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The effects of planting position, timing of nitrogen and phosphorus fertilizer rates on growth and yield of soybean (*Glycine max L*)

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Abstract

The amount of nitrogen fixed symbiotically is rarely adequate for optimal plant growth. Appropriate tillage systems can be adapted to specific soil conditions in order to amplify soybean yield response to added fertilizers. A 36-week field experiment was carried out at Chisumbanje Experiment Station (2048 S; 3214 E, elev. >300 m above sea level, Zimbabwe) on a soybean crop in order to determine the effect of timing nitrogen and phosphorus fertilizer application rates in three seedbed configurations on seedling emergence, nodule weight, plant height, aboveground biomass and yield (biometric characteristics) of soybean. Planting soybean on 0.5 m wide ridge seedbeds enhanced germination. Planting soybean on flat seedbeds reduced seed germination by 62.5% compared with 0.5 m wide ridge seedbeds. Widening ridge seedbeds to 1 m whittled down seed germination by 32.3% compared with 0.5 m wide ridges. High root nodule weight does not necessarily increase grain yield. The 0.5 m wide ridge beds, which had the highest seedling emergence score, recorded the largest yield responses. On flat seedbeds, basal application of P_{120} and N_{30} at planting increased biomass by 2.6 g plant^{1} while the reduction of P fertilizer application rate to 80 kg ha^{-1} and the delay of N_{30} topdressing to 6 weeks after planting improved aboveground vegetative dry weight by 2.9 g plant^{-1}. Cutting the ridge seedbed width from 1 m to 0.5 m increased soybean grain yield by 41.6% when P_{80} was applied as a pre-planting fertilizer and N_{30} as a top dressing at six weeks after planting. The 0.5 m wide ridge seedbeds had 27.3% more soybean grain yield over that in the 1 m wide ridges when P_{120} was applied as a pre-planting fertilizer and N_{30} was applied at planting. Delaying the application of N_{30} to six weeks after planting and downgrading P application rate from 120 to 80 kg ha^{1} reduced soybean yield by 20.3 g plot^{1} in the wide ridges, increased grain yield by 106.9 g and 67.6 g plot^{1} in the narrow ridge and flat seedbed variants respectively.

Key words: Soybean, seedbed configuration, fertilizer.

Introduction

A small minority of microorganisms are exceptional in being able to reduce molecular N_2 to NH_3. The NH_3, in turn, is combined with organic acids to form amino acids and, ultimately, proteins.The symbiotic N_2 fixation in legumes involves an endosymbiotic association with diazotrophic (N_2-fixation) soil bacteria of the family *Rhizobeaceae,* which include *Rhizobium, Bradyrhizobium, Mesorhizobium and Azorhizobium* bacteria. *Rhizobia* bacteria invade the root hairs and cortical cells, ultimately inducing the formation of nodules that serve as the home for the organisms (Santos *et al.*, 2001). Within these nodules, the differentiated bacteria (bacteroids) reduce N_2 with the participation of the enzyme nitrogenase as follows:

$$N_2 + 8e^- + 16ATP\ ?\ 2NH_3 + H_{2bnh} + 16ADP + 16Pi$$

The host plant supplies the bacteria with carbohydrates for energy, and the bacteria reciprocate by supplying the host plant with fixed nitrogen compounds, an association that is mutually beneficial (Long, 2001). For the continued success of legumes in agricultural systems, the legume should have effective root rhizosphere associations. Successful inoculate bacteroid strains must be able to rapidly colonise the soil and tolerate environmental stresses, as well as compete with populations of background *Rhizobia* for nodule formation (Brockwell *et al.*, 1995).

The rate of biological fixation of nitrogen is greatly dependent on the soil and climatic conditions (Richardson and Simpson, 1988; Brockwell *et al.*, 1995). The legume Rhizobium associations generally function best on soils that are not too acid and well supplied with essential nutrients. However, high levels of available nitrogen, whether from the soil or added in fertilizers, tend to depress biological nitrogen fixation. Apparently, symbiotic nitrogen fixation tends to operate only when the plant needs the nitrogen (Brady, 1990).

The competition between effective and non-effective bacterial strains at the time of root infection significantly reduces nodulation. A non-effective strain produces many nodules, which do not fix N_2, yet their presence inhibits nodulation by an effective strain (Slattery *et al.*, 2001). Inadequate photosynthate supply and moisture stress reduce a nodulated root's fixation capacity. Nodulation and N_2 fixation are generally stimulated by simultaneous infection of the roots by vascular-abuscular mycorrhizas due mainly to the enhanced supply of P to the host plant (White, 1999).

The response of N_2 fixation to N application is variable between legume species. Naisbitt and Sprent (1993) reported that even low concentrations of nitrate, known to stimulate nodulation in crop legumes, led to marked degradation of nodule fine structure in the caesalpinoid legume *Chaemaecrista fasciculate*. Adams and Attiwell (1984) noted that symbiotically fixed N contributed only a small part (10-40%) of the total N budget of an acacia. George and Singleton (1992) suggest that the limited fixation capacity (relative to soybean) of the papilionoid legume, *Phaseolus vulgaris*, reflects a superior capacity of this species to acquire and assimilate mineralized N.

The relationship between legume and rhizobium may be maintained as a symbiosis rather than a parasitism by the dependence of the nodule growth on its own N for growth. Upon cessation of N_2 fixation, nodule N requirements must be met from an exponentially declining soluble N pool, or from phloem import of N (Walsh *et al.*, 1989a). Under such conditions, nodule growth may be limited and N starvation may result in cytoplasmic degeneration witnessed in ultrstractural studies (Atkins *et al.*, 1984b).

Whereas soybean is well recognized for N_2 fixation and rarely receives N fertilization, soybean cultivars grown on nutritionally hostile soils can exhibit nitrogen deficiency during the first 30 to 40 days after planting.

Soybean may derive only 50% of their N needs from symbiosis (Harper, 1987). Macronutrient research has shown that supplemental applications of N have increased seed yield in some studies (Wesley *et al.*, 1998; Purcell and King, 1996; Syverud *et al.*, 1980; Garcia and Hanway, 1976). Soybean demand for N can exceed 92 g kg ^{1} seed for optimum seed yield (Flannery, 1986).

Demand for seed N is highest from the R5 to R8 soybean development stage as defined by Fuhr and Caviness (1977). During this period, the plant utilizes N from all sources, but in the early to mid-pod fill stages, fixation by *Bradyrhizobia* spp. decreases rapidly (Harper, 1987). The soybean plant compensates for this reduction in fixed N by utilizing N already incorporated in plant tissue, beginning in the R6 growth stage (Harper, 1987). Supplying N to the soybean plant during the peak time of seed demand may supplement existing N resources, prevent premature senescence and increase seed yield (Garcia and Hanway, 1976; Sinclair and DeWhit, 1976; Nelson *et al.*, 1984; Salado-Navarro *et al.*, 1985).

Pre-plant applied N at 134 kg ha $^{-1}$ on a silt loam soil in Nebraska to irrigated soybean did not consistently alter yield (Slater *et al.*, 1991) B1. Similarly, on a silty clay loam in Illinois, N applications from 0 to 900 kg ha^{1} yr^{1} applied pre-plant and as side-dress elicited no yield effect, except for slight yield reductions at higher N rates (Slater *et al.*, 1991). However, N applications made before reproductive growth stages are reported to decrease *Bradyrhizobia* spp. activity, exhibited by reduced growth of nodules and lower N fixation, thus further increasing the difference between supply and demand (Ham *et al.*, 1975; Yoshida 1979; Yoneyama *et al.*, 1985).

Numerous research studies have confirmed that the maintenance of optimum levels of P in the soil encourages vigorous growth of soybean root systems, which in turn significantly enhances uptake of other nutrients in the soil. P is particularly necessary during periods of intensive early growth phases and synthesis of biomass materials during grain filling period when protein and starch synthesis are intensive (Garcia, and Hanway, 1976). Elevated contents of soil N in nitrate forms, which cannot be assimilated by soybean plants into protein in that state, require relatively higher content of available P for synthesis of high-energy releasing materials (ATP) for the energy-consuming transformation of nitrate N into protein components. P is a component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), which are vital compounds in energy transformations in plants. ATP, which is synthesized from ADP in both respiration and photosynthesis processes, carries a high-energy phosphate bond that drives most biochemical reactions including the energy consuming active uptake of other nutrients from the soil solution by plant roots (Slater, *et al.*, 1991).

The soybean yield response to P fertilizer application in vertisols has been reported to be unpredictable. This has been ascribed to the high P fixation due to high smectitic clay content (Sakar and Uppal, 1994). Increased P fertilizer uptake efficiency has been noted when P was applied with N fertilizers. The effect of added N may be physiological enhancement of P uptake with added NH_4^+, enhanced P uptake when applied in band with N (Harper, 1987), or NH_4^+-induced acidification near the root and an increase in the concentration of $H_2PO_4^-$ compared with HPO_4^{2-} (Sakar and Uppal, 1994).

Soya beans need large quantities of P particularly at the beginning of pod formation till 10 days before seed development (Paliyal and Verma, 1999). Where the external P concentration is increased from 20 to 2000 mol L 1 at pH 5.9, an eleven-fold increase in the attachment of *Sinorhizobium meliloti* strain CC169 to *M. polymorpha* was observed (Howieson *et al.*, 1993) C. The average increase in soybean grain yield as a consequence of P fertilizer application of 30, 60 and 90 mg kg^{1} soil amounted to about 104, 170 and 227 percent (Paliyal and Verma, 1999).

Besides fertilizer applications, intensive soybean production systems have adopted ridge tillage (RT) practices in an effort to increase yield. RT is a cultural practice widely used throughout the world with many different modifications but with the same goal: to prepare a seedbed that is elevated above the land surface of the field (Lal, 1990). The following were listed as reasons for adopting RT: enhanced soil fertility, better water management, improved water and wind erosion control, facilitated multiple cropping, enhanced rooting depth and improved pest management (Griffith *et al.*, 1990). The ridge is typically 10 to 15 cm higher than the furrow between rows, which provides ample space to accommodate crop residue and loose soil moved into the area between the rows. Reeder (1990) reported crop yield increases of about 12% in RT compared to intensive tillage systems in the rolling terrain and deep loess soils of western Iowa. E.

Soil temperature in the seedbed is critical for rapid seed germination and emergence. Radke (1982) found soil warming in the ridge to be related to configuration of the ridge; the soil was warmer than other tillage systems with similar residue cover. These warmer temperatures were attributed to a reduced water content related to accelerated gravitational drainage in the ridge and lower specific heat in the ridged soil (Shaw and Buchele, 1957) E. Buchele *et al.* (1955) had found that time between seeding and germination in a wet soil was decreased, and that the number of emerged seedlings increased when planting on the ridge compared to conventional planting. Benjamin *et al.* (1990) simulated the movement of water within a ridge; a gradient of water potential caused water to move from the ridge to the furrow where it replaced evaporation from the furrow position. Fausey (1990) observed that soybean yields were improved under RT on Mollic Planosols due to improved drainage.

The amount of nitrogen fixed symbiotically is rarely adequate for optimal plant growth. For some leguminous crops such as beans, peas and soybeans, most of the nitrogen must come from the soil. Consequently, it must not be assumed that the symbiotic systems consistently increase soil nitrogen. In this respect, a combination of fertilizers, synchronized with peak uptake, can be applied to soybean in order to enhance growth rates and yields. In addition to that, appropriate tillage systems can be adapted to specific soil conditions in order to amplify soybean yield response to added fertilizers. Accordingly, a 36-week field experiment was carried out at Chisumbanje Experiment Station (2048 S; 3214 E, elev. >300 m above sea level, Zimbabwe) on a soybean crop in September 2004 to May 2005 summer season. The first objective of the study was to determine the effect of timing nitrogen and phosphorus fertilizer application rates on seedling emergence, nodule weight, plant height, aboveground biomass and yield (biometric characteristics) of soybean. The second objective was to explore the effect of planted ridge widths on the biometric characteristics of soybean. In this study, we hypothesised that the different timings of nitrogen and rates of phosphorus fertilizer rates coupled with varied planted ridge widths generated a mosaic of soil conditions that were responsible for the differences in soybean emergence count and biomass characterization.

Materials and Methods

Trial site

The study was conducted at Chisumbanje Experiment Station (2048 S; 3214 E, elev. >300 m above sea level) about 240 km south of the city of Mutare in Zimbabwe. The soils at the experiment station are dark colored, swelling, self-churning, deep Vertisols derived from basalt (Nyamapfene, 1991). The area lies in Natural Region V receiving rainfall ranging from 250 to 1000 mm annum $^{-1}$ (average 500 mm per annum) with a coefficient of variation of 19% and mean growing season of 70 days. The mean annual temperature is 26.5C with insignificant frost occurrence in the months of June and July. The rainfall occurs during a single rainy season extending from November to April (Vincent and Thomas, 1960).

Experimental design and treatments

The experiment was designed as Randomized Complete Block as 3^3 structures with 3 replicates in which the blocking factor was the gradient. The trial was set up on a site that had been previously put to cotton and wheat in the last summer and winter respectively. The main factor of the experiment was soybean seed planting positions on 15 cm high ridges of two different widths measuring 1 m (narrow ridge), 0.5 m (wide ridge) and on flat beds. The sub-factor in the experiment was rate of phosphorus basal applications in three doses of 0 kg ha ^{1}, 80 kg ha ^{1} and 120 kg ha ^{1}. Timing of nitrogen fertilizer application in three events of no nitrogen fertilizer (0 kg N ha $^{-1}$) application, 30 kg N ha $^{-1}$ applied at planting, and 30 kg ha $^{-1}$ applied at 6 weeks after planting (AP) constituted the sub-sub-factor in the experiment. In each type of seedbed configuration the P_0N_0 fertilizer applications constituted the control plots. A self-nodulating soybean variety Soma planted at a rate of 80 kg ha ^{1} was used as an assay crop planted on the same day in this study. Nitrogen and phosphorus fertilizers were applied in the form of ammonium nitrate and single super phosphate respectively. Each gross experiment plot measured 6 m long and 4 m wide. The net plot measured 4 m long by 2 m wide. A mould board plough was used in land preparation. Ridging was done using a hand hoe. Hand hoe weeding and irrigation schedules were undertaken as per recommendations.

Measurements

Stand count at emergence

Seedling emergence count was determined by recording the number emerged seedlings within a 1 m by 1m quadrants randomly thrown three times in each plot.

Nodule dry weight

Plant samples for determination of nodule dry weight were collected at flowering stage. Sampling was done by carefully digging out five randomly selected plants from each plot. Care was exercised to retrieve as much of the root system with nodules intact as possible. Plant samples from which the soil was carefully shaken off were placed in labelled paper bags and

Nine combinations of the three variables were used to generate nine treatments as follows:

Table 1: Treatment combinations for the study

Treatments	Planting positions	Basal P application rates, kg ha $^{-1}$	Split application of N timing kg ha $^{-1}$
T_1	1 m wide ridges	0	0
T_2	1 m wide ridges	80	30 at 6 weeks
T_3	1 m wide ridges	120	30 at planting
T_4	0.5 m wide ridges	0	0
T_5	0.5 m wide ridges	120	30 at planting
T_6	0.5 m wide ridges	80	30 at 6 weeks
T_7	Flat beds	0	0
T_8	Flat beds	80	30 at 6 weeks
T_9	Flat beds	120	30 at planting

Table 2: Treatment effect on emergence and biometric characteristics of soybeans

Treatments	Seedling emergence count, m $^{-2}$	Nodule dry weight, mg plant $^{-1}$	Plant height at maturity, cm	Aboveground dry mass, g plant $^{-1}$	Grain yield, g plot $^{-1}$
T_1	9^{b}	19.0^{a}	30.3^{a}	123.3^{a}	691.86^{a}
T_2	8^{b}	32.0^{b}	31.8^{a}	123.7^{a}	924.40^{b}
T_3	10^{b}	48.0^{c}	33.0^{a}	123.7^{a}	944.70^{c}
T_4	12^{c}	21.0^{a}	31.8^{a}	121.7^{c}	793.20^{a}
T_5	13^{c}	35.0^{b}	32.8^{a}	124.3^{b}	1309.40^{c}
T_6	15^{c}	41.0^{c}	33.3^{a}	125.7^{b}	1202.50^{d}
T_7	6^{a}	23.7^{a}	26.3^{a}	120.7^{c}	420.19^{e}
T_8	4^{a}	30.0^{b}	27.2^{a}	123.3^{a}	586.26^{a}
T_9	5^{a}	44.7^{c}	28.8^{a}	122.7^{a}	518.70^{a}
Grand mean	9	31.7	33.3	123.7	930.04
CV%	47.3	21.4	24.5	2.8	33.45
LSD	3.9	5.9	7.2	3	209.6

NB: *Figures superscripted with different letters have significant difference while those with the same letters have no significant difference.*

taken to a laboratory. Nodules were then plucked off by hand and placed in an oven set at 70C for 24 hours. Thereafter, nodule samples were weighed to determine their dry weight.

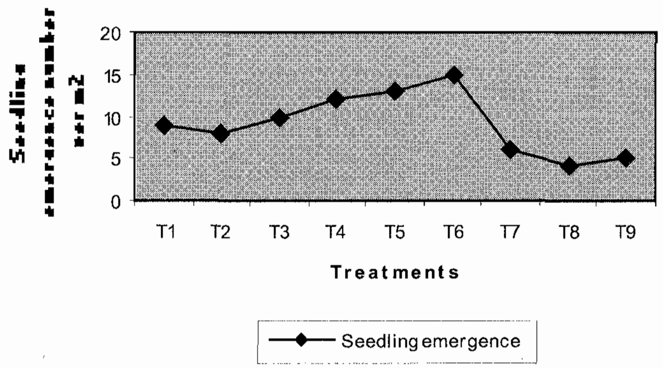
Aboveground dry mass

Five randomly selected aboveground plant samples from each plot were placed in an oven set at 70C for 48 hours. Each plant sample was then weighed to determine dry matter yield.

Plant height and grain yield determination

Plant height measurements were undertaken on ten plants randomly selected from each plot at physiological maturity. Grain yield determination was done by removing whole soybean plants from each net plot and allowing them to sundry before

Figure 1: Treatments effect on germination



threshing. Five samples of grain for each plot were analyzed for grain moisture content using a Digital Grain Master moisture meter. All grain yield data were adjusted to 80% moisture content for grain yield computation.

Data validation

Analysis of variance (ANOVA) was used to test the significance of treatments effects on seedling emergence and biometric characteristics of soybean (MSTAT, 1988).

Results and Discussion

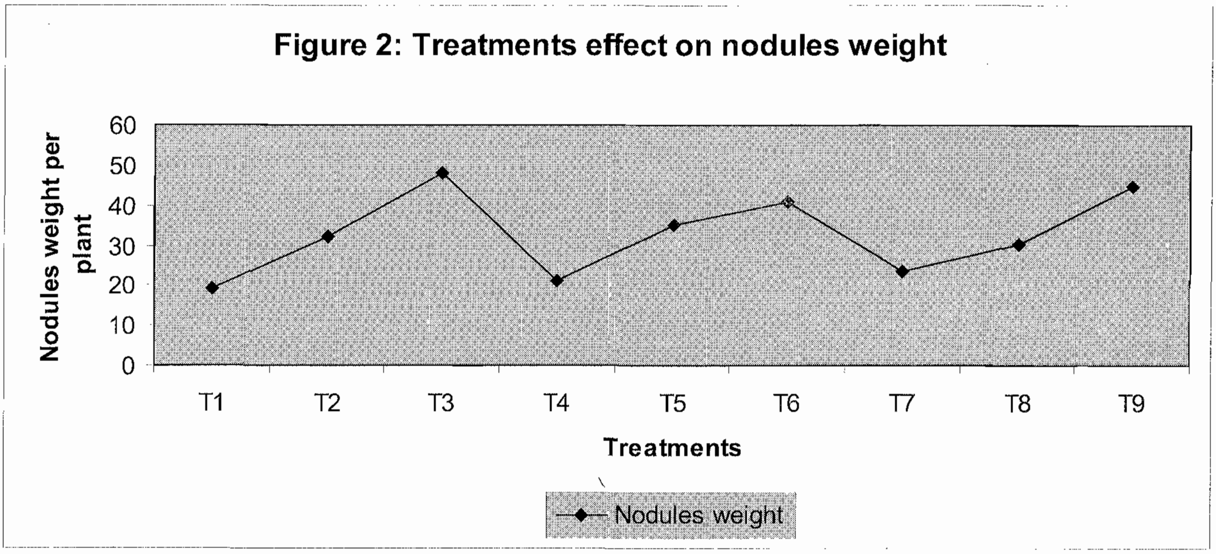
A summary of the study results shown in Table 2 clearly indicate that the variation of seedbed configurations had significant effect on seedling emergence, nodule dry weight, aboveground dry mass and yield of the soybean crop ($P < 0.01$). However, the planted ridge widths did not significantly influence soybean plant height at maturity ($P > 0.01$). Generally, while timing of post-planting split applications of nitrogen and pre-planting variations of phosphorus fertilizer rates did not effectively determine seedling emergence counts, their effects on nodule weight, aboveground biomass and grain yield were comparatively significant ($P < 0.01$).

The highest seedling germination counts were recorded on 0.5 m wide ridges, where seedling emergence was 150-200% in excess of the lowest counts recorded on flat seedbeds (Table 2, Figure 1). The narrow ridge seedbeds recorded 8-9 and 3-5 more emerged seedlings m^{-2} than those observed on the flat and wide ridge seedbeds respectively. Sowing soybean seeds on the flat seedbeds minimized seed germination by 8 seed emergence counts m^{-2} or 62.5% when compared with that on 0.5 m wide ridge seedbeds. Soybean seed placement on 1 m wide ridge seedbeds whittled down seed germination by 32.3% when compared with that on 0.5 m wide ridges (Table 2, Figure 1).

The high rate of soybean seedling emergence on the narrow ridge seedbeds was largely attributable to the accelerated gravitational drainage, which effectively lowered specific heat of a smaller mass of soil in the rapidly drying narrow ridge. The accelerated evacuation of water from the narrow ridges by gravity conferred the soil a reduced specific heat that enhanced the rapid heating up of the soil necessary successful germination of the soybean seed. The 1 m wide ridge seedbeds held more water by virtue of their wider humps, which significantly elevated the quantity of heat energy required to raise the soil temperature for rapid germination of the soybean seed. The slow soil drainage in the flat seedbeds variants of the trial encouraged settlement of water in the soil mass, which, for similar reasons, cooled the soil. This had the effect of reducing the heat energy content required for successful seed germination, which effectively whittled down germination counts in the flat seedbeds observed in this study. This trend in the effect of seedbed configurations on germination and emergence of soybean was not particularly surprising as it confirmed research findings elsewhere. In a study on ridge farming for soil and water control, Buchele *et al.* (1955) had found that time between seeding and germination in a wet soil was decreased, and that the number of emerged seedlings increased when planting on the ridge compared to conventional planting. Benjamin *et al.* (1990) simulated the movement of water within a ridge and concluded that a gradient of water potential caused water to move from the ridge to the furrow where it replaced evaporation from the furrow position thereby increasing specific heat capacity of the soil in the furrow that effectively cooled the soil.

Fertilizer treatments effect on seedling emergence in the three different seedbeds did not statistically differ. Logically, N and P nutrient availability, their timing and rate of application interferences on germination and emergence of soybean are largely insignificant regardless of their seemingly huge effect on the water diffusion determinants and osmotic gradients of the soil systems. At this stage, water availability and its attendant effects on the thermodynamics of the soil systems are the major determinants of the soybean germination and emergence processes.

Seedbed configurations and fertilizer amendments strongly monitored soybean nodule weights ($P < 0.01$). While soybean germination and seedling emergence were reduced by the increase in planted ridge width, nodule weights were significantly enhanced by the increase of the width of ridge seedbeds and early application of fertilizers in T_3 and T_9 plots (Table 2, Figure 2). The heaviest nodules per plant station were recorded in T_3 plots. Widening the ridge seedbed to 1 m and pre-emergence applications of 120 kg P and 30 N kg ha^1 in T_3 variants increased nodule weight by 37.1% and 7.1% in duplicated fertilizer amendments in T_5 and T_9 plots on 0.5 m wide and flat seedbeds respectively. Early applications P_{120} and N_{30} on soybean crop planted on broad ridges amplifies nodule biomass weight by 29 mg and 16 mg $plant^{1}$ when compared with nodule weight per plant in T_1 (no-fertilizer) and T_2 (pre-plant P_{80} and N_{30} 6 weeks AP) respectively within the 1 m wide ridge seedbeds. Spectacular declines of 29 mg, 20 mg and 21 mg



plant¹ were recorded in the zero-fertilizer plots (T_1, T_4, T_7) from the highest nodule weights in I m (T_3), 0.5 m (T_6) wide ridges and flat seedbeds (T_9) respectively.

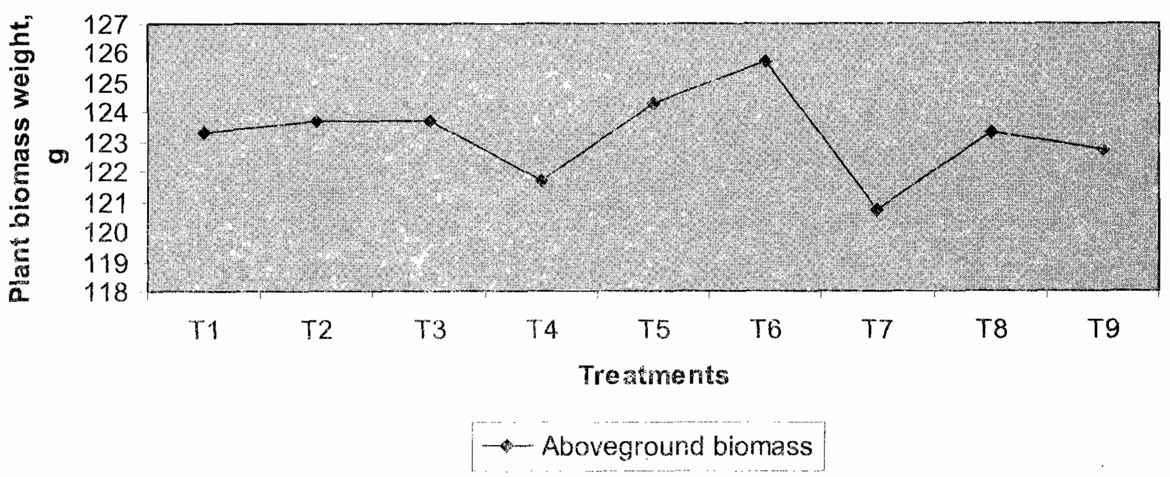
The enhanced nodule weights in the wider ridge seedbeds amended with an early application of N and P fertilizers observed in this study were a root nodule biomass synthesis response to not only nutritionally favourable soil conditions, but moderate soil moisture content associated with this seedbed configuration. An early presence of vital nutrients in a soil mass that is neither too wet (in flat seedbeds) nor too dry (narrow ridge) induced a bulge in root nodule biomass. The gradient of water potential in a greater mass of soil on a wider ridge is flatter than that in smaller mass of soil on the narrower ridges. Accordingly, the drainage of a broader ridge soil is slower than that in the narrow ridge soil, which effectively enhanced moisture accumulation in the wide ridge that supported root nodule biomass build-ups recorded in this study. Coupled with improved soil moisture content, an early application of the vital nutrients ensured a synchrony of peak root biomass accumulations with availability of N and P in the soil, which clearly encouraged soybean nodule substance synthesis observed in the T_3 variants of the trial. The delayed application of N fertilizer coupled with soybean planting on either narrow ridges where water rapidly drained to generate rather dry soil conditions or flat beds where excessive water accumulations were experienced reduced nodule biomass build-ups.

The soybean nodule response to N fertilizer applications observed in this study is in direct contradiction with results reported by Ham *et al.* (1975), Yoshida (1979) and Yoneyama *et al.* (1985). The researchers concluded that N applications made before reproductive growth stages decrease growth of nodules and lower N fixation. This variation in the results was not particularly surprising. Naisbitt and Sprent (1993) reported variable nodule biomass accumulation response to N fertilizer applications between legume species. In support of our results, Garcia and Hanway (1976), Syverud *et al.* (1980), Purcell and King (1996) and Wesley *et al.* (1998) reported that soybean cultivars grown on nutritionally hostile soils could exhibit nitrogen deficiency during the first 30 to 40 days after planting. Soybean may derive only 50% of their N needs from symbiosis (Harper, 1987). Macronutrient research has shown that supplemental applications of N have increased seed yield in some studies (Garcia and Hanway, 1976; Syverud *et al.*, 1980; Purcell and King, 1996; Wesley *et al.*, 1998).

The no-fertilizer variants in this study had the smallest weights of nodules per plant station largely due to lack of vital nutrients in the soil. In this respect, White (1999) observed that nodulation and N_2 fixation are generally stimulated by simultaneous infection of the roots by vascular-abuscular mycorrhizas due mainly to the enhanced supply of P to the host plant.

In this study, seedbed configuration was the largest single determinant of the soil water potential gradient in the same soil type seedbeds. Seedbed configurations that encouraged either a rapid drainage or excessive water accumulations significantly dwarfed nodule weights per plant station. Amongst a host of soil environment conditions that affect nodulation, Richardson and Simpson (1988) and Brockwell *et al.* (1995) singled out soil moisture content as the most important.

Figure 3: Treatments effect on aboveground biomass weight



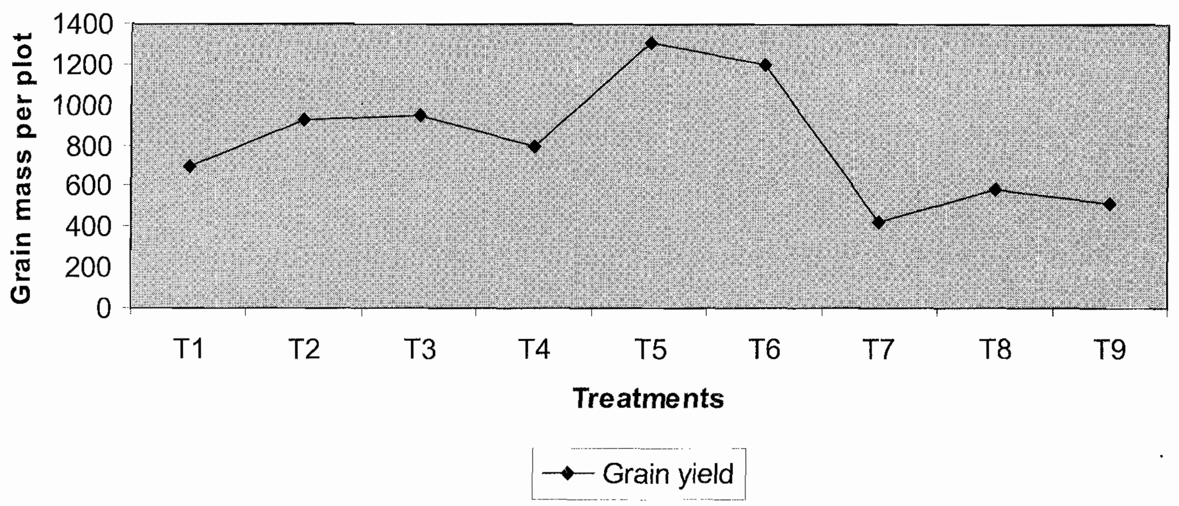
Neither the alterations of ridge configuration nor pre-plant applications of different rates of P and timing of topdressing N fertilizers conferred significant soybean plant height effect ($P > 0.01$).

Aboveground soybean plant biomass accumulations were not significantly ($P > 0.01$) determined by seedbed type. In addition to that, varying the topdressing timing of N and pre-plant P fertilizer application rates in all the three seedbed types did not significantly affect soybean plant biomass accumulations (Table 1, Figure 3). Nevertheless, there were comparatively significant biomass build-ups in the fertilized plots when compared with those in the no-fertilizer ridge and flat seedbeds. In the wide ridge seedbed plots, plant biomass weights on fertilized and no-fertilizer seedbeds did not differ. Application of P_{120} as a basal fertilizer and N_{30} at planting increased plant biomass by 2.6 g plant^{-1} or 2.1% in excess of that in unfertilized plots under 0.5 m ridge seedbeds. Under the same seedbed type, the reduction of P application rate to P_{80} and a delay in N_{30} timing to 6 weeks after planting amplified soybean plant biomass weight by 4.0 g plant^{-1} or 3.3% over that in the no-fertilizer plots. On flat seedbeds, the basal application of P_{120} and N_{30} at planting increased biomass accumulation by 2.6 g plant^{1} while the reduction of P fertilizer application rate to 80 kg ha^{-1} and the delay of N_{30} topdressing to 6 weeks after planting improved aboveground dry weight by 2.9 g plant^{-1}.

On the narrow ridge seedbeds, the fact that a reduction of P application rate and a delayed timing of N fertilizer actually increased biomass weight margin between the fertilized and zero-fertilizer plots is a clear indication that the rate of P fertilizer application does not determine aboveground biomass build-ups of soybean. The soybean response to P fertilizer application in vertisols has been reported to be unpredictable (Sakar and Uppal, 1994). In fact, it was the delayed timing of N fertilizer application in the vegetative period of the soybean that enhanced the aboveground vegetable mass. Consequently, it was hydrology of the seedbed configurations that monitored the effect of the highly mobile N on biomass accumulations by soybean. We indicated earlier on that the narrow ridge seedbeds, by their configuration, had the steepest gradients of water potential amongst the three seedbed types. This physical characteristic conferred them a rapid drainage of water, which kept them rather dry (Benjamin *et al.*, 1990). Under such conditions the loss of N through leaching processes was kept at a minimum. This had the effect of accentuating fertilizer N effect on the aboveground biomass accumulations in the narrow ridge plots over those recorded in the control plots. The other two seedbed configurations tended to allow excessive water accumulations during rain and irrigation events that leached out Fertilizer N. For this reason, biomass weights in fertilized plots of the wide ridge and flat seedbeds in excess of those recorded in the zero-fertilizer plots were comparatively lower than those in the narrow ridge seedbeds (Fausey, 1990).

Figure 4 summarises the soybean yield responses to the treatments. Generally, there was a detectable trend in the effect of seedbed type, timing N and rates of P fertilizer applications on grain yield of soybean ($P < 0.01$). A comparison of yield data from control and fertilized variants for each seedbed type clearly show that application of fertilizers to soybean amplify grain

Figure 4: Treatment yield responses



yield per plot by 232.54 252.84 g, 409.30 516.20 g and 98.51 166.07 g in the narrow, wide ridges and flat seedbeds respectively.

While the soybean plant is unique in its ability to convert atmospheric N_2 into organic forms that are available to all forms of life on Earth, its need for supplementary Source of N as fertilizer was amply demonstrated by the positive yield response to N applications. Harper (1987) reported that soybean cultivars grown on nutritionally hostile soils could exhibit nitrogen deficiency during the first 30 to 40 days after planting. Adams and Attiwell (1984) reported very small contributions (10-40%) of symbiotically fixed N towards the total N budget of a legume. George and Singleton (1992) suggest that the limited fixation capacity (relative to soybean) of the papilionoid legume, *Phaseolus vulgaris*, reflects a superior capacity of this species to acquire and assimilate mineralized N. In addition to that, the combined application of N and P fertilizers enhanced the uptake and assimilation of N and other vital nutrients. P encourages vigorous growth of soybean root systems, which in turn significantly enhances uptake of other nutrients in the soil. P is particularly necessary during periods of intensive early growth phases and synthesis of biomass materials during grain filling period when protein and starch synthesis are intensive (Garcia, and Hanway, 1976). Elevated contents of soil N in nitrate forms, which cannot be assimilated by soybean plants into protein in that state, require relatively higher content of available P for synthesis of high-energy releasing materials (ATP) for the energy-consuming transformation of nitrate N into protein components. In this respect, the positive yield responses recorded in this study were not particularly surprising.

Cutting the ridge seedbed width from 1 m to 0.5 m increased soybean grain yield by 385.0 g plot $^{-1}$or 41.6% when P_{80} was applied as a pre-planting fertilizer and N_{30} as a top dressing at six weeks after planting. The 0.5 m wide ridge seedbeds had 257.8 g plot $^{-1}$ or 27.3% more soybean grain yield over that in the 1 m wide ridges when P_{120} was applied as a pre-planting fertilizer and N_{30} was applied at planting. Planting soybean on flat beds whittled down grain yield responses by 39.3 47.0% and 36.6 60.4% in the control and fertilized plots respectively. Delaying the application of N_{30} to six weeks after planting and downgrading P application rate from 120 to 80 kg ha ^{1} reduced soybean yield by 20.3 g plot ^{1} in the wide ridges, increased grain yield by 106.9 g and 67.6 g plot ^{1} in the narrow ridge and flat seedbed variants respectively.

The highest nodule weights, which logically should have boosted yields through enhanced N fixation, recorded in the wide ridge seedbeds did not support the highest yield in the trial. In fact, the narrow ridge seedbed variants that scored the highest seed germination and emergence count had the highest soybean grain yield regardless of the rate of P and timing of N fertilizer applications. We attributed this trend in soybean yield response to high germination and emergence rates that elevated plant populations in the narrow ridge seedbed variants. Logically, this had a yield magnifying effect in the T_5 and T_6 plots.

Reeder (1990) reported crop yield increases of about 12% in RT compared to intensive tillage systems in the rolling terrain and deep loess soils of western Iowa. Fausey (1990) observed that soybean yields were improved under RT on Mollic Planosols due to improved drainage.

From the study results, it can be concluded that the soil conditions for growth and development of soybean, which were largely monitored by the seedbed configuration and rates of P and timing N fertilizer applications were responsible for the varied seedling emergence, nodule weight, plant height, aboveground biomass and yield responses. Planting soybean on 0.5 m wide ridge seedbeds significantly enhances germination and seedling emergence. Flat seedbed planting practice minimized seed germination by 62.5% when compared with that on 0.5 m wide ridge seedbeds. Widening ridge seedbeds to 1 m whittled down seed germination by 32.3% when compared with that on 0.5 m wide ridges. Enhanced moisture retention with minimized possibilities of waterlogging conditions conferred 1 m wide ridge seedbeds the highest nodule weights. Elevated nodule weights recorded on wide ridge seedbeds did not enhance soybean yields. Accordingly, high nodule weights on soybean roots does not necessarily increase grain yield. The 0.5 m wide ridge beds, which had the highest seedling emergence score, in fact, recorded the largest yield responses. Consequently, in legume crop production systems, while enhancement of nodulation rates is important, ensuring seedbed conditions that encourage high percentages of germination and seedling emergence is fundamental in achieving the highest soybean grain yield.

Early applications of P_{120} and N_{30} on soybean crop planted on broad ridges amplify nodule biomass weight. Cutting the ridge seedbed width from 1 m to 0.5 m increased soybean grain yield by 41.6% when P_{80} was applied as a pre-planting fertilizer and N_{30} as a top dressing at six weeks after planting. The 0.5 m wide ridge seedbeds had 27.3% more soybean grain yield over that in the 1 m wide ridges when P_{120} was applied as a pre-planting fertilizer and N_{30} was applied at planting. Delaying the application of N_{30} to six weeks after planting and downgrading P application rate from 120 to 80 kg ha^{1} reduced soybean yield by 20:3 g plot^{1} in the wide ridges, increased grain yield by 106.9 g and 67.6 g plot^{1} in the narrow ridge and flat seedbed variants respectively.

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