Improving Food Production by Understanding the Effects of Intercropping and Plant Population on Soybean Nitrogen Fixing Attributes

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Abstract

This paper quantifies the effects of population density and intercropping on the development and growth of nitrogen fixing attributes of soybean and explains how these attributes influence food through yielding process. Information for this study was obtained from a field study conducted over two rainy seasons comprising of the short and long rains in Kenya. Inoculated soybean was grown in two combinations; sole and intercropped with sorghum at three levels of population densities; 66, 666; 83, 333 and 111, 111 plants ha^{-1}. Estimates of nodule mass, position, density, number, effective nodules and nodulation frequency were monitored at various intervals during the growing season. The responses of nitrogen fixing attributes of soybean varied with cropping pattern, density, stage of growth and the growing season. Intercropping caused decreases in nodule biomass at 21 days after planning (DAP), number of nodules, and nodulation frequency at the 1st, harvest of the 3rd season and at the 1st, 2nd and 3rd harvests of the 4th growing seasons. Significant increases in dinitrogen fixing attributes within intercropped stands were demonstrated for nodule position, percent effective nodules, and percent nodulation frequency at the 2nd and 4th harvests of the 3rd growing season. Influences of density on nodulation frequency during the 4th harvest were highly variable. Density and inter-cropping interactions caused significant decreases for nodule biomass at 21 DAP, percent nodulation at the 4th harvest during the 3rd growing in contrast to those decreases noted at the 2nd, 3rd and 4th only. The study indicates that for soybean yield, any management factors that cause a reduction in nitrogen fixing attributes are crucial to improving yield of soybean. There is therefore need to study the physiology of dinitrogen fixing attributes in order to understand yield processes.

Introduction

In 1999, the official UN estimate for the world population exceeded 6 billion people. Within the first 25 years of the twenty first century, the world's population will increase by another nearly 2 billion people. Virtually all of this increase will occur in the developing countries. The population will become increasingly urban, not only will the total demand for food be greater than it as ever been, but the nature of that demand will be different. There is evidence of charges in dietary habits, as well as in methods of food production, processing and marketing, international trade in raw commodities and processed foods. The quality of food is entirely dependent on the physiological processes of the plant, its agronomic and environmental conditions (Akunda 1981).

With a projected world population of 7.8 billion people by the years 2025, there is considerable concern about the ability to provide for this number of human beings and to meet their changing demands, in an adequate and sustainable way. The physiological understanding of how agronomic and environmental influences the food production will become increasingly important. Rooting patterns affects the physiological processes of plants through their effects on nutrition of the plant.

Deep rooted plants survive drought better than shallow rooted plants because more water is accessible to deep rooted systems (Kramer, 1969). Thus in circumstances where there is occasional drought, for example due to environmental or cultural management practices, species or varieties that root deeply often yield more than others (Taylor and Klapper, 1973). Nitrogen metabolism is greatly influenced by water. In wheat, fertilizer nitrogen has been generally known to increase top growth, yield and water use during drought spells, this is also dependent on the management systems.

Intercropping may be helpful to solve future food problems in developing countries (Tsubo *et al.*, 2001). This may be through efficient use of radiant energy and due to the fact that the intercropped crops are planted in a given area of land. Similarly optimization of land is achieved when crops are intercropped and plant density increased (Rosalind *et al.*, 2000) demonstrated that higher soybean populations than are traditionally recommended provided a way to optimizing growth yields in time – constrained systems. Thus plant population can be used as a tool to manage crop growth, maximize biomass, the time required for canopy closure and yield. The pattern of growth is in turn influenced by intercropping. Both intercropping and plant density affect nitrogen fixing attributes. Symbiotic nitrogen fixation in soybean is very sensitive to soil drying, which may be brought by competitive effects of plant population and intercropping.

In soybean nitrogen fixation activity occurs earlier in the drying cycle than apparently any other observed physiological process (Serraj *et al.*, 1999). As a result of this loss in activity yield loses appear to be a common feature of soybean production. The activity of nitrogen fixation may be estimated through various nodulation parameters. This may be based on assessment of nodule formation and development, nodulation frequency, nodule biomass, numbers and effective nitrogen fixing nodules (Abaidoo *et al.*, 1999). Assessments of nitrogen fixing attributes are pivotal to understanding the use of legumes for various farming management technologies.

Nitrogen management in no – tillage grain Sorghum production has to be investigated by Kholsa *et al.*, (2000). Their work on multi rate N fertilization on dry land sorghum indicated that production of sorghum on soils testing high in mineral N (50 kg N ha^{-1} in the surface 0.3 m) at planting did not require any starter band N for economic returns to nitrogen fertilization. This pattern may be different from an intercropping situation.

Intercropping systems influence yield variables of the component crops, such as harvest index, seed weight, number of reproductive organs, number of seeds, within each reproductive unit and nitrogen fixing attributes (Carruthers *et. al.*, 2000). In combination with various lupin and forages, these authors showed that soybean grain yield was decreased by most treatments. In order to limit over population and pollution risks, low nitrogen fertilizer agricultural systems are likely to be advocated. Intercropping of sorghum and inoculated soybean at high densities may be one of such systems. Productivity of such systems can be increased with minimum N- fertilizer additions, as a great amount of nitrogen would be supplied through symbiotic nitrogen – fixing attributes and which in turn depend on agronomic management systems of the crops.

Nitrogen is the nutrient needed in the greatest quantity by plants. It represents the limiting factor to achieve high yields in crop plants. Due to this, there has been an increase in the use of chemical nitrogen fertilizers to the detriment of environment. Nitrogen fixation provides a partial solution to this - environmental pollution by the use of N – fertilizer. However, the particular challenge in nitrogen fixation is in achieving more sustainable farming systems by increasing also food production in the cheapest possible way through biological nitrogen fixation. This can be done via intercropping and inoculation to increase the availability of nitrogen to staple food crops. In addition to intercropping of legumes with cereals, legumes add to the protein source to households.

To increase the productivity of such systems, an in depth understanding of the attributes are of crucial importance. In this study, nitrogen-fixing attributes of inoculated soybean intercropped with grain sorghum at three plant populations were monitoring through out the growing period.

Materials and Methods

The nitrogen fixing attributes was carried on a field experiment at the University of Nairobi during the short and long periods seasons. The design was a split plot replicated four times with treatments comprising of two inter cropping patterns; sole and inter crops of sorghum and soybean with three planting densities at a population of 1:1 designated as low density (LD), normal density (ND), and high density (HD) of 66,666, plants ha^{-1}, 83,333 plants ha^{-1} and 111,111 plants ha^{-1} respectively. The density formed the main plot while crop combinations the sub plots. In order to ensure the above densities the following spacing were used, 75cm x 20cm, 60cm x 20cm, and 45cm x 20cm. The choice of planting density was based on the ecological spread that sorghum and soybean can grow under Kenyan conditions.

Agronomic management of the experiment was kept to optimum except nitrogen fertilizer was not added during planting nor was there top dressing. Instead the soybean was inoculated before planting with rhizobium strain 7210 supplied by MICERN - Nairobi. Phosphate fertilizer was applied in the form of P_2O_5 at the rate of 45kg ha^{-1} in furrows between planted rows at the time of planting.

Nitrogen fixing attributes were used as parameters to help understand how inter cropping and density interact with each other in affecting productively and nitrogen use efficiency. The estimated nodule biomass, number of nodules, nodule position, percent effective nodules and nodulation frequency at various growing periods during the short and long rains. These estimates were employed as parameters to help understand how cropping patterns and plant density influence N_2 - fixation.

The estimates of N_2-fixing attributes were carried out, at various harvesting intervals. The harvesting interval started after 21 days after planting (DAP) and was repeated from 10 to 12 days interval throughout the growing period. Sub samples of four plants were randomly selected in each plot for determination of the N_2 - fixing attributes. Nodule mass was estimated at 21 DAP, flowering and pod hardening stage, nodule position, density and number were assessed at the closure of the canopy. The closure of canopy was taken, as the stage at which there was high competitive effects for environmental resources. These measurements were only restricted to the long rains. Assessment of percent nodulation frequency was carried out on plants grown during the short and long rains, hereby referred to as the 3rd and 4th growing seasons respectively. The study reported in this paper formed a part of a large program, which covered a total of four growing seasons (hence 3rd and 4th seasons). Nodulation frequency was estimated at four intervals, first, second third and fourth starting from 21 DAP and separated by 10-12 days intervals.

The mass of nodules was estimated from the four plants taken from each plot. These nodules were strip off the soybean plants and bulked per each plot then dried at 80 °C for 24 hours and weighed.

There is a close relationship between nitrogenase activities and hemoglobin of the nodules. (Sprent, 1972) used an indirect method of estimating dinitrogen fixation to monitor the effectiveness nodules in fixing nitrogen. This was based on the colour of 100 nodules taken from the four plants per plot at random. Nodules were sliced in pieces to observe their colour. Red nodules were considered as fixing atmospheric nitrogen while white nodules were non-fixing (Brun, 1976).

Nodule position was defined, as the difference from the soil surface (Zero position). Thus intact roots were carefully excavated and their nodule position measured from the surface downwards. The density of nodules were estimated by weighing their fresh weight followed by determining their volume using a displacement method. Data from these estimates was used to calculate the density of nodules by dividing the fresh weight of nodules with their volume.

Legume root nodules have limited functioned life span, and the onset of decline in their nitrogen fixing activity is usually considered as an index of nodule frequency (number of nodules per unit length i.e. 30cm in the mid region was used as the basis for estimating nodulation frequency. The average number of nodules, which were on the roots within a particular distance from the surface, was compared to the total distance of the root standardized at 30cm length. Nodule intactness per plant was used as a parameter to demonstrate the efficiency of the dinitrogen fixation at various phases of growth. This intactness is hereafter referred to as nodulation frequency.

Fig 1 a, b, c, d, e, f and g. Nitrogen fixing attributes. Nodule mass at 21 DAP, flowering and pod hardening; nodule number, nodule position, percent effective nodules and nodule density

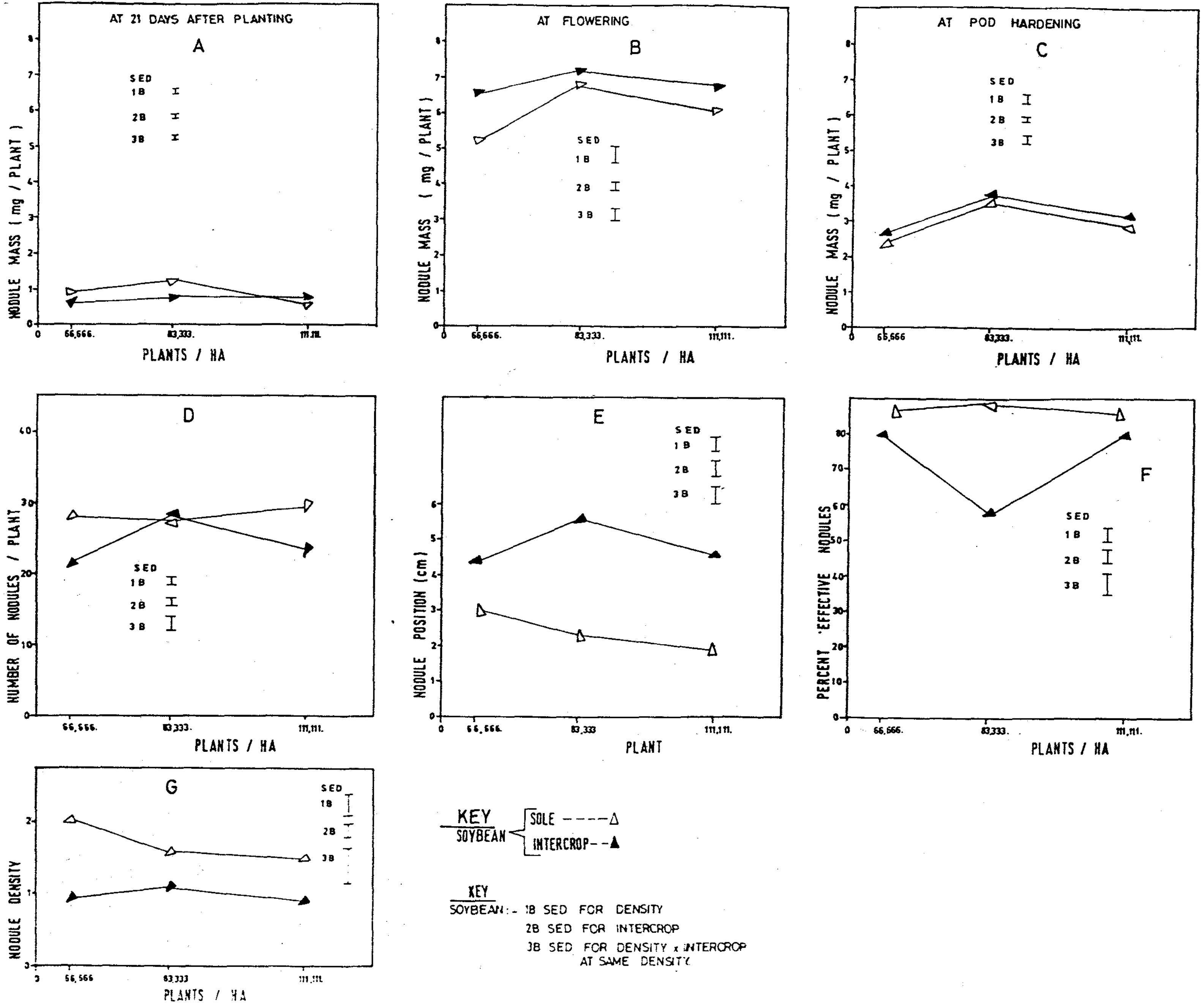
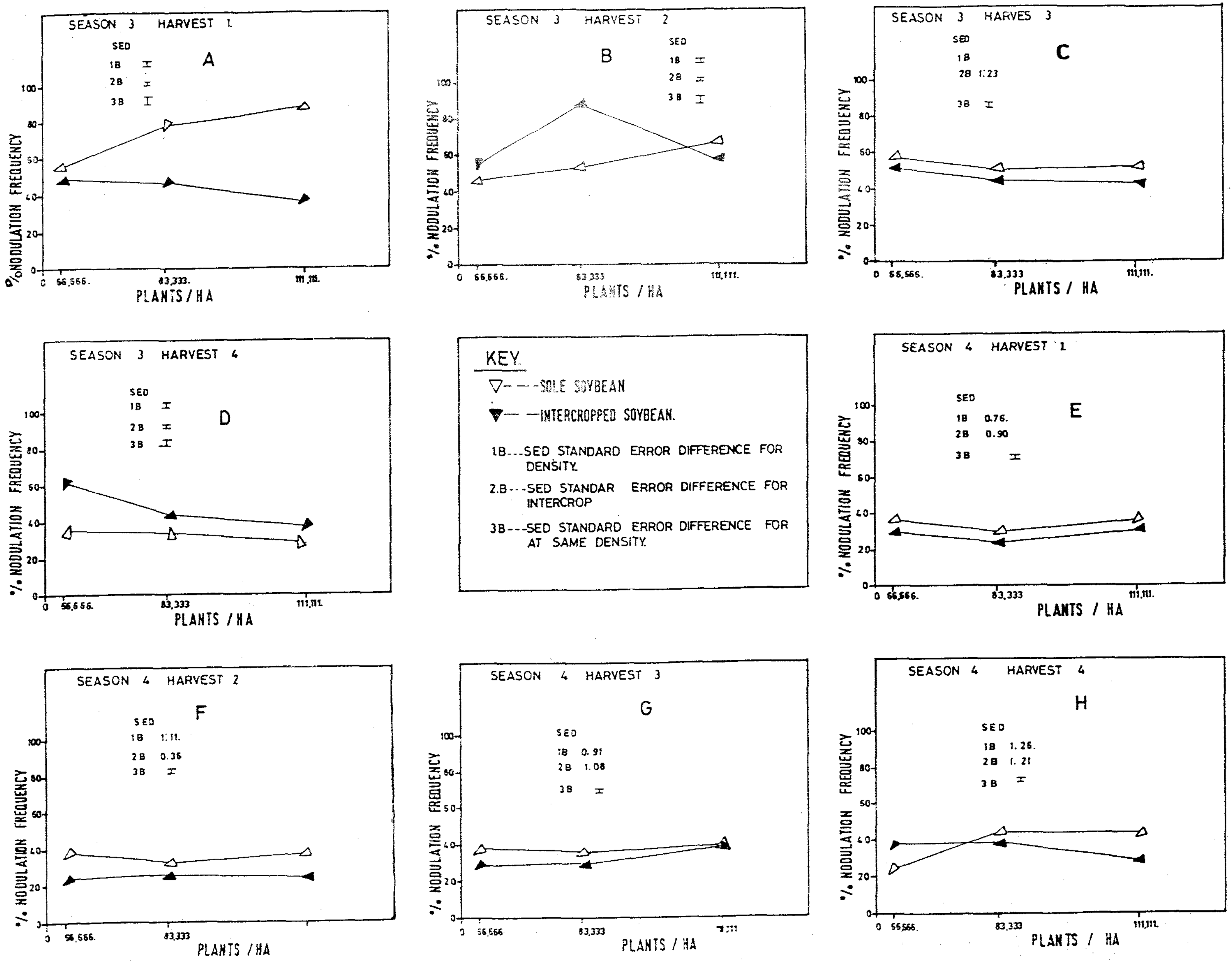


Fig 2 a, b, c, d, e, f, g, and h: Nitrogen fixing attributes; the percentage nodulation frequency for the 3rd ad 4th growing seasons harvests 1, 2, 3, and 4.



Results

Dinitrogen fixing attributes are shown in **Fig 1a, b, c, d, e and f**. Nodule biomass in the inter crops decreased significantly (p=0.05) at the 21 DAP, while it Significantly (p=0.05) increased at ND and decreased at HD as population density increased. The nodule biomass increase non-significantly within the inter crops at pod hardening stage. This was in contrast to significant (p=0.01) increase observed at the same stage as population density increased. Significant (p=0.05) decreasing interactive effects of inter cropping and density for nodule biomass was only observed at the 21 DAP.

The number of nodules and nodule position varied among treatments. Inter cropping caused a significant decrease (p=0.01) contrary to a non-significant increase followed by a slight decline as plant population increased. There was highly significant (p=0.01) increase in nodule position in the inter cropped stands, compared to plant density. Increasing plant density, did not affect nodule position.

There were significant (p=0.01) increase in percent effective nodules within inter cropped stands. Increasing plant population on the other hand, caused a significant (p=0.01) decreases and increases at ND and HD respectively. Decreasing percent effective nodules were noted for the inter cropping. The reducing effect on nodule density due to the interactive influences of density and inter cropping were however non-significant.

Two growing seasons contrasted each other with respect to percent nodulation frequency (**Fig 2a, b, c, d, e, f, g and h**). These contrasts are also explicit with respect to sample (harvest) intervals. Nodulation development (nodulation frequency) significantly (p=0.01) decreased at the first harvest, then increased significantly (p=0.01) increased at the 2nd and 4th harvests within the inter crops during the 3rd season (fig. 2b and d). The 3rd season fell within the short rains while the 4th in the long rains.

The rate of nodulation was affected by population density in a varied pattern. Increasing plant population had a high significant effect on nodulation frequency throughout the 3rd growing season. At the first and second harvests, there were high significant (p=0.01) increases in nodule frequency. This contrasted with the subsequent harvests (3rd and 4th harvests), in which an increase in population density consistently caused a highly significant (p=0.01) decrease.

The 4th growing season was characterized by inter cropping significantly affecting nodulation frequency at most harvest, with the exception of the 4th harvest. For most harvests, inter cropping tended to cause a decrease in nodulation frequency. The influence of population density on nodulation frequency was only significant at the 1st, 3rd and 4th harvest. During the first harvest, there was a significant (p=0.05) decrease at ND followed by an increase at HD. Although such trend was noted at the second harvest, this was however non-significant. The similar trend during the 3rd harvest was however significant (p=0.01). At the 4th harvest increase in population caused a high significant (p=0.01) increase at ND followed by decreases at HD. The interactive effects of density and inter cropping significant (p=0.05) decreased nodulation frequently at the 1st, 2nd, 3rd and 4th harvests during the 3rd growing season. This contrasted significant (p=0.05) decreasing interactive effects of density and inter cropping at the 2nd, 3rd, and 4th harvests during the 4th growing season.

Discussions

Intercropping effects on nitrogen fixing attributes of soybean were influenced by population density. Increase in plant population results into increased leaf area formation. The increase in leaf area formation in addition to uniform distribution of these leaves will result into efficient interception of irradiance by the crop canopy. Symbiotic dinitrogen fixation is highly dependent upon the flow of photosynthate to nodules (Paul and Kucey 1981). This relation is also coupled to yield. Thus any factors that influence photosynthesis will concomitantly influence nitrogen fixing attributes. Plant density influenced canopy development. Intercropped soybean provided a heavy shading as though they were a cover crop. Light penetration in such heavy shading was minimal. This in turn influenced photosynthetic process. Such response may have been responsible for the observed decreases in number of nodules, percent nodulation frequency at the 1st and 2nd harvest (12% and 20%) respectively.

Legume root nodules have a limited functional span and the onset of or decline in their dinitrogen fixing activity is usually considered as an index of the initiation of nodule senescence. The observed declines in nodulation frequency of 41% during the first harvest during the third growing season in the intercropped soybean stands and similar results noted for the first and second harvests of the 4th season may be linked to photosynthetic process. The heavy shade of intercropped soybean eminating from sorghum and self shading of soybean limited photosynthesis and thereby indirectly influenced the processes of nodulation. There is a strong linkage between photosynthesis and dinitrogen fixation (Streeter *et. al.*, 1979). This implies that negative influences on nitrogen fixing attributes influences the yield of soybean and consequently causes food insecurity. Improvements in the N_2 – attributes would in turn improve food situation.

The growing of crops at high density is used to help attain efficient interception of irradiance. Thus there is a relationship between plant population and yield (Holiday 1960a, b, c, and Rosalinda *et. al.*, 2000). Some of the common effects of density on dinitrogen fixation attributes would for example be high N_2 –fixation per nodule at higher planting density than at low-density. However, greater nodule number and mass in the lower densities can compensate this. Such responses are in turn influenced by photosynthesis. This reasoning supports the observed trends in percent nodulation frequencies in this experiment. The results in this study indicate that in order to increase the productivity of soybean under intercropping and density management, there is urgent need to have a thorough understanding of the N_2 – fixing attributes as these are greatly linked to photosynthesis and yield.

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