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Enhancement of the Productivity of Groundnut in Malawi through the Combined Use of Inoculants and Foliar Application of Nutrients

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Authors' contributions

The work was conducted in collaboration among all authors. Author ATP designed the study. Authors PS and DK managed the experiments and collected data. Author DK performed laboratory analysis of soil samples. Author ATP performed the statistical analysis and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Low productivity characterizes the production of groundnut among smallholder farmers in Malawi. There is a need to explore options capable of increasing the productivity of the crop sustainably more especially under the changing climate. Against this background, experiments were conducted during the 2016/17 cropping season to investigate the potential to enhance the productivity of groundnut in Malawi through the combined use of inoculants (Graph-Ex and Histick-BASF) and foliar application of nutrients using Allwin fertilizer (legumes). The experiments were established at Bvumbwe and Chitala Agricultural research Stations and were laid in a randomized complete block design (RCBD) replicated four times. Data collected were analyzed in Genstat Discovery Edition 4 and were subjected to analysis of variance (ANOVA) at a 95% level of confidence. Means were separated by the least significant difference ($LSD_{0.05}$). In general, foliar application of Allwin fertilizer alone particularly when conducted twice at two and four weeks after emergence produced a positive significant ($p<0.05$) groundnut grain yield response (97.8-170.8%) above the control. The yield increase is attributable to enhanced growth and development of the groundnut through the foliar

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supply of nutrients. In general, under the changing climate and amidst other constraints foliar feeding of nutrients using Allwin fertilizer alone particularly when conducted twice can increase significantly groundnut productivity in Malawi.

Keywords: Groundnut; foliar; inoculants; productivity; nutrients; soil; climate.

1. INTRODUCTION

In Malawi, the groundnut (*Arachis hypogaea)*, which is a legume is important not only for its ability to improve soil fertility but also for meeting human nutritional deficiencies through home-based food recipes [1]. The crop is a source of income for smallholder farmers, feed for livestock and industrial raw material for oil extraction [2]. At the continental level, Malawi ranks first in Africa in terms of productivity per hectare with an average yield of 940 kg ha^{-1} [3], but against a yield potential of 3 ton ha^{-1} [4]. The low productivity of the groundnut has principally been attributed to poor agronomic practices like wide inter-row spacing that reduces plant population per unit area, late planting, use of the recycled seed, poor field management like untimely or lack of weeding that lead to an increase in competition for growth resources, inherent low soil fertility and cultivation in marginal areas [5] and in recent years, climate variability [6].

Being a legume, the groundnut fixes nitrogen (N) from the atmosphere biologically through a mutually beneficial relationship with *rhizobium* bacteria that make a home in nodules of the roots of the plant [7]. The N nutritional needs of the groundnut largely are partially met through this symbiotic relationship and also from the soil N pool. Nitrogen, in general, is essential for the vegetative growth of the legume. Crucially the nutrient is an integral part of an essential protein in the leaves that is central in chloroplast synthesis and photosynthesis [8]. Biological nitrogen fixation (BNF) requires energy, hence making the adequate supply of phosphorus (P) in the soil an imperative. Worth highlighting is the fact that energy is required in the development and growth of roots in legumes and the subsequent formation of nodules following root infection by the N fixing bacteria. The energy is supplied by the P containing ATP molecule [9]. As such, adequate supply of P in the soil is critical. Therefore, N and P deficiency in the soil impedes N fixation, general crop growth and development, photosynthesis and eventually lead to a reduction in the productivity of the groundnut. This is cemented with the fact that 25 to 60% of the N present in the dry matter of most legumes is generated through BNF, while the remaining fraction is taken up from the soil [10]. Supply of N and P is crucial during the initial growth phase of the groundnut before the commencement of BNF by rhizobia in the nodules. Meanwhile, worth mentioning is another nutrient, Sulfur (S), which is vital for general growth and proper physiological functioning of crops [11]. However, documented corroborations allude to the fact that the growth of certain strains of *Bradyrhizobia* in the nodules of legumes is constrained by the deficiency of Sulfur [12]. Additionally, leguminous crops like the groundnut require more iron (Fe) [13]. The nutrient is required for the production of proteins having Fe like leghemoglobin, nitrogenase and cytochromes of the electron transport chain in bacteroids [13]. Deficiency of the nutrient impacts nodulation negatively [13], however Fe deficiency in soils is not common in Malawi. Over 40% of soils in Malawi are Oxisols and Ultisols which are highly weathered [14].Intense weathering and leaching in these soils increased the loss of base cations and silica, producing a residual buildup of Fe and Al oxides over time [15], hence the high Fe content.

Generally, soils in Malawi have low fertility [16, 17]. As pointed out earlier, the challenge of low soil fertility among other factors constrains the productivity of groundnut in the country. Traditionally, the crop is grown without inoculation and fertilizer application. Under the changing climate and in the face of low soil fertility, foliar feeding of nutrients has the potential to increase groundnut yields. Foliar feeding is advantageous unlike the use of granular N containing fertilizer since the possibility of depressing the activities of N fixing bacteria in the nodules through the excess external supply of N to the soil is minimal. Application of high rates of N to the soil considerably affects the number, weight, and nitrogenase activity of nodules [18]. Foliar feeding of the groundnut would provide initial nutritional requirements before the commencement of N fixation in the nodules. Furthermore, during development, nutrient uptake from the roots and utilization in the crop would be supported through foliar feeding. Like foliar feeding of nutrients, use of inoculants let alone their combined use in groundnut production is not practiced among smallholder farmers in the country. Usually, the effective strains of *rhizobium* that form a symbiotic relationship with the crop are available in the soil [19]. However, the strains could be unavailable if groundnut has not been grown before in an area. Such a scenario necessitates seed inoculation with commercial inoculants before planting to enhance productivity [19]. A study, therefore, was undertaken to investigate the potential effect on groundnut yield of the combined use of inoculants and foliar application of nutrients in Malawi, under the changing climate. The specific objectives were; i) to evaluate the effects of combined use of foliar feeding and inoculation on nodule development and effectiveness for the groundnut ii) and to evaluate the effects of combined use of foliar feeding and inoculation on groundnut grain yields.

2. MATERIALS AND METHODS

2.1 Materials

The following were used; groundnut seed (CG7; yield potential of 3 t ha^{-1}), Allwin foliar fertilizer (Legumes), Graph-Ex and Histick-BASF (groundnut inoculants) and knapsack sprayers.

2.2 Laboratory and Data Analysis

Baseline composite soil samples made from four positions were collected at depths 0-20 cm and 20-40 cm at Bvumbwe and Chitala Agricultural Research Stations in Malawi. Laboratory soil analysis was done to characterize the soil. Soil samples were analyzed for OC, total N, available P, K, Mg, Ca and soil pH (H_2O). Soil pH was quantified in water (1:2.5) using a pH meter [20]. Soil analysis for P, K, Mg and Ca was done by Mehlich 3 extraction procedures [21] while OC was determined using the colorimetric method [22] and total N was determined by Kjeldahl method [23]. Molybdenum (Mo) was analyzed using the handheld XRF machine [24]. Biomass yields for the legumes were assessed as described by [25]. All the agronomic data were analyzed using Genstat statistical package and were subjected to analysis of variance at a 95% level of confidence. Means were separated by the least significant difference (P<0.05).

2.3 Soil Physical and Chemical Characteristics at the Study Sites

Tables 1-3 show the soil physical and chemical characteristics at the study sites. In general, the laboratory analytical data indicate that the soil at Bvumbwe has a soil texture that is predominantly sandy clay loam (SCL) to sandy loam (SL), while pH was slightly acid (6.1-6.5) between 0-20 cm to moderately acid (5.6-6.0) between 20-40 cm. Across the experiment field, OC was low (<0.88%) while total N was very low (<0.08%) between 0-20 cm to 20-40 cm. Available P was adequate (25-33 mg kg^{-1}) at both sampled levels while K was very low (0.05 cmol kg^{-1}). Ca was adequate (> 2 cmol kg^{-1}) while Mg was low (<3.0 cmol kg^{-1}), Zinc was very low (<1.0 mg kg^{-1}) and Cu was low (<0.3 mg kg^{-1}).

At Chitala soil texture was predominantly sandy loam (SL), pH was strongly acid (4.5-5.0) between 0-20 cm and acid (5.1-5.5) between 20-40 cm, OC was within the medium range (0.88-2.35%) between 0-20 cm and low (<0.88%) between 20-40 cm. Total N content was low (0.08-0.12%) between 0-20 cm to very low (0.08%) between 20-40 cm. Available P was very low (<8.0 mg kg^{-1}) K was low (0.06-0.10 cmol kg^{-1}) between 0-20 cm but adequate (0.11-0.40 cmol kg^{-1}) between 20-40 cm. Ca was adequate (> 2 cmol kg^{-1}), Mg was low (<3.0 cmol kg^{-1}) while Zinc was very low (<1.0 mg kg^{-1}).

2.4 Rainfall Characteristics of the Study Sites

The study sites received adequate rainfall (Figs. 1 and 2) during the 2016/2017 cropping season with the highest amount recorded in Bvumbwe (3,108.8 mm), followed by Chitala (868.3 mm).

2.5 Methods

The experiments were laid in a randomized complete block design (RCBD) replicated four times, with twelve treatments. Plot size was 5m x 5 m for each treatment. The experiments were conducted (on the station) at Bvumbwe and Chitala agricultural research station during the 2016/2017 cropping season.

2.5.1 Treatments

Treatments were as follows: 1. Control (groundnut only), 2. Inoculated groundnut (Graph-EX), 3. Inoculated groundnut (Histick-BASF), 4. None-inoculated groundnut, + Allwin (3 gm/l) sprayed once at two weeks from emergence, 5. None-inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence, 6. None-inoculated groundnut+ Allwin (3 gm/l) sprayed twice; at two and four

Table 1. The soils' physical and chemical properties before the experiment at Bvumbwe agricultural research station, Allwin project study site

Depth (cm)	Silt %	Clay %	Class	pH	O C %	N %	P mg kg^{-1}	K cmol kg^{-1}	Cacmol kg^{-1}	Mg cmol kg^{-1}	Zn mg kg^{-1}	Cu mg kg^{-1}	Mo mg kg^{-1}
0-20	8	35	SCL/SC	6.2	0.70	0.06	25.7	0.03	2.9	0.21	0.14	0.28	76.0
20-40	8	35	SCL/SC	5.9	0.70	0.06	24.9	0.03	2.7	0.18	0.13	0.17	78.5

Table 2. The soils' physical and chemical properties before the experiment at Chitala agricultural research station, Allwin project study site

Depth(cm)	Silt %	Clay%	Class	pH	O C%	N%	P mg kg^{-1}	Kcmol kg^{-1}	Cacmol kg^{-1}	Mgcmol kg^{-1}	Zn mg kg^{-1}	Mo mg kg^{-1}
0-20	8	17	SL	5.0	0.88	0.08	6.88	0.06	7.20	0.49	0.01	2.0
20-40	8	19	SL	5.5	0.54	0.05	6.43	0.11	5.71	0.34	0.04	5.0

Rainfall at Bvumbwe during the 2016/17 cropping season

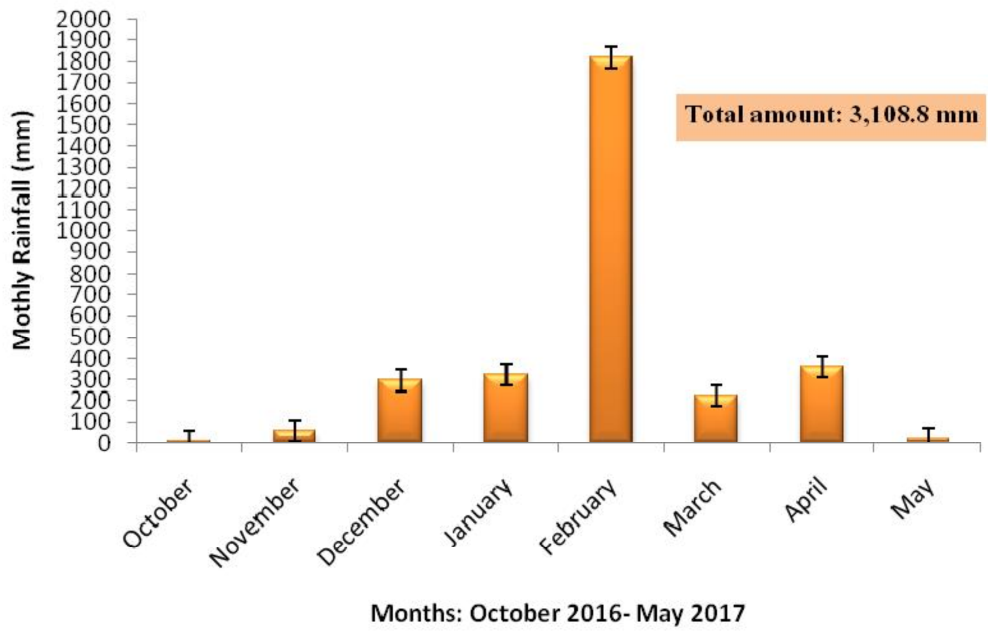

Fig. 1. Rainfall at Bvumbwe during the 2016/17 cropping season

Rainfall at Chitala during the 2016/17 cropping season

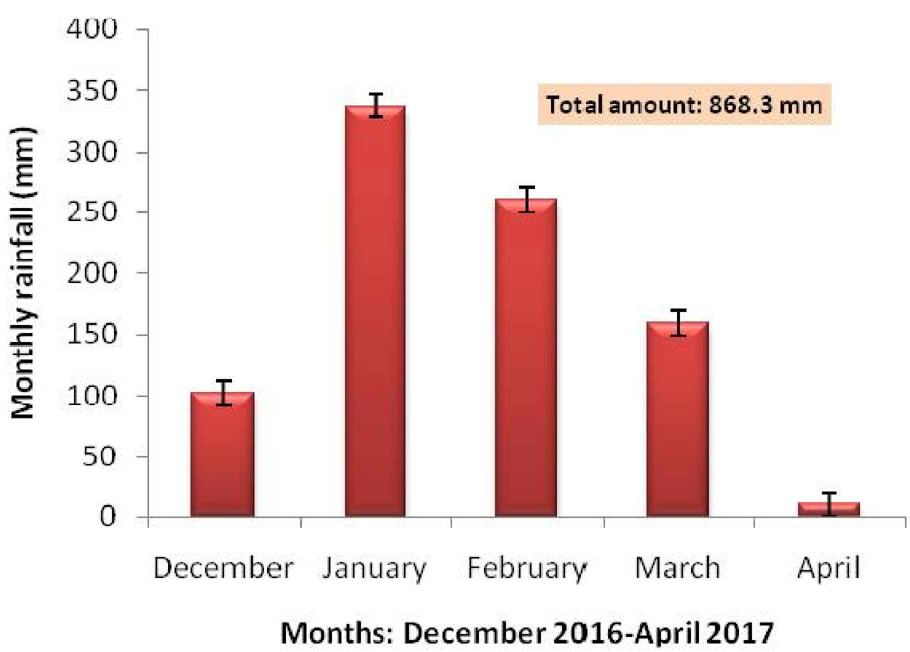

Fig. 2. Rainfall at Chitala during the 2016/17 cropping season

weeks from emergence, 7. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at two weeks from emergence, 8. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence, 9. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence, 10. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at two weeks from emergence, 11. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence, 12. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence. Spraying Allwin (3 gm/l) once at two weeks from emergence translated to applying 0.1 kg N ha^{-1}, 0.01 kg P ha^{-1}, 0.01 kg Fe ha^{-1} and 0.02 kg S ha^{-1}; while spraying Allwin (3 gm/l) once at four weeks from emergence translated to applying 0.2 kg N ha^{-1}, 0.02 kg P ha^{-1}, 0.02 kg Fe ha^{-1} and 0.04 kg S ha^{-1} and spraying Allwin (3 gm/l) twice at two and four weeks from emergence translated to applying 0.8 kg N ha^{-1}. 0.12 kg P ha^{-1}, 0.10 kg Fe ha^{-1} and 0.20 kg S ha^{-1}. Spraying Allwin (3 gm/l) once at two weeks from emergence translated to applying 0.1 kg N ha^{-1}, 0.02 kg P ha^{-1}, 0.02 kg Fe ha^{-1} and 0.03 kg S ha^{-1}; while spraying Allwin (3gm/l) once at four weeks from emergence translated to applying 0.3 kg N ha^{-1}, 0.06 kg P ha^{-1}, 0.05 kg Fe ha^{-1} and 0.10 kg S ha^{-1} and spraying Allwin (3 gm/l) twice at two and four weeks from emergence translated to applying 0.4 kg N ha^{-1}, 0.08 kg P ha^{-1}, 0.07 kg Fe ha^{-1} and 0.13 kg S ha^{-1}.

2.6 Inoculation of Groundnut

Dry seed treatment was used to inoculate seeds with Graph-EX. The seeds were treated before planting at the rate of 60 g of Graph-EX per 50 kg of groundnut seed. While light wetting seed treatment was used to inoculate seeds with Histick-BASF. The seeds were treated before planting at the rate of 400 g of Histick-BASF per 90 kg of groundnut seed.

2.7 Height Measurement

Height measurement was conducted on samples collected before the first application of Allwin foliar fertilizer and samples collected at two weeks after the second application of Allwin and harvest. The vertical growth rate was calculated by dividing the measured height with the number of days from seedling emergence [26].

2.8 Nodulation Study

A 0 to 5 scoring system was employed; where 0 = no nodules, 1 = 1 to 5 nodules (rare), 2 = 6 to 10 nodules (few), 3 = 10 to 20 nodules (moderate), 4 = 20 to 50 nodules (abundant) and 5 = >50 nodules (extra abundant) [27]. Fifteen nodules were sampled per plant and studied for effectiveness. The nodules were cut open and nodule contents described as red (including pink) indicating effective nodulation or other (white, green or grey) indicating none effective nodulation.

2.9 Biomass and Grain Yields Assessment for the Legumes

Grain yields assessment was conducted at physiological maturity. Pods were harvested from a 2 m x 2 ridges net plot. The pods were shelled and weighing of the grains and the husks/shells was done. These were later oven-dried for 24 hours at 70 °C to constant weights. Estimation of the mean number of pods per plant was done by counting the total number pods from five plants in the net plot and dividing by five to get the mean.

3. RESULTS

3.1 Groundnut Growth Rate

3.1.1 Groundnut growth rate at Bvumbwe agricultural research station

Fig. 3 shows the effect of combining inoculation of groundnut with Graph-EX and foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut at Bvumbwe Agricultural Research Station. Combining the foliar application of Allwin fertilizer (legumes) either once at two or four weeks from the emergence and twice, at two and four weeks from emergence with inoculation of groundnut with Graph-EX seemed not to have increased groundnut growth rate compared with the control or sole inoculation.

Fig. 4 shows the effect of combining inoculation of groundnut with Histick-BASF and foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut. Combining the foliar application of Allwin fertilizer (legumes) either once at two or four weeks from the emergence and twice, at two and four weeks from emergence with inoculation of groundnut with Histick-BASF seemed not to have increased groundnut growth rate compared with the control, but sole inoculation had accentuated growth rate towards maturity above other treatments.

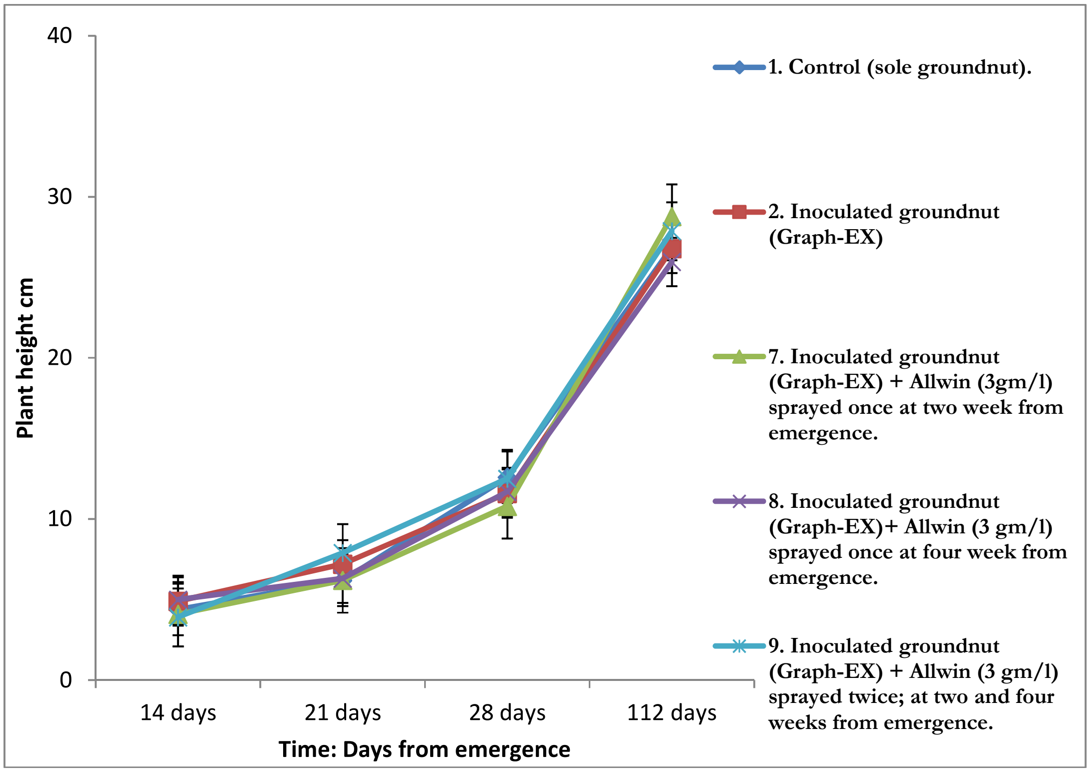

Fig. 3. Effect of combining inoculation of groundnut with Graph-EX and foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut

Fig. 5 shows the effect of foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut. Foliar application of Allwin fertilizer (legumes) once at two weeks from emergence and twice, at two and four weeks from emergence seemed not to have increased groundnut growth rate compared with the control. However, in the treatment where the foliar application of Allwin fertilizer (legumes) was conducted once at four weeks from emergence, accelerated growth rate was observed after about sixty-five days from emergence above other treatments.

4. NODULATION OF GROUNDNUT

4.1 Nodulation of Groundnut at Bvumbwe Agricultural Research Station at Six Weeks from Emergence

Table 3 shows the treatment effect on groundnut nodulation at Bvumbwe Agricultural Research Station at six weeks from emergence.

Scores of nodules at six weeks from emergence indicated that treatment nine (combining inoculation (Graph-EX) with the application of Allwin foliar fertilizer twice at two and four weeks from emergence) promoted nodulation (score of 4 = abundant) above the control (score of 3 = moderate). On nodule effectiveness, however, sampled nodules indicate that combining inoculation (Graph-EX) with the application of Allwin foliar fertilizer twice at two and four weeks from emergence generated none significantly higher ($p>0.05$) number of effective nodules and none significantly lower ($p>0.05$) number of none effective nodules compared with the control.

Scores of nodules at six weeks from emergence indicated that treatment 10 (combining inoculation (Histick-BASF) with the application of Allwin foliar fertilizer once at two from emergence) promoted nodulation (score of 4 = abundant) above the control (score of 3 = moderate). On nodule effectiveness, however, sampled nodules indicate none significant ($p>0.05$) differences on the number of effective and none effective nodules across treatments.

Scores of nodules for sole application of Allwin at six weeks from emergence indicated that treatment six (application of Allwin foliar fertilizer twice at two and four weeks from emergence)

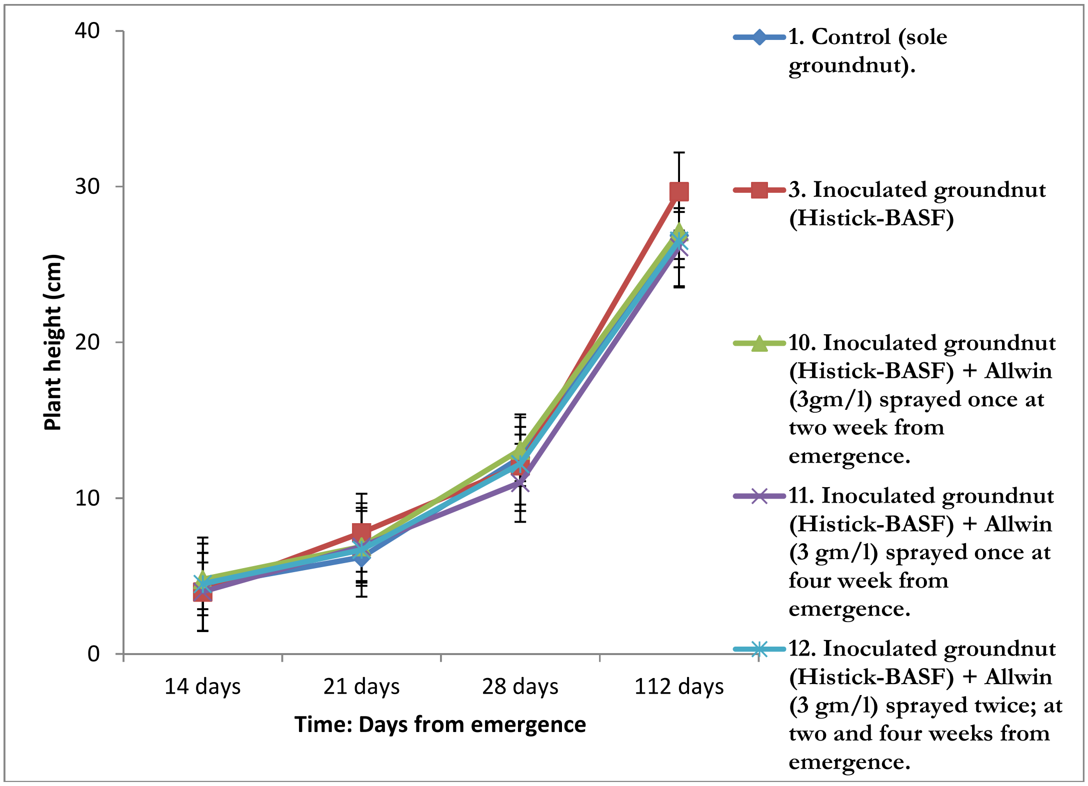

Fig. 4. Effect of combining inoculation of groundnut with Histick-BASF and foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut

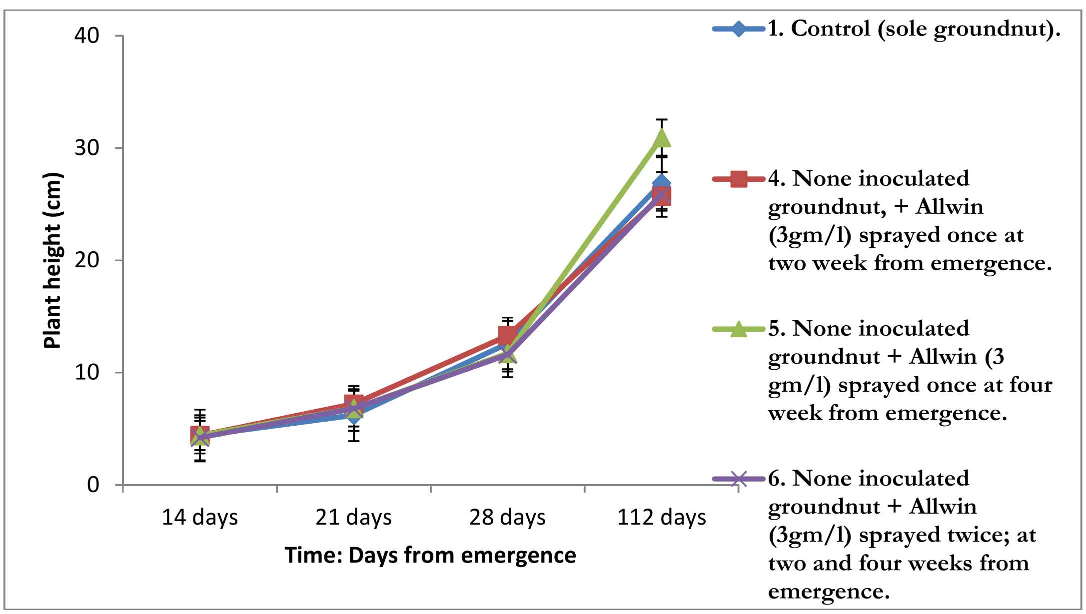

Fig. 5. Effect of foliar application of Allwin (legumes) fertilizer on the growth rate of groundnut

promoted nodulation (score of 4 = abundant) above the control (score of 3 = moderate). On nodule effectiveness, however, sampled nodules indicate that application of Allwin foliar fertilizer twice at two and four weeks from emergence generated significantly higher ($p<0.05$) number of effective nodules and significantly lower ($p<0.05$) number of none effective nodules compared with the control.

4.2 Nodulation of Groundnut at Chitala Agricultural Research Station at Six Weeks from Emergence

Table 4 shows the nodulation of groundnut at Chitala Agricultural Research Station at six weeks from emergence. Nodulation data across all treatments indicated moderate nodulation (score of 3). Furthermore, data on nodule effectiveness showed that across all treatments 99-100% of the nodules were none effective.

5. GROUNDNUT YIELDS

5.1 Groundnut Yields at Bvumbwe Agricultural Research Station

Table 5 shows the treatment effect on groundnut yields at Bvumbwe Agricultural Research Station at harvest.

Where Allwin fertilizer was applied without inoculation, significant differences ($p<0.05$) in the number of pods/plant across treatments were observed, treatments five (none inoculated groundnut + Allwin (3 gm/l) sprayed once at four

Table 3. Effect of foliar application of Allwin fertilizer on nodulation of groundnut

Treatments	Sample of effective nodules plant^{-1}	Sample of none effective nodules plant^{-1}	Nodule score plant^{-1}
1. Control (sole groundnut).	9	6	3
2. Inoculated groundnut (Graph-EX)	8	7	3
3. Inoculated groundnut (Histick-BASF)	8	7	3
4. None inoculated groundnut, + Allwin (3 gm/l) sprayed once at two weeks from emergence.	10	5	4
5. None inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence.	9	6	3
6. None inoculated groundnut+ Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	12	3	4
7. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at two weeks from emergence.	9	6	3
8. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	10	5	3
9. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	11	4	4
10. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at two weeks from emergence.	10	5	4
11. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	10	5	3
12. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	9	6	3
$LSD_{0.05}$	3	3	1
CV%	16	29.7	5.7

Table 4. Nodulation of groundnut at Chitala Agricultural Research Station at six weeks from emergence

Treatments	Sample of effective nodules plant^{-1}	Sample of none effective nodules plant^{-1}	Nodule score Plant^{-1}
1. Control (sole groundnut).	0	15	3
2. Inoculated groundnut (Graph-EX)	0	15	3
3. Inoculated groundnut (Histick-BASF)	0	15	3
4. None inoculated groundnut, + Allwin (3 gm/l) sprayed once at two weeks from emergence.	0	15	3
5. None inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence.	1	14	3
6. None inoculated groundnut+ Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	1	14	3
7. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at two weeks from emergence.	0	15	3
8. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	1	14	3
9. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	0	15	3
10. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at two weeks from emergence.	1	14	3
11. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	1	14	3
12. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	1	14	3
$LSD_{0.05}$	0.8	0.8	0.7
CV%	17.8	0.7	2

weeks from emergence) and six (none inoculated groundnut + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) having a significantly higher number ($p<0.05$) of pods/plant above the control. Seed size, measured by the weight of 100 seeds, seemed to have been increased significantly ($p<0.05$) by foliar application of Allwin fertilizer. However, on biomass yields, treatment six (none inoculated groundnut + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) had significantly higher ($p<0.05$) biomass yield compared with the control. Pod and grain yields were significantly higher ($p<0.05$) in treatments five (none inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence) and six (none inoculated groundnut + Allwin (3gm/l) sprayed twice; at two and four weeks from emergence) above the control.

In treatments where Allwin fertilizer was applied in combination with inoculation of groundnut using Graph-EX, significant differences ($p<0.05$) in the number of pods/plant across treatments were observed, with treatment nine (inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) having significantly higher number ($p<0.05$) of pods/plant above the control. Seed size, measured by the weight of 100 seeds, seemed to have been increased significantly ($p<0.05$) above the control by combining inoculation of groundnut with Graph-EX and foliar application of Allwin fertilizer. However, on biomass yields, treatment eight (inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence) and nine (Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) had significantly higher ($p<0.05$) biomass yield compared with the control. Pod and grain yields were significantly higher ($p<0.05$) in treatment nine (inoculated groundnut (Graph-EX) + Allwin

(3 gm/l) sprayed twice; at two and four weeks from emergence) above the control.

In treatments where Allwin fertilizer was applied in combination with inoculation of groundnut using Histick-BASF, significant differences ($p<0.05$) in the number of pods/plant across treatments were observed, with treatment three (inoculated groundnut (Histick-BASF), ten (inoculated groundnut (Histick-BASF) + Allwin (3gm/l) sprayed once at two weeks from emergence) and twelve (inoculated groundnut (Histick-BASF)+ Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) having a significantly higher number ($p<0.05$) of pods/plant above the control. However, the number of pods/plant in treatment ten (inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at two weeks from emergence) and twelve (inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) were not significantly different ($p>0.05$) to treatment three (inoculated groundnut (Histick-BASF).

Seed size, measured by the weight of 100 seeds, seemed to have been increased significantly ($p<0.05$) above the control by sole inoculation and combining inoculation of groundnut with Histick-BASF with foliar application of Allwin fertilizer particularly when conducted twice at two and four weeks after emergence.

On biomass yields, treatment eleven (Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence) and twelve (inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) had significantly higher ($p<0.05$) biomass yield compared with the control. However, biomass yield was significantly higher ($p<0.05$) in treatment twelve compared with treatment eleven. Pod and grain yields were significantly higher ($p<0.05$) in treatment twelve (inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) above the control.

5.2 Groundnut Yields at Chitala Agricultural Research Station

Table 6 shows the treatment effect on groundnut yields at Chitala Agricultural Research Station at harvest.

Where Allwin fertilizer was applied without inoculation, none significant differences ($p<0.05$) in the number of pods/plant, seed size, pod and biomass yields across treatments were observed. However, grain yields were significantly higher ($p<0.05$) in treatment four (none inoculated groundnut + Allwin (3 gm/l) sprayed once at two weeks from emergence, five (none inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence) and six (none inoculated groundnut+ Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) above the control.

Where Allwin fertilizer was applied in combination with inoculation of groundnut using Graph-EX, significant differences ($p<0.05$) in the number of pods/plant across treatments were observed, with treatment nine (inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) having a significantly higher number ($p<0.05$) of pods/plant above the control. Seed size, measured by the weight of 100 seeds, pod and biomass yields were not increased significantly ($p>0.05$) above the control by combining inoculation of groundnut with Graph-EX with foliar application of Allwin fertilizer. However, grain yields were significantly higher ($p<0.05$) in treatment two (inoculated groundnut (Graph-EX), seven (Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at two weeks from emergence) and nine (inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) above the control.

In treatments where Allwin fertilizer was applied in combination with inoculation of groundnut using Histick-BASF, none significant differences ($p<0.05$) in the number of pods/plant and seed size across treatments were observed. Biomass, pods and grain yields, were significantly higher ($p<0.05$) in treatment twelve (inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence) above the control.

6. DISCUSSION

6.1 Groundnut Growth Rate

The growth rate of the groundnut was assessed at Bvumbwe Agricultural Research Station. Sole application and combining the foliar application of Allwin fertilizer either once at two or four weeks from the emergence and twice, at two and four weeks from emergence with inoculation of

Table 5. Groundnut yields at Bvumbwe

Treatments	**100 grains (g)**	**Number of pods plant^{-1}**	**Grain yield kg ha^{-1}**	**Shells yield kg ha^{-1}**	**Pod yield kg ha^{-1}**	**Biomass yield kg ha^{-1}**
1. Control (sole groundnut).	42^{h}	39^{cd}	1,559^{c}	942^{b}	2,501^{f}	3,147^{def}
2. Inoculated groundnut (Graph-EX)	49^{g}	51^{bcd}	2,650^{bc}	1,101^{b}	3,751^{de}	3,701^{bcde}
3. Inoculated groundnut (Histick-BASF)	62^{a}	56^{ab}	2,478^{bc}	1,177^{b}	3,655^{e}	2,967^{ef}
4. None inoculated groundnut, + Allwin (3gm/l) sprayed once at two weeks from emergence.	56^{def}	37^{d}	2,230^{c}	1,258^{b}	3,488^{ef}	2,751^{f}
5. None inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence.	61^{ab}	63^{ab}	3,447^{ab}	1,289^{b}	4,736^{bcd}	3,823^{bcd}
6. None inoculated groundnut+ Allwin (3gm/l) sprayed twice; at two and four weeks from emergence.	54^{f}	58^{ab}	3,083^{ab}	1,863^{ab}	4,946^{bc}	4,045^{bc}
7. Inoculated groundnut (Graph-EX) + Allwin (3gm/l) sprayed once at two weeks from emergence.	57^{cdef}	52^{bcd}	2,394^{bc}	1,647^{ab}	4,041^{cde}	3,549^{cde}
8. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	55^{ef}	40^{c}	2,562^{bc}	1,168^{b}	3,730^{e}	4,422^{ab}
9. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	59^{abd}	68^{a}	3,494^{ab}	2,436^{a}	5,930^{a}	4,157^{bc}
10. Inoculated groundnut (Histick-BASF) + Allwin (3gm/l) sprayed once at two weeks from emergence.	56^{def}	59^{ab}	2,432^{bc}	2,435^{a}	4,867^{bc}	2,713^{f}
11. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	58^{bcde}	38^{d}	2,131^{c}	1,030^{b}	3,161^{ef}	3,961^{bc}
12. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	60^{abc}	54^{abc}	4,221^{a}	1,092^{b}	5,313^{ab}	5,132^{a}
LSD$_{0.05}$	4	16	1,172	1,118	995	754
CV%	4.24	15.23	26.1	48.1	15.8	12.5

Table 6. Groundnut grain yield at Chitala

Treatments	100 grains (g)	Number of pods plant^{-1}	Grain yield kg ha^{-1}	Shells yield kg ha^{-1}	Pod yield kg ha^{-1}	Biomass yield kg ha^{-1}
1. Control (sole groundnut).	48	7^{b}	294^{d}	$1,575^{b}$	$1,869^{bc}$	$2,622^{b}$
2. Inoculated groundnut (Graph-EX)	45	10^{ab}	664^{abc}	$2,240^{ab}$	$2,858^{abc}$	$2,892^{b}$
3. Inoculated groundnut (Histick-BASF)	46	8^{b}	360^{cd}	$1,675^{ab}$	$2,035^{bc}$	$2,119^{b}$
4. Non-inoculated groundnut, + Allwin (3gm/l) sprayed once at two weeks from emergence.	57	10^{ab}	688^{abc}	$1,641^{ab}$	$2,329^{abc}$	$2,668^{b}$
5. Non-inoculated groundnut + Allwin (3 gm/l) sprayed once at four weeks from emergence.	56	9^{ab}	871^{ab}	$1,615^{b}$	$2,486^{abc}$	$3,179^{ab}$
6. Non-inoculated groundnut+ Allwin (3gm/l) sprayed twice; at two and four weeks from emergence.	57	11^{ab}	861^{ab}	$2,420^{a}$	$3,281^{ab}$	$3,040^{b}$
7. Inoculated groundnut (Graph-EX) + Allwin (3gm/l) sprayed once at two weeks from emergence.	52	9^{ab}	754^{ab}	$2,399^{ab}$	$3,053^{abc}$	$3,336^{ab}$
8. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	50	10^{ab}	568^{bcd}	$1,095^{b}$	$1,663^{c}$	$2,134^{b}$
9. Inoculated groundnut (Graph-EX) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	55	14^{a}	786^{ab}	$1,441^{b}$	$2,227^{abc}$	$3,375^{ab}$
10. Inoculated groundnut (Histick-BASF) + Allwin (3gm/l) sprayed once at two weeks from emergence.	57	8^{b}	957^{a}	$1,858^{ab}$	$2,815^{abc}$	$3,183^{ab}$
11. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed once at four weeks from emergence.	48	7^{b}	510^{bcd}	$1,316^{b}$	$1,826^{c}$	$2,088^{b}$
12. Inoculated groundnut (Histick-BASF) + Allwin (3 gm/l) sprayed twice; at two and four weeks from emergence.	46	12^{ab}	747^{ab}	$2,887^{a}$	$3,633^{a}$	$4,477^{a}$
$LSD_{0.05}$	14	6	369	1,252	1,431	1,405
CV%	17	38.7	35.4	42.3	35.7	30

groundnut with Graph-EX or Histick-BASF seemed not to have an increased groundnut growth rate vertically, compared with the control or sole inoculation. It is worthwhile to note at this point that in groundnut, grossly, vegetative growth includes; leaf production and increase in shoot/biomass weight [28]. Notwithstanding the above, however, in the treatment where the sole foliar application of Allwin fertilizer was conducted once at four weeks from emergence, the accelerated vertical growth rate was observed after about sixty-five days from emergence above other treatments. In groundnut, the period of maximum growth is between 56 and 97 days in bunch varieties like CG7, the planted variety [28].

6.2 Nodulation of Groundnut

Generally, at Bvumbwe Agricultural Research Station combining inoculation with the application of Allwin foliar fertilizer promoted nodulation above the control. The improvement in nodulation has to do with improvement in plant nutrition. While on nodule effectiveness, however, the sampled nodules indicate that compared with sole application of Allwin fertilizer, combining inoculation with the application of Allwin foliar fertilizer twice at two and four weeks from emergence did not influence nodule effectiveness, potentially because of the presence of superior indigenous strains of rhizobia in the soil [29]. Nevertheless, the sole application of Allwin twice at two and four weeks from emergence promoted nodulation and effectiveness over the control. The potential positive interaction of nutrients supplied through foliar application, with nutrients absorbed by plants through the roots, might have stimulated the growth of the groundnut plant and influenced nodule development and functioning, in the presence of superior strains of indigenous rhizobia in the soil.

At Chitala Agricultural Research Station, nodulation data across all treatments indicated moderate nodulation. Furthermore, data on nodule effectiveness showed that across all treatments largely the sampled nodules were none effective, suggesting that inoculation using Graph-EX or Histick-BASF and/or foliar application of nutrients through Allwin fertilizer did not influence nodulation. The observed trend is attributable to soil pH which was strongly acid with very low available across the field. Phosphorus influences nodule development through its basic function in plants as the source of energy while acidity in the soil hinders rhizobia from effective creation of nod factor and formation of nodules [29].

6.3 Groundnut Grain Yields

At Bvumbwe Agricultural Research Station, data on nodule effectiveness suggest the presence of superior indigenous strains of rhizobia at the site aided by an adequate level of available P. In tandem with this observation, subsequently, sole application of Allwin fertilizer and combining the application of Allwin fertilizer either once at four or twice at two and four weeks from emergence, with inoculation of groundnut using Graph-EX or Histick-BASF produced a similar effect on the number of pods/plant, seed size, biomass and grain yields above the control. Potentially, treatments, where Allwin fertilizer was applied alone, were not at a disadvantage as the indigenous strains of rhizobia were equally effective in nodulating and fixing N biologically as the strains of rhizobia present in Graph-EX or Histick-BASF.

Generally, at Chitala, very low grain yields were generated across treatments due to poor seed stock, late planting and the general infertility of the soil. Notwithstanding the same, grain yield was higher above the control in Allwin fertilizer treated plots. High grain yields were obtained at Bvumbwe despite a myriad of challenges owing to the presence of relatively fertile soil conditions. An additional challenge at this site was the groundnut digging and eating crows. Timely supplying the gaps in the experiment was conducted. Overall, foliar application of Allwin fertilizer particularly when conducted twice at two and four weeks after emergence produced higher groundnut grain yield response (97.8-170.75%) above the control. In principle, therefore, at both sites, any yield response observed across all treatments could be interpreted as being a function of the application of Allwin fertilizer and not inoculation or the combination of the two. The yield increase is attributable to the stimulation of root and shoots growth by the foliar supply of nutrients to groundnut through the application of Allwin. A related study, [30] reported that 40 kg N ha^{-1} from conventional fertilizer produced grain yields of 1.48 ton ha^{-1} compared with 0.90 ton ha^{-1} under the none fertilized control. The results agree with findings by [31] reported an increase in groundnut yields upon the basal application of 20 kg N, 60 kg P_2O_5, 25 kg K_2O ha^{-1}plus the foliar application of nitrogen at 7 kg N ha^{-1} at 45 days after sowing and foliar application of nitrogen at 7 kg N ha^{-1} at 60 days after sowing above the control.

7. CONCLUSION

From the research, it can be concluded that under the conditions of the study foliar feeding has a variable effect on nodulation of groundnut. Furthermore, in conditions that impede nodulation foliar feeding could do little to influence nodulation. However, under favourable soil conditions, foliar feeding can promote nodulation through improved plant nutrition. Additionally, in the presence of effective indigenous strains of rhizobia, combining inoculation with foliar feeding of nutrients does not influence nodule effectiveness. In such cases, the use of inoculants on groundnut may not be valuable. Largely, application of nutrients to groundnut produced significantly higher biomass and grain yields above none treated plots. Generally, under the changing climate and amidst other constraints foliar feeding of nutrients using Allwin fertilizer alone particularly when conducted twice can increase significantly groundnut productivity in Malawi.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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