July to 28.5°C during the hot dry months of September to mid- November. The mean annual temperature is 19 °C. The farm simulates conditions under which most large commercial farmers are located (Mudita, 2004), hence the relevance of the study as a basis for future research work and also more importantly, for extrapolation to the smallholder farmers who are now located in similar agro-ecological conditions.

3.2 Description of Cultivar Used in the Experiment

Solitaire is an indeterminate soyabean cultivar, which can grow up to 95 cm in height and is suitable in the middleveld (800 to 1200 masl) where it takes 120 days to 95 % maturity and in the highveld (over 1200 masl) where it takes 125 days to 95 % maturity (Seed Co., 2002). The cultivar is resistant to most leaf diseases but susceptible to soyabean rust (*Phakospora pachyrrhizi*). It is slightly susceptible to Wildfire but is resistant to other diseases including red leaf blotch, downey mildew and bacterial blight. Some mustard spot may occur but this does not appear to reduce yields. Solitaire has a very high potential of over 4 t/ha and is very well adapted to the highveld and middleveld. Agronomically, it is an excellent variety with high resistance to lodging and shattering, a good clearance of the lower pods and good plant dehydration at maturity making it very suitable for combine harvesting.

3.3 Description of Fertilizers Used in Experiment

A combination of OmniBoost and Folifert Molibor foliar fertilizers, as recommended by the manufacturer, was applied (Table 3.1). OmniBoost (7.7 % N, 39.6 % P_2O_5, 4.2 % S, 3.1 % Mg, 0.35 % Fe, 0.004 % Cu, 0.092 % Mn, 0.004 % Zn, 0.008 % Mo) is a solid supplementary foliar applied fertilizer recommended for application on soyabean at 4 weeks after crop emergence (8 leaf stage). It is a water-soluble foliar product which stimulates the plant to perform its natural functions more efficiently by enhancing characteristics such as root development necessary for effective uptake of water and nutrients (Omnia, 2006). Folifert Molibor (1.1 g/L N, 1.5g/L P, 5.0g/L B, 23.8g/L Mo, 16mg/L Zn, 16mg/L Cu, 16mg/L Mn, 32mg/L Fe) is a liquid foliar fertilizer that supplies all the necessary micro nutrients as well as N and P in well balanced ratios for crops with a high boron and molybdenum demand like soyabeans, dry beans, sunflower, cotton, deciduous fruit. It is intended to supplement and not to substitute normal fertilizer programmes. The recommended rate for soyabean is 2-6 L/ha 2-4 weeks after germination (Omnia , 2006).

Table 3.1 Applied Nutrient Rates From A Combined Fertilizer Of Omniboost And Folifert Molibor (OB Represents Omniboost and FM Represents Folifert Molibor).

Combined spray in g/ha	N	P	Mg	Fe	Cu	Mn	Zn	B	Mo
Control	0	0	0	0	0	0	0	0	0
0.5kg/ha OB + 0.5L/ha FM	78.1	171.8	31	3.532	0.056	0.936	0.02	5.92	23.88
1kg/ha OB + 1L/ha FM	156.2	343.6	62	7.064	0.112	1.872	0.04	11.84	47.76
1.5kg/ha OB + 1.5L/ha FM	234.3	515.4	93	10.596	0.168	2.808	0.06	17.76	71.64
2kg/ha OB + 2 L/ha FM	312.4	687.2	124	14.128	0.224	3.744	0.08	23.68	95.52
2.5kg/ha OB + 2.5L/ha FM	390.5	859	155	17.66	0.28	4.68	0.1	29.6	119.4

KEY (OB = OmniBoost, FM = Folifert Molibor).

In addition to foliar application, Compound D (7% N: 14% P_2O: 7% K_2O) was applied as basal dressing at 150 kg/ha. *Rhizobium japonicum* (strain 1491) from Seed Co, was used to inoculate the soyabean seed at 0.8g/kg of seed. The need for inoculation is of paramount importance because in any situation where soyabean respond to nitrogen fertilization, more effective nodulation is needed.

3.4 Research Design And Experimental Treatments

Foliar fertilizer rate (Table 3.1) and application time (7, 8 and 9 Weeks After Crop Emergence (WACE)) were tested in a 6 x 3 factorial experiment with 16 treatments (incomplete factorial, since the Rate 1 plot was same for all application times). One additional treatment was Rate 5 at 4 WACE, making a total of 17 treatments. The experimental treatments were as follows,

Table 3.2 Experimental Treatment Combinations Used In The Experiment

rate / time	0 kg/ha OB + 0 L/ha FM	0.5kg/ha OB + 0.5L/ha	1kg/ha OB + 1L/ha FM	1.5kg/ha OB + 1.5L/ha FM	2kg/ha OB + 2L/ha FM	2.5kg/ha OB + 2.5L/ha FM
4 WACE					2	
7 WACE	1	3	6	9	12	15
8 WACE	1	4	7	10	13	16
9 WACE	1	5	8	11	14	17

3.5 Measurements And Records

Above ground biomass was determined by randomly sampling four plants from the net plot. The samples were oven dried to a constant weight at 60 °C for 48 hours, and the dry weights were determined. The four sampled plants were then crushed to powder and were analysed at the Department of Soil Science at the University of Zimbabwe for N, P, K, Mg, Ca, Zn, Cu and Fe.

At harvesting grain yield performance was determined from the net plots. Moisture standardization was done by weighing the grain sample and reweighing after oven drying. The yield was then corrected to 11 % moisture content. The other measurement was the 1000 seed weight, where 100 seeds were put in a Petri dish and weighed. The weight was then multiplied by 10 to determine weight of 1000 seeds.

Some other yield components that were also determined include the average number of plants, pods and seeds per plant. Four plants were randomly sampled from the net plot and an average number of branches, pods and seeds per plant were determined. Total grain N, P K, Crude Protein, Mg, Ca, Mn, Fe, Zn, Mo, B were also determined. Nutrient use efficiencies under the respective treatments were also estimated.

However, a standard germination test was carried out to determine the germination capacity of the soyabean seeds. Samples of the 17 treatments were arranged as an RCBD in the incubator with four replications, at a constant temperature of 25 °C for eight days to determine germination percentage.

CHAPTER 4

4.0 EXPERIMENT 1: EVALUATION OF SOYABEAN YIELD BENEFITS AND AGRONOMIC EFFICIENCY FROM FOLIAR FERTILIZATION DURING POD SEED FILLING

4.1 Introduction

The pod filling stage of soyabean is usually concurrent with a reduction in root activity and increased translocation of nutrients and metabolites into the seed, which may result in decreased photosynthesis, leaf senescence, and consequently lower grain yields (Kelling, 2003). Some foliar fertilizers have recently and locally been formulated to enhance root development necessary for effective uptake of water and nutrients, and delayed leaf senescence. These fertilizers include OmniBoost and Folifert Molibor, products from Omnia Fertilizer Company. However, no information has been reported on effectiveness of these foliar fertilizers, applied at pod filling, in improving soyabean grain yield.

Foliar applications are often timed to coincide with specific vegetative or fruiting stages of growth, and one of the important benefits of foliar fertilizer is the increased uptake of nutrients from the soil (Haq and Mallarino, 2000). This notion is based on the belief that foliar fertilizer causes the plant to pump more sugars and other exudates from its roots in the rhizosphere (Kuepper, 1998). In addition, beneficial microbial populations in the root zone are stimulated by the increased availability of these exudates. It is this notion that reinforces the use of foliar fertilizer in crop production.

This experiment was conducted to evaluate the effect of a combination of OmniBoost and Folifert Molibor application during soyabean pod filling stage. The aim was to determine the ideal time and rate of application, and the research objective was based on the hypothesis that there is no difference in grain yield and performance of soyabean when a combination of OmniBoost and Folifert Molibor is applied during the pod filling stage.

4.2 Materials and Methods

4.2.1 Trial Sites

The experiment was conducted during the 2006/2007 cropping season at Thornpark Farm, which was described in Section 3.1.

4.2.2 Experimental Treatments

The experiment evaluated the response of one soyabean cultivar (*Solitaire*) to different application times and rates of OmniBoost and Folifert Molibor during the pod filling period. The 17 treatments were as given in Section 3.4, with Rate 1 as the control (non foliar-fertilized). Rate 2 was effected by combining 0.5 kg of OmniBoost with 0.5 L of Folifert Molibor, while Rates 3 to 6 were effected by 0.5 kg (OmniBoost) and 0.5 L (Folifert Molibor) consecutive increments up to 2.5 kg (OmniBoost) and 2.5 L (Folifert Molibor), respectively. The 4 Weeks After Crop Emergence (WACE) application time was considered to be the standard as advised by the manufacturer, while the 7, 8 and 9 WACE were considered as the tested application times during the pod filling period, although this period can range up to 10 WACE.

4.2.3 Research Design And Trial Management

The research design was a 3 x 6 factorial (Section 3.4). Conventional tillage was used to prepare the land using tractor drawn reversible plough and was disked to obtain a fine tilth. The gross plot size was 3.5 m x 6 m. The trial was planted in the third week of December 2006 at 0.45 m x 0.07 m spacing, giving a total of 14 planted lines per plot. Seed was inoculated with *Rhizobium japonicum* strain 1491 and Compound D (7% N: 14% P_2O: 7% K_2O) was used to as a basal fertilizer at 150 kg/ha. Soyabean seed was hand dribbled along the opened furrows. The furrows were covered using hoes. The trial was hand weeded twice at two and five weeks after crop emergence.

During the third week after crop emergence the plants were attacked by snout beetles. The beetles emerged in large numbers and they fed on foliage, giving a ragged appearance. Cabaryl 85WP at 600g per 100L of water per hectare was used to control the beetles. During the eighth week after crop emergence, the crop was attacked by semi- lopper caterpillars. The severe attack of semi-loppers was mainly in the boarder rows, resulted in heavy defoliation of the leaves. Cabaryl 85WP at 1kg per 100 L of water per hectare was used to control the pest. The crop was rain fed, and throughout the cropping season rainfall data at the site was collected from another experimental station managed by the Department of Physics (University of Zimbabwe), located about 150 m from the study site. Foliar sprayings of Rates 1 to 6 were done at 4, 7, 8 and 9 WACE using a hand operated and calibrated knapsack sprayer. The sprayings were conducted in the mornings when the weather conditions were relatively calm.

Hand harvesting was done at 16 WACE using sickles by cutting aboveground soyabean plant in the net plot that was obtained by discarding the four lines at two ends of the plot and 1 m at the other ends of the plot, giving a net plot of 3.4 m^2. The grain was first tested for harvest readiness by shattering the pods and observing the pods colour and leaf drop. Easy shatter, brown pods and leaf drop-off indicated that the harvest was ready.

The grain moisture was determined (sample weight at harvest – oven dry sample weight)/sample weight as harvest), and the final grain yield was adjusted to 11% moisture content. The standardization of yield data was done and net income was calculated for the various treatments.

4.2.4 Nutrient Use Efficiency

The comparison of how well the crop used supplied nutrients under the respective treatments (Nutrient Use Efficiency) was done using the Agronomic Efficiency (AE) and the Partial Factor Productivity (PFP) described by Dobermann (2007).

The AE and PFP were calculated as:

$$AE = \frac{\text{Crop yield with applied nutrients} - \text{Crop yield with zero foliar fertilizer}}{\text{Foliar fertilizer rate}}$$

$$PFP = \frac{\text{Crop yield with applied nutrients}}{\text{Foliar fertilizer rate}}$$

4.2.5 Statistical Analysis

All the data was subjected to analysis of variance using Genstat Version 8.0 and SPSS Version 12. Probability plots were used to test for normality. Log transformation (log base 10) and square root transformation were used to transform the data. Pearson's Correlation was carried out to establish relationships that existed between yield and yield components.

4.3 Results

4.3.1 Rainfall Distribution

The rainfall distribution at the study site during the 2006 – 2007 cropping season is shown in Figure 4.1. The total rainfall between October 2006 and May 2007 was about 540 mm, and the rainfall was poorly distributed.

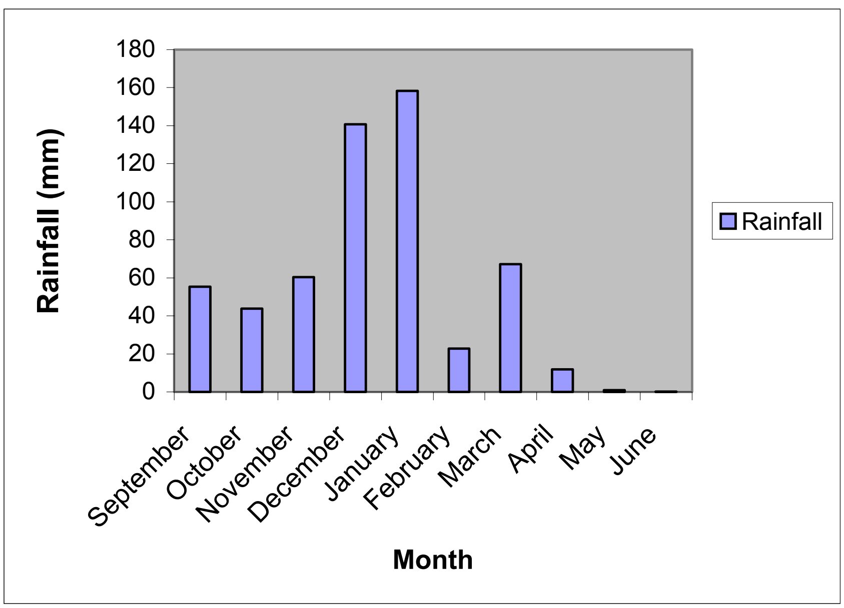

Figure 4.1 Rainfall Distribution During The 2006-2007 Cropping Season At Thornpark Farm (mm).

4.3.2 Effects Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On Soyabean Grain Yield

Soyabean grain yield was higher in treatments were foliar fertilizer was applied due to the main factor of application rate. Yields from 2705 kg/ha to 3461 kg/ha were realized and were comparable. However, the control was significantly (P < 0.05) lower than the rest of the treatments with 1914 kg/ha. There was no significant difference (P > 0.05) due to the main factors of time of application (including the standard time of 4 WACE) and time x rate interaction on soyabean grain yield (Figure 4.2). There was a strong positive correlation between grain yield, 1000 seeds weight and above ground biomass (P < 0.01).

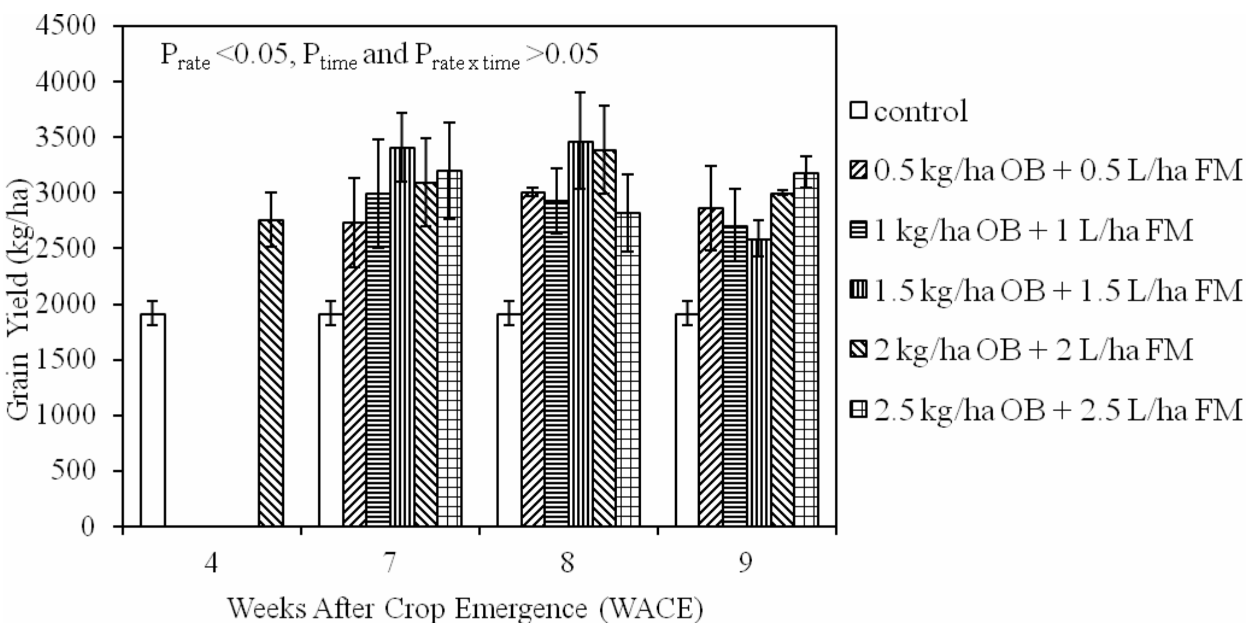

Figure 4.2 Response of soyabean grain yield to six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence. The rates are as given in Table 3.1. The error bars represent the standard errors of means.

4.3.3 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On Weight Of 1000 Soyabean Seeds

The results showed that application rate of foliar fertilizer during the pod filling stage had a significant effect ($P < 0.05$) on the weight of 1000 seeds (Figure 4.3). The control, where no foliar fertilizer was applied was significantly lower than all the other treatments. The control had a weight of 0.165 kg/ha as compared to other treatments, which ranged from to 0.188 kg/ha to 0.207 kg/ha, and were comparable. However, there were no significant differences due to the main factors of time and interaction between time and rate of application.

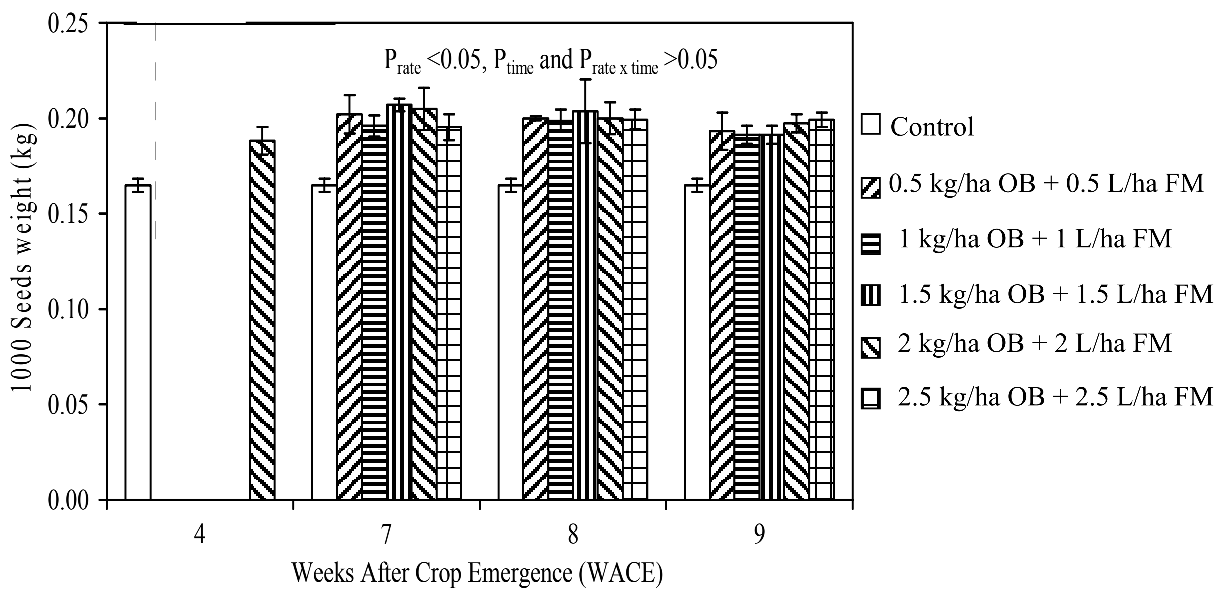

Figure 4.3 Response of 1000 seeds weight to six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence. The error bars represent the standard errors of means.

4.3.4 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On Soyabean Aboveground Biomass Of Soyabean Plants

Aboveground biomass ranged from 8150 to 14020 kg/ha (Figure 4.4). There was no significant effects ($P > 0.05$) due to the main factors of rate and time of application. The time of application, and rate x time interaction of foliar fertilizer also had no effect on aboveground biomass

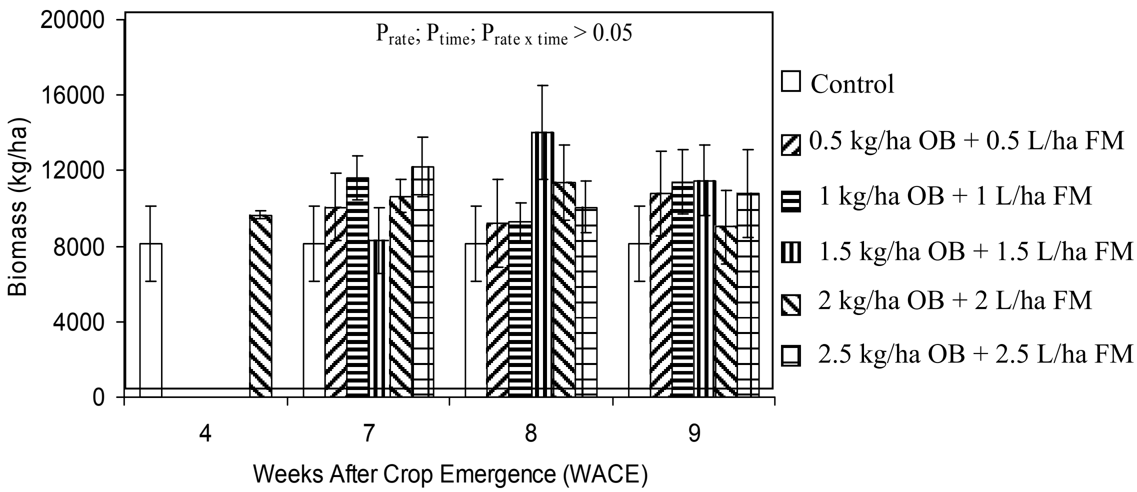

Figure 4.4 Response of Above Ground Biomass to six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop. The error bars represent the standard errors of means.

4.3.5 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On The Number Of Branches Per Plant

The number of branches per plant (means range, 2 to 5) increased ($P < 0.05$) due to the main effect of rate of application. The control was significantly lower than all the other treatments with a mean of 2 branches per plant. The other treatments where foliar fertilizer was applied had comparable numbers of branches per plant. There was no significant difference ($P > 0.05$) due to main factors of application time and time x rate interaction (Figure 4.5)

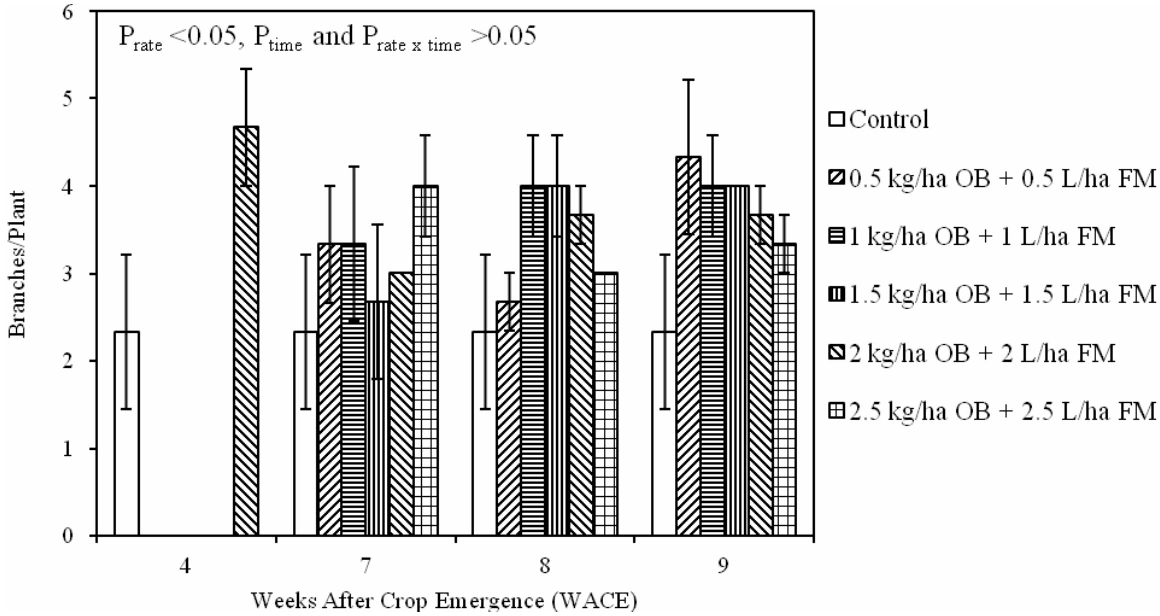

Figure 4.5 Effect of six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence on the number of branches per plant. The error bars represent the standard errors of means.

4.3.6 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On The Number Of, Pods And Seeds and Barren Pods Per Plant.

The application rates and application time of foliar fertilizer during the pod filling period had no significant effect ($P > 0.05$) on the percentage of barren pods, the number of pods per plant and number of seeds per plant (Figures 4.6, 4.7 and 4.8, respectively). Number of pods ranged from 28 to 55 per plant, while the number of seeds ranged from 63 to 110 per plant. Barren pods ranged from none to 6 per plant. There was also no significant difference due to rate x time interaction.

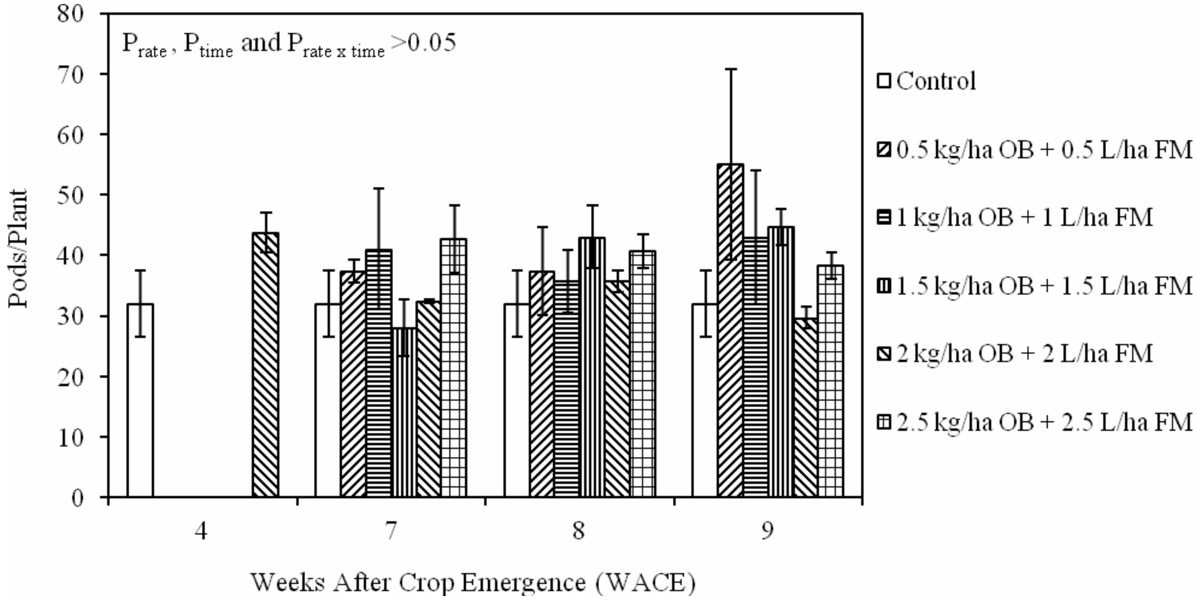

Figure 4.6 Effect of six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence on pods number per plant. The error bars represent the standard errors of means.

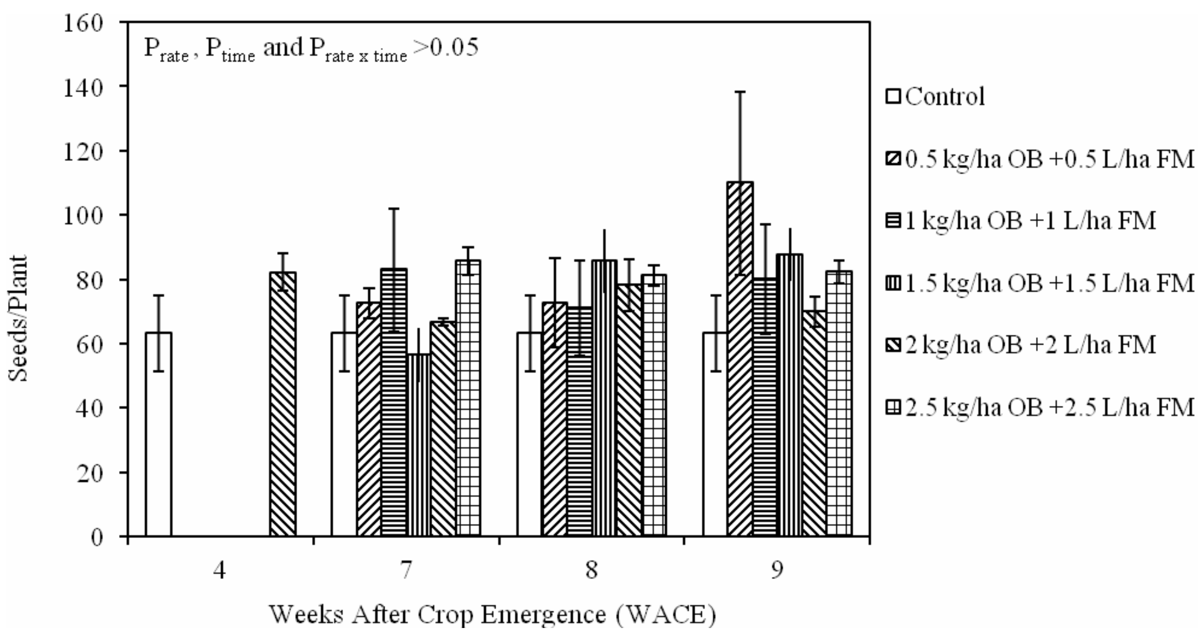

Figure 4.7 Response of soyabean seeds per plant to six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence. The error bars represent the standard errors of means.

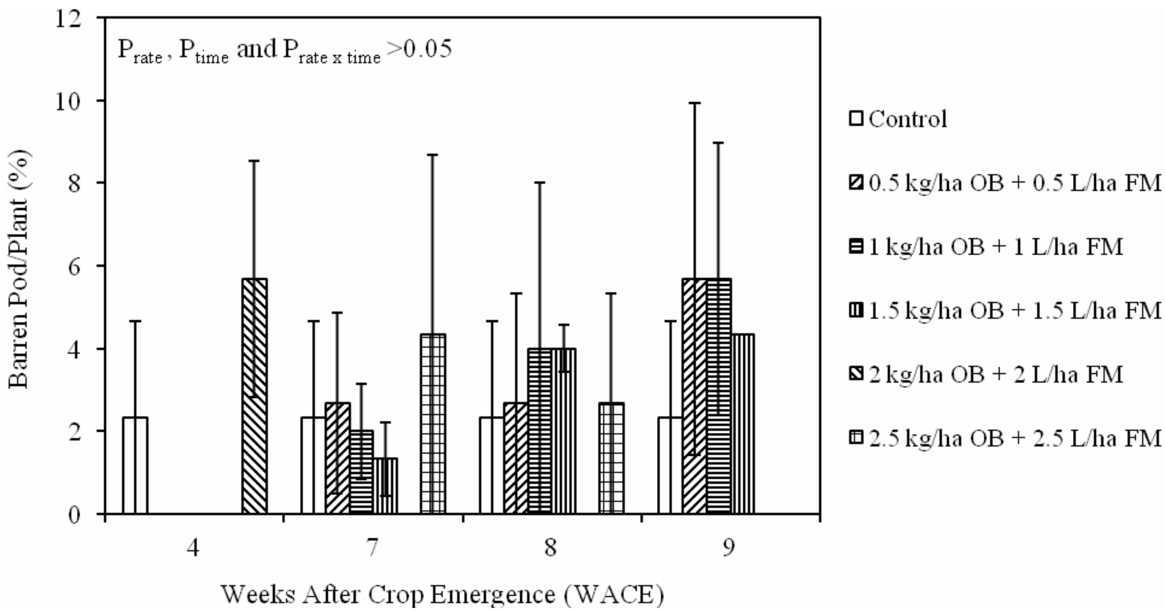

Figure 4.8 Effect of six rates of a combination of Omniboost and Folifert Molibor applied at 4 (standard), 7th, 8th and 9th week after crop emergence on % barren pods per plant. The error bars represent the standard errors of means.

4.4 Aboveground Whole Plant Nutrient Composition

The application rate and application time of foliar fertilizer during the pod filling period had no significant effect ($P > 0.05$) on N, P, K, Mg, Mn, Ca, Fe, Zn and Cu content in aboveground plant biomass at the 10th week after crop emergence (Table 4.1). There was also no significant interaction between the time and the rate of application on foliar nutrients.

Table 4.1: Nutrients Content Of Aboveground Soyabean Biomass (At The Tenth week After Crop Emergency) Under Seven Selected Treatments

Treatment (quantity per ha, and time)	N	Ca	Mg	K	P	Fe	Mn	Zn
	-----------------------%--------------------						-----mg kg^{-1}--	
Control	1.38	2.04	1.24	3.22	0.30	3.02	94.3	31.0
0.5 kg OB + 0.5 L FM @ 7 WACE	2.28	2.69	1.53	3.19	0.30	3.27	101.7	32.3
0.5 kg OB + 0.5 L FM @ 9 WACE	1.38	2.19	1.23	3.31	0.30	3.18	124.3	34.0
1.5 kg OB + 1.5 L FM @ 7 WACE	2.88	2.46	1.47	3.23	0.31	3.31	114.3	35.3
1.5 kg OB + 1.5 L FM @ 9 WACE	2.68	2.35	1.36	3.22	0.28	3.28	108.3	28.7
2.5 kg OB + 2.5 L FM @ 7 WACE	2.97	1.88	1.09	2.98	0.29	2.32	72.3	25.0
2.5 kg OB + 2.5 L FM @ 9 WACE	3.19	2.10	1.33	3.43	0.33	2.61	93.7	30.0
Significance	NS	NS	NS	NS	NS	NS	NS	NS
Cv, %	2.7	23.7	11.7	4.8	2.5	14.2	10.1	2.1

NS = Not Significant

4.5 Soyabean Grain Nutrient Composition

Results showed that there were no significant effects ($P > 0.05$) on grain N, K, Mg, Ca, Mn, Fe, Zn content of soyabean due to the main effects of application time and application rate of foliar fertilizer applied during the pod filling period (Table 4.2). There were no significant differences in the concentrations of these elements due to the rate and time interaction (Appendix 4).

However, there was a significant difference ($P < 0.05$) in molybdenum (Mo) and phosphorus (P) accumulation due to main effect of application rate x time (Figures 4.9 and 4.10). The grain that received no foliar fertilizer (control, rate 1) has significantly lowest Mo (6.17 mg/kg), followed by rates 2 and 4 at 7 and 9 WACE (14.2 and 16.3 mg/kg, respectively), while rate 6 at 9 WACE had the highest Mo content (21 mg/kg). Phosphorus content, like Mo, was significantly lowest in rate 1 (control), followed by rates 2 and 4 at 7 and 9 WACE (0.22-0.23 %), while rate 6 at 9 WACE also had the highest P content (0.25 %).

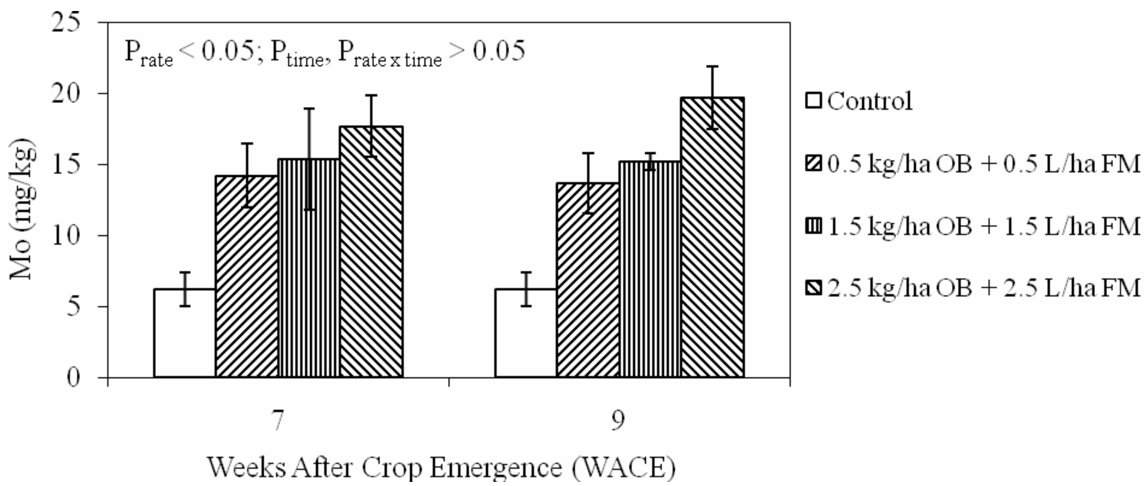

Figure 4.9 Effect of four rates and two application times of foliar fertilizer on soyabean grain molybdenum (Mo) content. Error bars represent the standard errors of means (SEMs).

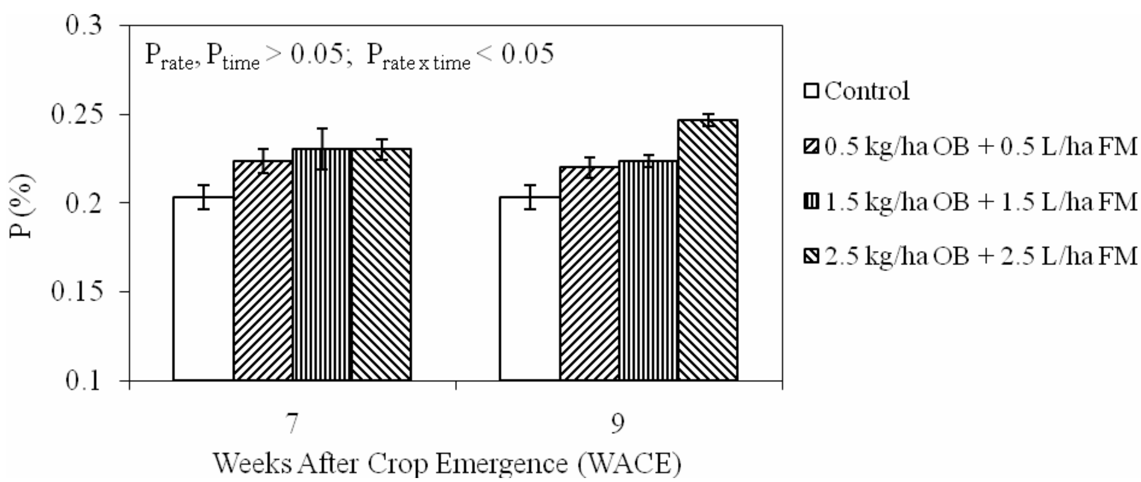

Figure 4.10 Effect of four application rates and two application times of foliar fertilizer on soyabean grain phosphorus (P) content. Error bars represent the standard errors of means (SEMs)

4.6 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On Net Income

The estimated net profits from the sale of soyabean produced under the respective treatments are given in Table 4.3. The calculations established that the optimum application rate was 0.5 kg/ha OB+ 0.5 L/ha FM, and that any application higher than this rate resulted in lower net profit. However, all foliar applications improved the net income considerably when compared with the net income from non-foliar fertilized soyabean.

Table 4.2 Estimated Net Profits From Sale Of Soyabean Produced At 6 Application Rates Of Omniboost Plus Folifert Molibor Foliar Fertilizer As At December 2006, US$ 1 =.ZW$ 250.

Application Rate	Foliar Fertilizer Cost	Fertilizer Application Cost	Grain Yield	Producer Price	Gross income	#Net profit (±)	±Net profit (#)
	------------ZW$/ha---------		t/ha	---------------------ZW$/t-----------------------			
0kg/haOB+0L/haFM	0	0	1.914[a]	4 500 000	8 613 000	8 613 000	8 613 000
0.5kg/haOB+0.5L/haFM	50 000	1 000 000	2.863[b]	4 500 000	12 883 500	11 833 500	11 833 500
1kg/haOB+1L/haFM	100 000	1 000 000	2.874[b]	4 500 000	12 933 000	11 833 000	11 783 500
1.5kg/haOB+1.5L/haFM	150 000	1 000 000	3.151[b]	4 500 000	14 179 500	13 029 500	11 868 500
2kg/haOB+2L/haFM	200 000	1 000 000	3.157[b]	4 500 000	14 206 500	13 006 500	11 683 500
2.5kg/haOB+2.5L/haFM	250 000	1 000 000	3.065[b]	4 500 000	13 792 500	12 542 500	11 633 500

The net profits were calculated with (±) and without (#) considering the significant differences in grain yield. Where yield differences were considered the yields from rates 3 to 6 were the same as of rate 2, i.e., 2.863 t/ha. Different subscript letters on the yield mean values within each column indicate that the means are significantly different (*P* < 0.05).

4.7 Fertilizer Use Efficiency

The foliar fertilizer use efficiencies in terms of N, P, Mg, Mo, B were estimated from the Agronomic Efficiency (AE) and the Partial Factor Productivity (PFP) (Table 4.4).

The AE (kg increase in yield per kg fertilizer applied) of rate 0f 0.5kg/ha OB+ 0.5L/ha FM was significantly higher than treatments with higher rates. The PFP (kg yield per kg fertilizer rate) decreased with increasing fertilizer from 0.5kg/ha OB+ 0.5L/ha FM to 2.5kg/ha OB+ 2.5L/ha FM.

Table 4.3 Mean Agronomic Efficiency (AE) Of Three Selected Fertilizer Rates Applied To Soyabean. SEs Represent Standard Errors.

Element	**Application Rate**	**Rate g/ha**	**Agronomic Efficiency**		**LSD**	**CV %**
			AE kg kg^{-1})	SE		
N	0.5kg/ha OB + 0.5L/ha	78	11302[a]	3010	5487	69.7
	1.5kg/ha OB + 1.5L/ha	234	4620[b]	782		
	2.5kg/ha OB + 2.5L/ha	391	3266[b]	517		
P	0.5kg/ha OB + 0.5L/ha	172	10276[a]	2737	4988	69.7
	1.5kg/ha OB + 1.5L/ha	344	4196[b]	710		
	2.5kg/ha OB + 2.5L/ha	515	2973[b]	471		
Mg	0.5kg/ha OB + 0.5L/ha	31	56946[a]	15166	27645	69.7
	1.5kg/ha OB + 1.5L/ha	62	23280[b]	3941		
	2.5kg/ha OB + 2.5L/ha	93	16454[b]	2607		
Mo	0.5kg/ha OB + 0.5L/ha	24	73925[a]	19688	35881	69.8
	1.5kg/ha OB + 1.5L/ha	48	30120[b]	5099		
	2.5kg/ha OB + 2.5L/ha	72	21360[b]	3384		
B	0.5kg/ha OB + 0.5L/ha	6	298198[a]	79416	144764	67.9
	1.5kg/ha OB + 1.5L/ha	12	121903[b]	20639		
	2.5kg/ha OB + 2.5L/ha	18	86160[b]	13651		

Table 4.4. Mean Agronomic Efficiency (AE) Of Three Selected Fertilizer Rates Applied To Soyabean. SEs Represent Standard Errors.

Element	Application Rate Number	Rate g/ha	PFP (kg/kg)	SE	LSD	CV %
N	0.5kg/ha OB+0.5L/ha	78	35805[a]	3182	5892	25.3
	1.5kg/ha OB+1.5L/ha	234	12788[b]	1032		
	2.5kg/ha OB+2.5L/ha	391	8166[c]	523		
P	0.5kg/ha OB+0.5L/ha	172	32554[a]	2893	5357	25.3
	1.5kg/ha OB+1.5L/ha	344	11613[b]	937		
	2.5kg/ha OB+2.5L/ha	515	7433[c]	476		
Mg	0.5kg/ha OB+0.5L/ha	31	180409[a]	16033	29689	25.3
	1.5kg/ha OB+1.5L/ha	62	64434[b]	5200		
	2.5kg/ha OB+2.5L/ha	93	41146[c]	2633		
Mo	0.5kg/ha OB+0.5L/ha	24	234199[a]	20814	28530	25.3
	1.5kg/ha OB+1.5L/ha	48	83366[b]	6727		
	2.5kg/ha OB+2.5L/ha	72	53414[c]	3418		
B	0.5kg/ha OB+0.5L/ha	6	944707[a]	83959	155470	25.3
	1.5kg/ha OB+1.5L/ha	12	337406[b]	27228		
	2.5kg/ha OB+2.5L/ha	18	215462[c]	13787		

Different subscript letters on the mean values within each column indicate that the means are significantly different ($P < 0.05$).

4.8 Correlation Among Yield Components

There was a strong positive correlation between above ground biomass, number of pods and seeds per plant ($P < 0.01$). Aboveground biomass was also positively correlated to the number of branches per plant and grain yield ($P < 0.05$). The weight of a 1000 seeds was strongly correlated to grain yield. However, some negative correlations were noted between grain yield, weight of 1000 seeds and the number of barren pods per plant.

4.9 Discussion

The results indicated that foliar application of a combination of OmniBoost and Folifert Molibor during pod-filling significantly improved soyabean grain yield, relative to non-foliar fertilized soyabean. The optimum rate of application was established to be a combination of 0.5 kg/ha Omniboost and 0.5 L/ha Folifert Molibor, and results showed that applying double this rate or even higher rates (up to 5-fold) did not result in any significant increase in grain yield. Instead, it would only compromise on the net income as shown by the estimated decrease in net income of between ZW$50 000 and ZW$200 000/ha (US$1 = ZW$250, December, 2006). The lack of increased grain yield when foliar fertilizer rates were increased from the established optimum could be an indication that the crop required few nutrients through foliar application as the soils used in this study may have contained almost adequate nutrients. A study by Freeborn (2000) on yield response of soyabean to late N and B application also showed lack of yield response at high soil fertility.

Time of application within the pod filling period (7, 8 and 9 WACE) did not have any significant benefit on soyabean grain yield, and no interaction was found between time and rate of application at 5 % significance level. Previous studies proved that due to the physiology of the soyabean plant, the majority of nutrients demand occurs when seed development begins, and that at this time the seeds become the nutrient sinks (Freeborn, 2000). The results of this study indicate that this nutrients demand, if met at any time within the period studied (i.e., within the early two weeks of pod filling), would result in similar yield benefit. Time of application was not significant also because application intervals were too close to each other. All the applications were done in a space of 14 days (3 consecutive Mondays). As a result, interaction was not significant too.

The yield components namely, weight of 1000 seeds and number of branches per plant responded to the applied treatments similarly to yield. Application of foliar fertilizer improved seed weight by 23 to 42 g per 1000, relative to non-fertilized soyabean. The results also showed a general varietal performance improvement by about 20 g, since the weight of 1000 seed of Solitaire has been reported at 190 g (Seed Co, 2000). Weight of a 1000 seeds is a function of variety, so it may mean that Solitaire performs better when applied with foliar fertilizer. However, no response to treatment was observed with respect to aboveground biomass at the 10^{th} WACE, % of barren pods per plant, number of pods and number of seeds per plant. The lack of response of soyabean biomass sampled at 10 WACE may be attributed to the sampling time. At 10 WACE the soyabean plants may have not had adequate time to accumulate all the biomass possible since the final aboveground biomass also included manure grain. Other characteristics such as number of seeds and pods per plant may be attributed more to the soyabean variety (Solitaire) than to the environment or treatment.

The nutrient composition (N, P, K, Mg, Mn, Ca, Fe, Zn and Cu) of soyabean aboveground biomass at the 10^{th} WACE did not vary significantly across all foliar fertilizer rates or application time, and no significant time x rate interaction effect was found on these nutrients. Like the observation that was made with yield at higher application rates, the lack of response may also be attributed to high inherent soil fertility at the study site.

The nutrient composition of soyabean grain, like aboveground biomass, did not respond significantly to treatment, except for P and Mo that were both highest at the highest foliar fertilizer application rate of 2.5 kg/ha OB+ 2.5 L/ha FM applied at 9 WACE, while least in the control treatment. Both P and Mo content of the grain increased with application rate at both 7 and 9 WACE. The results of the study agree with findings by Schon and Blevins (1987) that grain P content increases with foliar application of phosphorus. Furthermore, plants do not exhibit luxury consumption of P, they take only what is adequate and leave the rest in the soil or on leaves if the fertilizer was foliar applied. Therefore, it could be that most of the foliar applied phosphorus was then channelled towards the seed which was the main sink at the time of grain filling. In maize molybdenum levels have been noted to be high and this was found to increase the seed quality,

Results on foliar fertilizer use efficiency showed increasingly poor nutrients-use efficiency with increasing application rate, as reflected by the agronomic efficiencies and partial factor productivities. The optimum fertilizer use efficiency was observed at application rate of 0.5 kg/ha Omniboost and 0.5 L/ha Folifert Molibor. Decrease in fertilizer use efficiency with application rate was also concurrent with a decrease in the estimated net income. The results can be attributed to inherent soil fertility and the time of foliar fertilizer application during the pod-filling stage. The plants may not have received ample time to utilize the foliar applied nutrients.

4.10 Conclusion

Based on the results of this study, it can be concluded that the foliar application of a combination of OmniBoost and Folifert Molibor significantly improved the grain yield of soyabean. The economically optimum supplementary application rate in relation to the inherently fertile soil found at the study site was found to be 0.5 kg/ha OmniBoost plus 0.5 L/ha Folifert Molibor. The elemental composition (N, K, Mg, Mn, Ca, Fe, Zn and Cu) of soyabean aboveground biomass at the 10^{th} WACE and grain did not vary significantly across all foliar fertilizer rates or application time, and no significant time x rate interaction effect was found on these nutrients. However, P and Mo content of the grain increased with application rate at both 7 and 9 WACE.

4.11 Recommendations

It is recommended that farmers use a combination of 0.5kg OmniBoost + 0.5L Folifert Molibor as it improved soyabean yield and seed quality, with reference to P and Mo levels in the seed.

CHAPTER 5

5.0 EXPERIMENT 2: EVALUATION OF THE EFFECT OF FOLIAR FERTILIZER APPLICATION DURING THE SOYABEAN PODFILL STAGE ON GERMINATION PERCENTAGE

5.1 Introduction

Seed quality is a major issue in the smallholder farming sector. As many as 43 % 0f smallholder farmers use home saved seed as found out in the 1988/1999 growing season by Soyabean Task Force (Rusike *et al* 2000). If seed is “carried over” to the second planting season following production, it must be monitored carefully to ensure the maintenance of sufficient quality for planting purposes. Most smallholder farmers retain seed or obtain it from neighbours who would have retained it and is usually of poor quality (Madhanzi, 2004). Therefore, it was imperative to carry out this study on germination of soyabean seed.

Seed quality is a multiple concept comprising several components. For a farmer, quality means suitability for sowing on his farm, at a certain time of the year and for his own particular purpose. Of most importance to the farmer is the germination capacity and seed ability to produce a normal and vigorous seedling (Mariga, 1991). Germination in a laboratory is defined as the emergence and development of those essential structures, which indicate the ability to grow into a normal plant. A seedling which displays those essential features is said to be normal.

5.2 Materials and Methods

5.2.1 Germination Test Procedure

The experiment was carried out in the laboratory at the University of Zimbabwe Crop Science Department. It was carried out to evaluate the germination capacity of soyabean seed treated with foliar fertilizer during podfill stage. The experiment was carried out as a Randomised Complete Block Design (RCBD) with four replications. Samples of 200 seeds were collected from seventeen treatments and a standard germination test was used to determine seed viability using the between paper method. Newsprint was moistened and placed on a table. A newspaper was placed on top of the newsprint and 50 seeds from each sample were spread evenly on top of the moist newsprint. The newsprint and the newspaper were rolled with seeds inside and placed in Petri dish, put in the incubator for five days. On the sixth day measurements were collected using a criterion for normal, abnormal, dead and dormant seed as given in Section 2.4.2.

5.3 Results

The results showed that there was an effect due to the main effect of rate ($P < 0.05$). The control (91.5 %) was significantly lower than all the other rates where foliar fertilizer was applied. A combination of 1 kg/ha OB+ 1 L/ha FM applied during the 9th WACE (98.33 %) was significantly higher than all the other treatments. However, the other treatment combinations were comparable. (Figure 5.1).

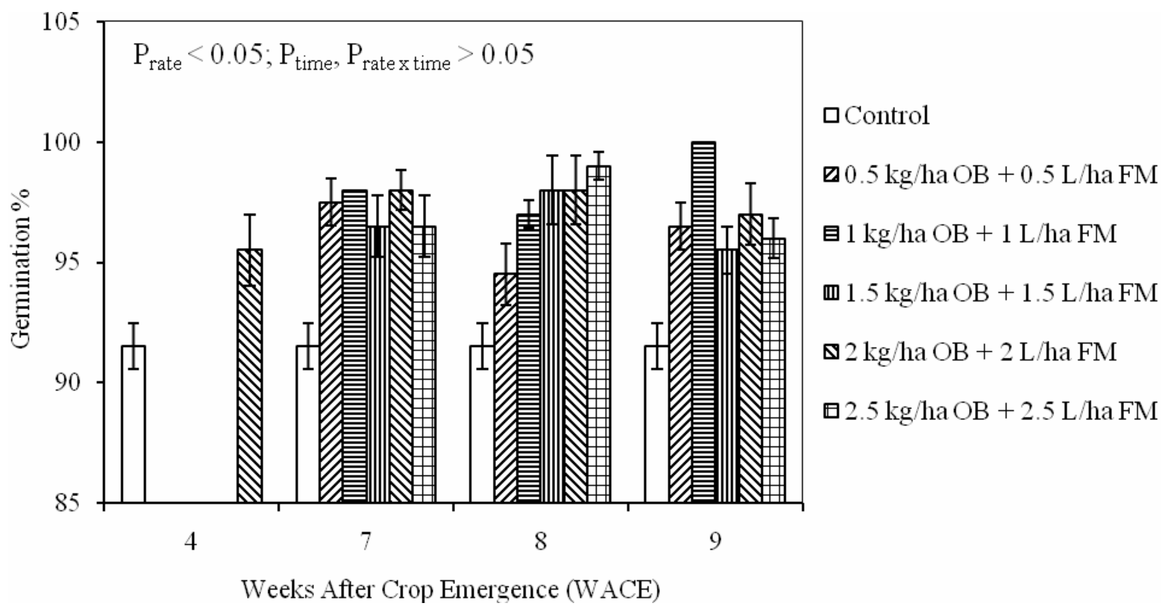

Figure 5.1 Effect Of Application Rate And Time Of A Combination Of Omniboost And Folifert Molibor Foliar Fertilizer During Podfill Stage On Germination % Of Soyabean Seeds

5.4 Discussion

There was no established trend on germination percentage between the treatments. However, the germination percentage was high as it ranged between 90-100 %. The reason for this finding can be attributed to residual soil fertility, which was possibly high as the soils at UZ Farm are heavily fertilized. An initial soil analysis to determine the type of soil was not done before the experiment. According to Seeds Regulation, (1971) the standard germination percentage of a good soyabean seed lot should not be less than 75 %. The results, however showed that the soyabean seed obtained from the experiment was a good quality seed with regards to germination percentage because it satisfied the requirements of the Seeds Regulation, 1971. The control had the least germination percentage with a mean of 91.5 % and the highest germination percentage mean was 98.33 %. Germination is a function of seed maturity and seedfill. It could possibly be that all the seeds had filled up and were physiologically mature at the time of harvest. This could have given rise to high germination percentages.

5.5 Conclusion

It can be concluded that application of OmniBoost and Folifert Molibor during the podfill stage can improve germination percentage of soyabean seed although there was no definite trend that was established of the germination rate amongst the different treatments of foliar fertilizer.

5.6 Recommendations

It is recommended to use a combination of OmniBoost and Folifert Molibor to improve germination percentage of soyabean seed.

CHAPTER 6

6.0 SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn based on this experimental study. Foliar fertilizer application of OmniBoost and Folifert Molibor at podfill stage significantly improved grain yields and seed quality of soyabean. The economically optimum supplementary application rate in relation to the inherently fertile soil found at the study site was found to be 0.5kg/ha OmniBoost + 0.5L/ha Folifert Molibor. The nutrient composition (N, K, Mg, Mn, Ca, Fe, Zn and Cu) of soyabean from the aboveground biomass did not vary significantly across all treatments. Foliar fertilizer rates, times of application, and rate x time interaction was not significant on foliar nutrients. However, P and Mo content of grain increased with application rate at both the tested 7 and 9 WACE. It can also be concluded that a combination of OmniBoost and Folifert Molibor can improve germination percentage of soyabean seed.

Therefore, it can be recommended that farmers use the established optimum of 0.5kg/ha OmniBoost + 0.5L/ha Folifert Molibor during podfill stage because it was found to be economic and farmers would realize less costs. It is also recommended that the experiment be repeated in soils with low inherent fertility. There is also a need to carry out another experiment with a rate which is lower than the optimum established by this experiment and evaluate whether it would still benefit the farmers. There is also great need to do further studies to evaluate the effect of foliar fertilizer on soyabean germination percentage, because from this experiment, no definite trend was established.

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APPENDICES

Appendix 1. Correlations Among Yield Components

Per plant		# of Branches	# of pods	# of seeds	# of barren pods	1000 seed weight	Yield	biomass
# of Branches	Pearson Correlation	1	0.723**	0.752**	0.158	-0.032	0.275*	0.289*
	Sig. (2-tailed)	.	0	0	0.242	0.816	0.038	0.029
# of pods	Pearson Correlation	0.723**	1	0.949**	0.328*	-0.179	0.062	0.379**
	Sig. (2-tailed)	0	.	0	0.013	0.184	0.647	0.004
# of seeds	Pearson Correlation	0.752**	0.949**	1	0.085	-0.146	0.161	0.368**
	Sig. (2-tailed)	0	0	.	0.53	0.277	0.231	0.005
# barren pods	Pearson Correlation	0.158	0.328*	0.085	1	-0.108	-0.164	0.226
	Sig. (2-tailed)	0.242	0.013	0.53	.	0.424	0.224	0.09
1000seed weight	Pearson Correlation	-0.032	-0.179	-0.146	-0.108	1	0.506**	-0.082
	Sig. (2-tailed)	0.816	0.184	0.277	0.424	.	0	0.544
Yield	Pearson Correlation	0.275*	0.062	0.161	-0.164	0.506**	1	0.264*
	Sig. (2-tailed)	0.038	0.647	0.231	0.224	0	.	0.047
Biomass	Pearson Correlation	0.289*	0.379**	0.368**	0.226	-0.082	0.264*	1
	Sig. (2-tailed)	0.029	0.004	0.005	0.09	0.544	0.047	.
	N	57	57	57	57	57	57	57

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Appendix 2 Analysis of Variance of Yield and Yield Components

2.1 Dependent Variable: Grain Yield (transformed – square root)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1157.229	17	68.072	2.830	.004
Intercept	151212.833	1	151212.833	6286.436	.000
RATE	977.225	5	195.445	8.125	**.000**
TIME	35.637	2	17.819	.741	.484
RATE * TIME	144.367	10	14.437	.600	.803
Error	865.938	36	24.054		
Total	153236.000	54			

2.2 Dependent Variable: 1000 Seeds weight (transformed – square root)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.274E-02	17	7.494E-04	3.866	.000
Intercept	10.404	1	10.404	53670.32	.000
RATE	1.182E-02	5	2.365E-03	12.198	**.000**
TIME	3.946E-04	2	1.973E-04	1.018	.372
RATE * TIME	5.217E-04	10	5.217E-05	.269	.984
Error	6.979E-03	36	1.939E-04		
Total	10.424	54			

2.3 Dependent Variable: %Barren pods per plant (transformed – square root)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21.069	17	1.239	.645	.832
Intercept	48.798	1	48.798	25.411	.000
RATE	13.579	5	2.716	1.414	.243
TIME	.579	2	.290	.151	.861
RATE * TIME	6.910	10	.691	.360	.956
Error	69.133	36	1.920		
Total	139.000	54			

2.4 Dependent Variable: Pods per plant (transformed – square root)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13.135	17	.773	1.085	.404
Intercept	2002.221	1	2002.221	2810.788	.000
RATE	5.609	5	1.122	1.575	.192
TIME	1.175	2	.587	.825	.447
RATE * TIME	6.351	10	.635	.892	.550
Error	25.644	36	.712		
Total	2041.000	54			

2.5 Dependent Variable: Branches per plant (transformed – log base 10)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.635	17	3.737E-02	1.243	.283
Intercept	13.087	1	13.087	435.358	.000
RATE	.407	5	8.133E-02	2.706	**.036**
TIME	5.518E-02	2	2.759E-02	.918	.409
RATE * TIME	.173	10	1.735E-02	.577	.821
Error	1.082	36	3.006E-02		
Total	14.804	54			

2.6 Dependent Variable: Seeds/plant (transformed – square root)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24.253	17	1.427	1.085	.403
Intercept	4048.429	1	4048.429	3080.093	.000
RATE	9.308	5	1.862	1.416	.242
TIME	3.186	2	1.593	1.212	.309
RATE * TIME	11.758	10	1.176	.895	.547
Error	47.318	36	1.314		
Total	4120.000	54			

Appendix 3: Analysis Of Variance For Foliar Nutrient Composition

3.1 Variate Fe %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.1876	0.0938	0.14	
rep.*Units* stratum					
A_Time_WACE	2	0.0154	0.0077	0.01	0.989
A_Rate_Kg_h	3	2.5262	0.8421	1.22	0.346
A_Time_WACE.A_Rate_Kg_h	1	0.1237	0.1237	0.18	0.680
Residual	12	8.3058	0.6921		
Total	20	11.1588			

3.2 Variate K%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.46837	0.23419	2.54	
rep.*Units* stratum					
A_Time_WACE	2	0.15680	0.07840	0.85	0.451
A_Rate_Kg_h	3	0.00614	0.00205	0.02	0.995
A_Time_WACE.A_Rate_Kg_h	1	0.17203	0.17203	1.87	0.197
Residual	12	1.10496	0.09208		
Total	20	1.90831			

3.3 Variate P%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.2857	0.1429	0.19	
rep.*Units* stratum					
A_Rate_Kg_h	3	2.4048	0.8016	1.06	0.401
A_Time_WACE	2	0.5000	0.2500	0.33	0.724
A_Rate_Kg_h.A_Time_WACE	1	0.3333	0.3333	0.44	0.519
Residual	12	9.0476	0.7540		
Total	20	12.5714			

3.4 Variate Mg %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.03247	0.01623	0.17	
rep.*Units* stratum					
A_Time_WACE	2	0.03820	0.01910	0.20	0.825
A_Rate_Kg_h	3	0.14023	0.04674	0.48	0.703
A_Time_WACE.A_Rate_Kg_h	1	0.22381	0.22381	2.29	0.156
Residual	12	1.17207	0.09767		
Total	20	1.60678			

3.5 Variate Ca % trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.1781	0.0890	0.38	
rep.*Units* stratum					
A_Time_WACE	2	0.2296	0.1148	0.48	0.627
A_Rate_Kg_h	3	0.7526	0.2509	1.06	0.403
A_Time_WACE.A_Rate_Kg_h	1	0.3862	0.3862	1.63	0.226
Residual	12	2.8424	0.2369		
Total	20	4.3889			

3.6: Variate Mn % trans

Variate: ppm_Mn_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	8.617	4.308	4.30	
rep.*Units* stratum					
A_Rate_Kg_h	3	8.935	2.978	2.97	0.068
A_Time_WACE	1	1.300	1.300	1.30	0.274
A_Rate_Kg_h.A_Time_WACE	3	2.474	0.825	0.82	0.503
Residual	14	14.031	1.002		
Total	23	35.357			

3.7: Variate Zn mg/kg trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.06446	0.03223	2.20	
rep.*Units* stratum					
A_Rate_Kg_h	3	0.16309	0.05436	3.71	0.038
A_Time_WACE	1	0.00029	0.00029	0.02	0.890
A_Rate_Kg_h.A_Time_WACE	3	0.01111	0.00370	0.25	0.858
Residual	14	0.20539	0.01467		
Total	23	0.44434			

Appendix 4: Analysis Of Variance For Grain Nutrient Composition

4.1: Variate Fe%_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.0029543	0.0004924	0.75	0.617
Residual	14	0.0091393	0.0006528		
Total	20	0.0120936			

4.2: Variate: Crude_protein_%_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
trt	6	0.0060740	0.0010123	1.04	0.443
Residual	14	0.0136901	0.0009779		
Total	20	0.0197640			

4.3: Variate_N% trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.0060187	0.0010031	1.02	0.449
Residual	14	0.0137064	0.0009790		
Total	20	0.0197251			

4.4: Variate K%_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.0032529	0.0005421	0.95	0.490
Residual	14	0.0079744	0.0005696		
Total	20	0.0112273			

4.5 Variate Ca%_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.00048194	0.00008032	1.28	0.329
Residual	14	0.00088148	0.00006296		
Total	20	0.00136342			

4.6 Variate Mg%_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.0014705	0.0002451	2.15	0.111
Residual	14	0.0015942	0.0001139		
Total	20	0.0030647			

4.7: Variate Cu_mg/_kg_trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.17169	0.02861	1.62	0.215
Residual	14	0.24805	0.01772		
Total	20	0.41974			

4.8: Variate P % trans

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	6	0.00038455	0.00006409	3.81	**0.018**
Residual	14	0.00023525	0.00001680		
Total	20	0.00061980			

4.9: Variate Mo mg/kg trans

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	427.667	7	61.095	3.193	.026
Intercept	4930.667	1	4930.667	257.672	.000
TIME	4.167	1	4.167	.218	.647
RATE	365.417	3	121.806	6.365	**.005**
TIME * RATE	58.083	3	19.361	1.012	.413
Error	306.167	16	19.135		
Total	5664.500	24			

4.10: Variate B mg/kg trans

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.305E-02	7	1.864E-03	1.051	.436
Intercept	6.912	1	6.912	3895.467	.000
TIME	3.192E-04	1	3.192E-04	.180	.677
RATE	2.028E-03	3	6.761E-04	.381	.768
TIME * RATE	1.070E-02	3	3.567E-03	2.010	.153
Error	2.839E-02	16	1.774E-03		
Total	6.953	24			

Appendix 5 Analysis of Variance for Nutrient Use Efficiency Parameters

5.1 Agronomy efficiency for N (Transformed data, natural log)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.713	2	.357	6.068	.012
Intercept	245.266	1	245.266	4173.304	.000
RATE	.713	2	.357	6.068	**.012**
Error	.882	15	5.877E-02		
Total	246.861	18			

5.2 Agronomy efficiency for P (Transformed data, natural log)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.712	2	.356	6.061	.012
Intercept	239.804	1	239.804	4080.247	.000
RATE	.712	2	.356	6.061	**.012**
Error	.882	15	5.877E-02		
Total	241.398	18			

5.3 Agronomy efficiency for Mg (Transformed data, natural log)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.713	2	.357	6.069	.012
Intercept	347.475	1	347.475	5912.578	.000
RATE	.713	2	.357	6.069	**.012**
Error	.882	15	5.877E-02		
Total	349.070	18			

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.285	2	.642	89.046	.000
Intercept	315.117	1	315.117	43684.188	.000
RATE	1.285	2	.642	89.046	**.000**
Error	.108	15	7.214E-03		
Total	316.510	18			

5.2 Agronomy efficiency for Mo (Transformed data, natural log)

5.3 Agronomy efficiency for B (Transformed data, natural log)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.714	2	.357	6.078	.012
Intercept	365.553	1	365.553	6220.085	.000
RATE	.714	2	.357	6.078	**.012**
Error	.882	15	5.877E-02		
Total	367.149	18			

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.713	2	.357	6.069	.012
Intercept	470.513	1	470.513	8006.166	.000
RATE	.713	2	.357	6.069	**.012**
Error	.882	15	5.877E-02		
Total	472.108	18			

Appendix 6: Nutrients use efficiency parameters

6.1 Partial Factor Productivity for N (Transformed data, natural log)

6.2 Partial Factor Productivity for P (Transformed data, natural log)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.284	2	.642	88.972	.000
Intercept	308.919	1	308.919	42825.992	.000
RATE	1.284	2	.642	88.972	**.000**
Error	.108	15	7.213E-03		
Total	310.311	18			

6.3 Partial Factor Productivity for Mg (Transformed data, natural log)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.285	2	.642	89.050	.000
Intercept	429.783	1	429.783	59581.370	.000
RATE	1.285	2	.642	89.050	**.000**
Error	.108	15	7.213E-03		
Total	431.176	18			

6.4 Partial Factor Productivity for Mo (Transformed data, natural log)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.286	2	.643	89.150	.000
Intercept	449.862	1	449.862	62363.581	.000
RATE	1.286	2	.643	89.150	**.000**
Error	.108	15	7.214E-03		
Total	451.257	18			

6.5 Partial Factor Productivity for B (Transformed data, natural log)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.285	2	.642	89.049	.000
Intercept	565.576	1	565.576	78405.738	.000
RATE	1.285	2	.642	89.049	**.000**
Error	.108	15	7.213E-03		
Total	566.968	18			

Appendix 7: Dependent Variable Germination %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	434.633	17	25.567	6.486	.000
Intercept	661904.188	1	661904.188	167911.805	.000
RATE	355.296	5	71.059	18.026	**.000**
TIME	1.231	2	.616	.156	.856
RATE * TIME	74.042	10	7.404	1.878	.069
Error	212.867	54	3.942		
Total	667660.000	72			