Partial Factor Productivity, Agronomic Efficiency, and Economic Analyses of Maize in Wheat-Maize Cropping System in Pakistan

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Abstract

Getting maximum benefits from cereals do not lie in reducing N-rate and its number of splits but lowering cost per unit cereal production through higher yields. Field experiments were conducted on maize (*Zea mays* L.) at the New Developmental research Farm of NWFP (Northwest Frontier Province) Agricultural University Peshawar-Pakistan during 2002-03 and 2003-04 in order to investigate effects of variable rates of N and its time of application on the partial factor productivity (PFP_N), agronomic efficiency (AE_N), net returns (NR), value-cost ratio (VCR) and marginal returns (MR). The 2 x 3 x 6 factorial experiment was designed having two plant densities (D_1 = 60,000 and D_2 = 100,000 plants ha^{-1}) and three N levels (N_1 = 60, N_2 = 120 and N_3 = 180 kg N ha^{-1}) applied to main plots, while six split application of N in different proportions were applied to subplots in two equal (T_1), three equal (T_2), three unequal (T_3), four equal (T_4), five equal (T_5) and five unequal splits (T_6) at sowing and with 1st, 2nd, 3rd and 4th irrigation at two wk intervals. Maize ranked first with maximum $PFP_{N,}$ AE_N, NR, VCR and MR at higher than at lower plant density, and the increase in all these parameters studied in the experiments was more in 2003-04 as compared to 2002-03. Both PFP_N and AE_N showed negative relationship with increase in N rates and the cast that vary, but NR, VCR and MR showed positive relationship with increase in N rates and the cost that vary. Among time of N application, maximum $PFP_{N,}$ AE_N, NR, VCR and MR were calculated when N was applied in five equal splits (T_5) almost comparable with T_4 and T_6 but was more economical when compared with T_1, T_2, and $T_{3.}$ In conclusion, the findings suggest that growing maize at D_2 applied with N_3 in four to five splits is more economical in the wheat-maize cropping system of NWFP.

Key words: maize, *Zea mays* L., planting density, nitrogen, agronomic efficiency, economics

Introduction

Maize (*Zea mays* L.) is the second most important crop after wheat in the North West Frontier Province (NWFP) of Pakistan but its yield per unit area is very low. The average yield in the Punjab province (4289 kg ha^{-1}) was far better than that of NWFP (1590 kg ha^{-1}) during 2005-06 growing season (Anonymous, 2007). This appreciable improvement in maize production in Punjab over NWFP was due to adoption of hybrid maize by the farmers which resulted 28.2 percent increase in yield in Punjab, on the other hand in NWFP which was the leading maize producing province in the recent past reduced its yield by minus 7.1 percent in 2005-06 as compared to 2004-05. During 2005-06, in overall nutrient uptake Punjab's share was 69.2 %, Sindh 22.7 %, NWFP 6.3 % and Baluchistan 2.6 %. Overall nutrient consumption in Punjab province increased by 3.9 %, Sindh by 0.7 %, Baluchistan by 12 %, while NWFP consumption of nutrient decreased by 3.3 % in 2005-06 as compared to 2004-05. The increase in consumption of N offtake (+ 4.7 %) against decrease in phosphate offtake (- 1.6 %) deteriorated N: P ratio from 3.23 in 2004-05 to 3.44 during 2005-06 (NFDC, 2006).

Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt et al., 2001). Judicious use of N is a key factor in the cereals based system of Pakistan for sustainable agriculture. Imbalanced fertilizer use especially in terms of phosphate (P) compared with N, has created concern in Pakistan as it may affect overall agricultural productivity and economic growth (FAO, 2007). In many developing countries N use, in relation to P and K use, is excessive (Bumb et al., 1996). This reduces the efficiencies of all nutrients and results from the tendency in many developing countries to save foreign exchange by minimizing imports of P and K-fertilizers. However, this does much harm because it reduces returns on investment in N-fertilizer, leads to degradation of soils and causes environmental problems (Cisse and Amar, 2000). The selection of fertilizers commonly depends upon price-the least costly fertilizer per kilogram of plant food is the one commonly selected (Plaster, 1992).

Nitrogen fertilizer is universally accepted as a key component to high yield and optimum economic return. Nitrogen (N) plays a very important role in crop productivity (Ahmad, 2000) and its deficiency is one of the major yield limiting factors for cereal production (Shah et al., 2003). Over N fertilization is a common problem for the wheat-maize rotation system (Zhao et al., 2006), while its restriction from seeding to V8 stage causes 30% reduction in yield, withholding N supply from V8 to maturity reduces yield by 22% but there is no yield reduction when N is restricted from silking or 3 wk after silking to physiological maturity (Subedi and Ma, 2005). Increasing plant density for short season maize increases cumulative intercepted photo synthetically active radiation, which compensates for a short growing season to achieve high yield with substantially less irrigation (Edwards et al., 2005).

Matching the N requirement of maize crop which is dynamic during its growth period is essential to increase the N use efficiency. Nitrogen application in splits up to silking significantly improves the vegetative and reproductive growth of maize except number of grains cob^{-1}, and the increase in the grain yield of maize depends on increase in cob bearing plants $plot^{-1}$ and 1000 grain weight (Akbar et al., 1999). Grain yield in maize increases with increase in grains cob^{-1} and number of ears 100^{-1} plants (Soliman et al., 1999). Plant density and nitrogen has significant effects on the yield as a result of increase in the number of seeds ear^{-1} and number of ears $plant^{-1}$ (Turgut, 2000). The increase in the grain yield of maize in high density plots is due to the improvement in light interception during the critical period for grain set, while number of seeds $plant^{-1}$ and plant growth rate is adversely affected by N deficiency and shading in the high density plots (Andrade et al., 2002). Grain yield in maize increases with increase in plant density, rate and spit application for N (Mariga et al., 2000; Scharf et al., 2002). Quality characteristics in maize such as ear size, tip fill and individual grain weight improves with increase in N level in both low and high density plots; ear size, tip fill and individual grain weight declines at high density regardless of N supply (Stone et al., 1998). Inadequate plant density and N application to maize crop results in low maize yield.

There have been many studies conducted on plant competition to determine the optimum plant density for maize (Olson and Sander, 2003). Yield reduction per plant was due to the effects of interplant competition for light, water, nutrition, and other potentially yield limiting environmental factors (Duncan, 2002). Increase in plant density delays maturity and decreases shelling percentage, thousand grain weight, grains ear^{-1} and grains row^{-1} (Sangoi et al., 2002; Ogunlela et al. 2005). Total dry matter, average leaf area and plant height maximized at 80,000 plants ha^{-1}, but harvest index decreased at high plant density (Amano and Salazer, 1989). Plant height and ear height increase with increasing plant density, but leaf area, ear length, grains row^{-1} and thousand grain weight decrease with increase in plant density, while number of leaves $plant^{-1}$, number of leaves above main ear and number of rows ear^{-1} are not affected by plant density (Hassan, 2000). Toler et al. (1999) reported 15% higher light interception and grain yield at higher than at lower plant density of maize. Increasing plant density for short season maize increases cumulative intercepted photo synthetically active radiation, which compensate for a short growing season to achieve high yield (Edwards et al., 2005). Plant height and ear height increases but leaf area decreases with increase in plant density (Hassan, 2000). Maize height and maturity are highly correlated to leaf number (Cross and Zuber, 1973) and the relative growth rate of leaves decreases with leaf number (Milthorpe and Moorby, 1974). Plant density in maize affects plant architecture, alters growth and developmental patterns and influences carbohydrate production and partition (Casal, 1985).

Getting maximum profitability lies not only in reducing use of N per unit area but also in lowering costs per unit crop production through higher yields. Therefore, economic analysis is required for making recommendation for farmers from agronomic experiments. Farmers in Pakistan are profit-oriented, and therefore, they are interested in net returns than the gross returns. In practice, not all farmers, however, can aim for the largest net returns because of the generally larger costs involved to other risks associated with farming (Saleem et al., 1986). According to Bhatti, (2006) and Saleem et al. (1986), the risk factors involved in agriculture, a VCR of 2 is recommended for farmers using high technology in Pakistan. A VCR of 2 represents 100 % return on the money invested on N-fertilizer. For farmers with low technology, with no credit available to them or limited capital, a fertilizer rate giving a VCR grater than 2 should be recommended. To increase yields and profits, fertilizers along with improved farming practices are the best investments farmers can make.

Adoption of inefficient N management practices is responsible for low partial factor productivity and agronomic efficiency. Partial factor productivity (PFP) and agronomic efficiency is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system (Yadav, 2003). Decline in partial productivity for N has been reported in cereal based system leading to higher investment in N to maintain higher yields. Decline in partial factor productivity for N may be attributed to nutrient imbalance, decline in indigenous soil N supply, subsoil compaction, reduced root volume and increased incidence of pests and diseases (Karim and Ramasamy, 2000). According to Cassman et al. (1996), PFP can be increased by increasing the amount, uptake and utilization of indigenous nutrients, and by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain. Application of a unit fertilizer is economical, if the value of the increase in the crop yield due to the quantity of fertilizer added is greater than the cost of fertilizer used. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004). The application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application, is the key to increased and sustained crop production (Cisse and Amar, 2000).

Since higher fertilizer use efficiency is always associated with low fertilizer rate, cultural practices meant for promoting integrated nutrient management will help to affect saving in the amount of fertilizer applied to the crops and therefore to improve fertilizer use efficiency (Karim and Ramasamy, 2000). The goal of N-fertilizer research is to maintain high levels of crop productivity with minimum nitrogen input i.e. to improve the agronomic efficiency of N. Agronomic efficiency of N can be increased by increasing plant uptake and use of N and by decreasing N losses from the soil-plant system. Agronomic approaches, such as fertilizer placement, proper level of fertilizer application in optimum plant density, time of fertilizer application and keep plant-available N in the plant root zone (Hauck, 1984). Primary philosophical approach to developing an N fertilizer recommendation for maize is to consider, as independent variables, yield goal, economic return, management level, and some measure of inherent differences in soil productivity (Oberle and Keeney, 1990). However, this approach may lead to over application of N fertilizer and result in elevated levels of NO_3 loss by leaching (Sogbedji et al., 2000). Fertilizer N applied in excess of crop needs may result when soil inorganic N content is not adequately considered or when predicted yield goals are considerably larger than could be expected for given soil types and climatic conditions (Keeney, 1987). Nitrogen use efficiency generally decreased with increasing level of available N (Halvorson et al., 2005). Efficient use of N for maize production is important for increasing grain yield, maximizing economic return and minimizing NO_3 leaching to ground water (Gehl et al., 2005).

Split application of N fertilizer in wheat between tillering and stem elongation, enhance crop NUE and reduce losses through leaching and runoff (Bellido et al., 2006). Fertilizer application in time at proper growth stage also determines NUE (Ashraf and Azam, 1998). Follett (2001) suggests that fertilizing crops for near maximum yield generally is an economically and environmentally acceptable practice. Over application of nitrogen causes nitrate leaching from the root zone while under fertilization limits yields (Randall and Schmitt, 1993). If crop inputs are applied uniformly across a field where plant, soil, and input interactions are variable, the field will be under fertilized in some areas and over fertilized in others (Mamo et al., 2003). Average return from the variable rate of nitrogen applied to maize was higher than that of uniform application strategy (Lambert et al., 2006). To maintain crop yields and at the same time to reduce losses of N and increase the profit of our farmers it is important to utilize applied N as efficiently as possible. The best agricultural technique to reduce losses of N is the split application of N fertilizer at farm level. Nitrogen utilization efficiency of maize and sorghum (defined as grain yield per unit N uptake) varies under different climatic, soil and management conditions, and that NUE declined when N was supplied at high levels (Muchow (1998). Akbar et al. (1999) applied nitrogen at 3 different times for increasing nitrogen use efficiency of maize in terms of above ground dry matter and grain yield. Nitrogen use efficiency in above ground dry matter yield was positively related to plant height, cob length and above ground dry matter, whereas nitrogen use efficiency in grain yield showed positive relationship with cob bearing plants per plot, 1000 grain weight and total grain yield per plot. N applied at silking proved an additional source for higher rate of photosynthesis and transport of photo-assimilates during grain filling.

The preceding limited literature suggests that planting density and N fertilizer affect growth and yields of maize. However, research information is lacking on the interactive effects of plant density x N rates x N timing on agronomic efficacy and economics on maize in the various agro-ecological wheat-maize growing zones of the world. For sustainable high crop production, improvement in the agronomic efficiency of N and net returns from maize crop, research on the interactive effects of plant density and N rate (D x N), plant density and N timings (D x T), N rate and timings (N x T), and plant density into N rate and timing (D x N x T) are indispensable. This experiment was therefore designed and performed with an objective to compare agronomic efficiencies and economics of maize planted at low and high densities with different N rates and its time of application aimed at higher yields and net benefits in the wheat-maize cropping system.

Materials and Methods

Site Description

Experiments were conducted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar during 2002 to 2004 on the same plots. The experimental farm is located at 34.01^o N latitude, 71.35^o E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil texture is clay loam, low in organic matter (0.87 %), extractable phosphorus (6.57 mg kg^{-1}), exchangeable potassium (121 mg kg^{-1}), and alkaline (pH 8.2) and is calcareous in nature. Soil physio-chemical properties such as soil texture (Gee and Bauder, 1986), organic matter (Nelson and Sommers, 1982), AB-DTPA extractable phosphorus and exchangeable potassium (Soltanpour, 1985) were determined. Rainfall during the experimental period varied from 1.0 to 73.2 mm (July), 116.6 to 51.6 mm (August) and 14.9 to 45.2 mm (September) in 2002-03 and 2003-04, respectively.

Experimentation

A 2 x 3 x 6 factorial experiment was conducted in randomized complete block (RCB) design with split-plot arrangement using four replications. Factorial experimental treatments were two plant densities [P1= 60,000 (Low) and P2= 100,000 plants ha^{-1}(High)] and three N rates [60 (50% lower), 120 (recommended) and 180 kg N ha^{-1}(50% higher)] applied to main plots, while six split application for N in different proportions were applied to subplots at sowing and then at 2 week interval in two equal splits [T_1 = 50% at sowing and 50% at 14 DAE (days after emergence)], three unequal splits [T_2 = 50% at sowing, 25% at 14 DAE and 25% at 28 DAE), three equal splits [T_3 = 33.3% each at sowing, 14 DAE and at 28 DAE), four equal splits [T_4 = 25% each at sowing, 14, 28, and 42 DAE), five equal splits [T_5 = 20% each at sowing, 14, 28, 42 and 56 DAE] and five unequal splits [T_6 = 8.3, 16.6, 25, 33.3 and 16.6% at sowing, 14, 28, 42, and 56 DAE, respectively].

Maize variety Azam was used in the experiment. A sub-plot size of 4.2 m x 6 m, having 6 rows, 6 m long and 70 cm apart, was used. Fertilizer N (urea) was applied at the time of sowing and with 1st, 2nd, 3rd and 4th irrigation at two wk intervals i.e. 14, 28, 42, and 56 DAE. A uniform basal dose of 60 kg P_2O_5 (single super phosphate) ha^{-1} and 50 kg K_2O (sulphate of potash) ha^{-1}

was applied and mixed with soil during seedbed preparation. The plots were planted thicker and the two desired plant densities of 60,000 and 100,000 plants ha^{-1} were maintained in the different experimental units by thinning one week after emergence. After maturity plants in the four central rows were harvested, dried, ears were separated, threshed, weighed and then converted to grain yield ha^{-1}. Stalks were dried and weighed to record data on stover yield.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel and Torrie (1980), and treatment means were compared using the least significant difference (LSD) at $P \leq 0.05$.

Economic Analysis

Net Returns (the value of the increased yield produced as a result of N-fertilizers applied, less the cost of N) and *Value-Cost Ratio* (the ratio between the value of the additional crop yield and the cost of N) was determined according to the procedures described by Saleem et al. (1986) and Bhatti (2006) while, *Partial Factor Productivity* (the ratio of the grain yield to the applied rate of N), *Agronomic Efficiency* (the ratio of the increase in grain yield over N-control plots to the applied rate of N) and *Marginal Return* (the ratio of net return to the cost of N) was determined according to Yadav (2003) and net benefit curve drawn according to CIMMYT (1988). The detail is given in Table 1.

Results and Discussions

Year effects

Maize had higher partial factor productivity (PFP_N) of 36.62 kg grains kg^{-1} N, agronomic efficiency (AE_N) of 22.49 kg grains kg^{-1} N, net return (NR) of Rs. 37727 ha^{-1}, value-cost ratio (VCR) of 3.95 and marginal returns (MR) of Rs. 1.30 $Rs.^{-1}$ spent on N application in the second year (2003-04) than in the first year (2002-03) as shown in Table 2. Harold et al. (2006) reported that maize N availability varied greatly from year to year based on weather conditions. The variation in PFP_N, AE_N, NR, VCR and MR of both years might be attributed to the variation in rainfall of two years. The average rainfall during the second year was greater than in the first year and as a result the crop produced maximum yields and that resulted in maximum PFP_N, AE_N, NR, VCR and MR in the second year as compared with that of the first year. Okalebo et al. (2006) suggested that site specific recommendations are needed for maize because of its differential response to nutrient inputs which varied widely within and across agro-ecological zones. Wang et al. (2007) reported that understanding concepts of ideal soil fertility level and response to nutrient management provide practical guidelines for improving nutrient management under the variable rainfall conditions. It is therefore suggested that N management and plant density recommendations for obtaining maximum benefits cannot be easily transposed among the diverse agro ecological zones of Northwest Pakistan. Therefore, zonal specific effective management practices need to be developed for different agro ecological zones of NWFP. As suggested by Jones (1987) that climatic variation poses a challenge for the development of technical recommendations targeted for diverse environments.

Main plots effects

Maize gave maximum PFP_N of 38.36 kg grains kg^{-1} N, AE_N of 24.23 kg grains kg^{-1} N, NR of Rs. 44575 ha^{-1}, VCR of 4.18 and MR of Rs. 1.54 Rs^{-1} spent on N application at the higher (100,000 plant ha^{-1}) than at low density (60,000 plant ha^{-1}) of maize (Table 2). The increase in $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR at high than at low maize density might be due to the improvement in leaf area index (LAI), crop growth rate (CGR) and light interception at high than at low density (Amanullah et al. 2008) not only increased yield components and yields ha^{-1} of maize but also gave maximum benefits in terms of $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR at high than at low density of maize. Increasing plant density for short season maize increased cumulative intercepted photo synthetically active radiation, which compensated for a short growing season to achieve high yield (Edwards et al., 2005). Change in plant architecture, growth and developmental patterns, carbohydrate production and partition with variation in plant density was earlier reported by Casal (1985).

Both PFP_N and AE_N showed negative relationship with increase in N rate (Table 2). Maximum partial factor productivity (PFP_N) of 55.98 kg grains kg^{-1} N and maximum agronomic efficiency (AE_N) of 27.73 kg grains kg^{-1} N was noticed when maize was applied at the low rate of N (60 kg ha^{-1}) and vice versa. Decline in partial factor productivity and agronomic efficiency at higher level of N may be attributed to nutrient imbalance and decline in indigenous soil N supply. Karim and Ramasamy (2000) suggested that higher fertilizer use efficiency which is always associated with low fertilizer rate, cultural practices meant for promoting integrated nutrient management will help to effect saving in the amount of fertilizer applied to the crops and there to improve fertilizer use efficiency. On the other hand, NR, VCR and MR showed positive relationship with increase in N rate (Table 2). The net benefit curve in relation to N rates and the total cost that vary is shown in Fig 1. Maximums NR of Rs. 55781 ha^{-1}, VCR of 4.37 and MR of Rs. 1.82 Rs^{-1} spent on N application were calculated for those plots applied with the higher rate of N (180 kg ha^{-1}). The improvement in leaf area index (LAI), crop growth rate (CGR) and light interception with higher rate of N (Amanullah et al. 2008) increased yield and yield components ha^{-1} of maize that resulted in benefits in terms of NR, VCR and MR as compared with the low rate of N. The increase in grain and stover yields with high N rate application was due to the decreased number of barren plants and increase in number of seeds ear^{-1} which might be the possible cause of maximum NR, VCR and MR with the high N rate of N as compared with low rate of N (60 kg N ha^{-1}). These results are comparable to results drawn by Mariga et al. (2000) who found significant improvement in maize yields with increase in N levels. Gehl et al. (2005) has also suggested that efficient use of N for maize production is important for increasing grain yield, maximizing economic return and minimizing NO_3 leaching to ground water.

Sub plots effects

Perusal of the data regarding N timing effects on PFP_N, AE_N, NR, VCR and MR showed that the mean values of all these parameters under study were increased in descending order from T_1 (2-equal splits of N) to T_5 (5-equal splits of N), but beyond T_5, at T_6 all these parameters showed decline in their mean values (Table 2). Maximum PFP_N (39.74 kg grains kg^{-1} N), AE_N (25.62 kg grains kg^{-1} N), NR (Rs. 47036 ha^{-1}), VCR (4.21) and MR (Rs.1.60 Rs^{-1} spent on N) were obtained from those plots of maize crop where N was applied in five equal splits (20% each at sowing, 14, 28, 42 and 56 DAE (days after emergence). The minimum mean values of PFP_N (32.28 kg grains kg^{-1} N), AE_N (18.16 kg grains kg^{-1} N) and NR (Rs. 25264 ha^{-1}) were noticed at T_1, but minimum VCR (3.54) was noticed at T_2 (3-unequal splits of N). However, there was no difference in the MR (Rs. 0.89 Rs^{-1} spent on N) of both T_1 and T_2. The net benefit curve in relation to N timing and the total cost that vary is shown in Fig 2. Nitrogen application in splits up to silking significantly improved the vegetative and reproductive growth of maize, increased cob bearing plants ha^{-1}, and grain weight because late N application up to silking proved an additional source for higher rate of photosynthesis and transport of photo-assimilates during grain filling that resulted in the higher grain and stover yields as well as maize economics. Improvement in leaf area index (LAI), crop growth rate (CGR) and light interception at T_5 (Amanullah et al. 2008) is associated with increase in yields and yield components of maize resulted in maximum benefits in terms of PFP_N, AE_N, NR, VCR and MR as compared with less number of N splits (T_1 to T_3). These findings of maximum benefits as a result of maximum cost that vary with greater number of N splits oppose the findings of Mariga et al. (2000) who reported that split application of N is uneconomic because of the higher labor cost. Subedi and Ma (2005) found that restriction of N from seeding to V8 stage caused 30 % reduction in yield but withholding N supply from V8 to maturity reduced yield by 22 %. Mariga et al. (2000) reported that grain yield in maize increased when N was applied up to tassel initiation stage while, Subedi and Ma (2005) found that the best method to increase maize yield is to apply some N before sowing and more as top dressing reported significant increase in maize yield with N split application.

Interactive effects

Perusal of plant density into N rates (D x N) interaction revealed that each PFP_N and AE_N showed negative relationship with increase in N rate at both low and high densities of maize (Table 3). About 30 % and 35 % reduction in PFP_N was noticed when N rate was increased from the low (60 kg ha^{-1}) to the recommended level (120 kg ha^{-1}) at low and high plant densities, respectively. But increase in N level from the recommended level to the higher level (180 kg ha^{-1}), declined PFP_N at the rate of 30 % at high density and 26 % at low density. In contrast, the decrease in AE_N was higher (22 % reduction) at high than at low plant density (7 % reduction) when N levels was increased from N_1 (60 kg ha^{-1}) to N_2 (120 kg ha^{-1}), but increase in N level from N_2 to N_3 (180 kg ha^{-1}) the reduction in of AE_N was higher at low (19 %) as compared with 14 % at high plant density. On the other hand NR, VCR and MR showed positive relationship with increase in N rate at both low and high densities of maize (Fig 3). Turgut (2000) reported that plant density and N interaction had significant effects on seed number ear^{-1}, number of ears $plant^{-1}$ and grain yield of maize. Quality characteristics in maize such as ear size, tip fill and individual grain weight improved with increase in N level in both low and high density plots; ear size, tip fill and individual grain weight declined at high density regardless of N supply (Stone et al., 1998). The increase in the grain yield of maize at high density plots is due to the improvement in light interception during the critical period for grain set, while number of seeds $plant^{-1}$ and plant growth rate is adversely affected by N deficiency and shading in the high density plots (Andrade et al., 2002).

Perusal of plant density into N timing (D x T) interaction indicated that at both low and high densities of maize, all the parameters studied gave better results with greater number of four to five N splits (T_4 to T_6) as compared with two or three N split applications (T_1 to T_3) (Table 4). Interestingly, at low density, PFP_N, AE_N, NR, VCR and MR ranked first when N was applied in five equal splits (T_5). On the other hand, at high density of maize, PFP_N, AE_N, NR, VCR and MR ranked first when N was applied in five unequal splits (T_6). The net benefit curve in relation to plant density and N timing (D x T) is given in Fig 4. Variations in the level of carbon and N induced by different planting rates, or any other factor, can strongly influence yield and its components sequentially (Jacobs and Pearson, 1991). Improvement in leaf area index (LAI), crop growth rate (CGR) and light interception with greater number of N splits at low and high densities of maize (Amanullah et al. 2008) showed positive relationship with yield and yield components of maize and so maximum benefits in terms of $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR were obtained with greater number of N splits (T_4 toT_6) as compared with minimum net benefits in terms of $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR with less number of N splits (T_1 to T_3).

Interactive effects of N rates into its time of application (N x T) in Table 5 revealed that when N was applied at the low rate of 60 kg ha^{-1}, each PFP_N, AE_N, NR, VCR and MR showed positive relationship with increase in number of N splits application, and the mean values of NR, VCR and MR were negative when N was applied with less number of N splits (T_1 and T_2). The net benefit curve in relation to N rates and its time of application (N x T) is shown in Fig 5. At the recommended (120 kg ha^{-1}) and higher rate (180 kg ha^{-1}) of N, maize gave better performance in terms of PFP_N, AE_N, NR, VCR and MR when N was applied in five equal numbers of splits (T_5), closely comparable with T_4 (four equal splits of N) and five unequal splits of N (T_6). Improvement in leaf area index (LAI), crop growth rate (CGR) and light interception with higher N rate and greater number of N splits at low and high densities of maize (Amanullah et al. 2008) resulted in remarkable increase in yield and yield components of maize which might have resulted in maximum benefits in terms of $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR with greater number of N splits (T_4 toT_6) as compared with minimum benefits in terms of $PFP_{N,}$ $AE_{N,}$ NR, VCR and MR with less number of N splits (T_1 to T_3). These results are comparable to results drawn by Mariga et al. (2000) and Gehl et al. (2005), who suggested that efficient use of N for maize production is important for increasing grain yield, maximizing economic returns, and minimizing NO_3 leaching to ground water. The residual effect of these experiments after two years of wheat-maize system, showed positive impacts on yield and yield components of the succeeding barley (*Hordeum vulgare* L.) in those plots where N was applied at higher rate and with maximum number of N splits to the previous maize crop (Nisar et al., 2007). Thus higher rate of N with late application up to tasseling of maize crop (T_5 and T_6) not only increased yield and economics of the current maize crop but its residual effect can also had beneficial impacts on the succeeding crops on sustainable basis.

Conclusions

Improper plant density and N management particularly with continued soil nutrient mining are major factors contributing to low crop yield which is not economical to farmers in the cereal based system in Northwestern Pakistan. Our findings suggest that farmers of NWFP who traditionally grow maize at high plant density but apply low N rate only at sowing time require demonstration of the benefits of the higher N rate with split applications. Application of high N level with four to five numbers of splits is the need of the hour as we have to not only sustain the current maize productivity but have no other option than to improve them to meet the growing population. Application of higher rate of N with four to five splits not only increased yield and net income but also improved the protein concentration of maize seeds crop while, the residual effect also improved the yield and economics of the succeeding crop on sustainable basis. Year effects on yield as well as maize economics with rainfall fluctuation in the two years indicate that N recommendations for increasing maize productivity to get maximum net benefits can not easily be transposed among diverse agro-ecological zones of NWFP. This problem poses a challenge for the development of technical recommendations targeted for diverse environments of NWFP. Further research work for understanding the impacts of plant density, rate and time of N application for high sustainable maize production in different agro-ecological conditions of NWFP is also suggested.

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Table 1. Abbreviations, formulae and units of different parameters studied in the experiment

Column	Parameter	Abbr.	Formula	Unit
1	Grain yield	GY	GY m^{-2} x 10,000	kg ha^{-1}
2	N-partial factor productivity	PFP_N	GY ha^{-1} ÷ rate of N applied	kg grains kg^{-1} N
3	Increase in GY over control	GY_{IOC}	GY with N - GY of N-control plots	kg ha^{-1}
4	N-agronomic efficiency	AE_N	GY_{IOC} ÷ by rate of N	kg grains kg^{-1} N
5	Grain yield value	GY_V	GY ha^{-1} x value of grains kg^{-1}	Rs. ha^{-1}
6	Stover yield value	SY_V	SY ha^{-1} x value of stovers kg^{-1}	Rs. ha^{-1}
7	Grass returns	GR	$GY_V + SY_V$	Rs. ha^{-1}
8	Increase in GR over control	GR_{IOC}	GR – cost that vary ($Cost_V$)	kg ha^{-1}
9	N-cost	C_N	Price per bag ÷ N content in a bag	Rs. ha^{-1}
10	Net returns	NR	$GR_{IOC} - Cost_V$	Rs. ha^{-1}
11	Value-cost ratio	VCR	$GR_{IOC} \div Cost_V$	Rs. Rs^{-1}
12	Marginal returns	MR	NR ÷ $Cost_V$	Rs. Rs^{-1}

Various costs in the experiments:

Urea	=	Rs. 640 per 50 kg bag (US $=PK Rs. 77)
Nitrogen	=	Rs. 28 per kg
N application	=	Rs. 400 per time ha^{-1}
Grains	=	Rs. 24 per kg
Stovers	=	Rs. 2 per kg
*Other uniform cost	=	Rs. 24110 ha^{-1}

Note: * Cost other than N used ha^{-1} and its application timing includes (seedbed preparation, land lease, seed, drill planting, K, P, irrigation, furadan for the control of stem borers, and labors used for various operations which was Rs. 24110 ha^{-1}).

Table 2. **Impacts of year, plant density, N rates and N timing on the partial factor productivity, agronomic efficiency and economic analysis of maize in Northwest Pakistan**

Treatments	(1) GY	(2) PFP_N	(3) GY_{IOC}	(4) AE_N	(5) GY_V	(6) SY_V	(7) GR	(8) GR_{IOC}	(9) $Cost_V$	(10) NR	(11) VCR	(12) MR
Year												
Y_1	4288	35.73	2593	21.61	102912	9236	112148	64648	28937	35711	3.88	1.23
Y_2	4394	36.62	2699	22.49	105456	8708	114164	66664	28937	37727	3.95	1.30
Density												
D_1	4079	33.99	2384	19.87	97896	7404	105300	57800	28937	28863	3.64	1.00
D_2	4603	38.36	2908	24.23	110472	10540	121012	73512	28937	44575	4.18	1.54
N-rates												
N_1	3359	55.98	1664	27.73	80616	8282	88898	41398	27257	14141	3.26	0.52
N_2	4492	37.43	2797	23.31	107808	8812	116620	69120	28937	40183	4.03	1.39
N_3	5170	28.72	3475	19.31	124080	9818	133898	86398	30617	55781	4.37	1.82
N-times												
T_1	3874	32.28	2179	18.16	92976	8058	101034	53534	28270	25264	3.57	0.89
T_2	3890	32.42	2195	18.29	93360	8252	101612	54112	28670	25442	3.54	0.89
T_3	4201	35.01	2506	20.88	100824	8786	109610	62110	28670	33440	3.82	1.17
T_4	4576	38.13	2881	24.01	109824	9376	119200	71700	29070	42630	4.10	1.47
T_5	4769	39.74	3074	25.62	114456	9550	124006	76506	29470	47036	4.21	1.60
T_6	4732	39.43	3037	25.31	113568	9804	123372	75872	29470	46402	4.19	1.57

Where:
D_1 = 60000 plants ha^{-1}, D_2 = 1000000 plants ha^{-1}, N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 = 180 kg N ha^{-1}
T_1= Two equal N-slits (50-50%), T_2 = Three un-equal N-splits (50-25-25%), T_3 = Three equal N-splits (33-33-33%),
T_4 = Four equal N-splits (25-25-25-25%), T_5 = Five equal N-splits (20-20-20-20-20%) and T_6 = Five un-equal N-splits (8-17-25-33-17%)

Table 3. **Interactive impacts of plant density and N rates (D x N) on the partial factor productivity, agronomic efficiency and economic analysis of maize in Northwest Pakistan**

D x N	(1) GY	(2) PFP_N	(3) GY_{IOC}	(4) AE_N	(5) GY_V	(6) SY_V	(7) GR	(8) GR_{IOC}	(9) $Cost_V$	(10) NR	(11) VCR	(12) MR
D_1 x N_1	3105	51.75	1410	23.50	74520	6400	80920	33420	27257	6163	2.97	0.23
D_1 x N_2	4315	35.96	2620	21.83	103560	7400	110960	63460	28937	34523	3.83	1.19
D_1 x N_3	4817	26.76	3122	17.34	115608	8500	124108	76608	30617	45991	4.05	1.50
D_2 x N_1	3614	60.23	1919	31.98	86736	10000	96736	49236	27257	21979	3.55	0.81
D_2 x N_2	4670	38.92	2975	24.79	112080	10372	122452	74952	28937	46015	4.23	1.59
D_2 x N_3	5524	30.69	3829	21.27	132576	11450	144026	96526	30617	65909	4.70	2.15

Where:
D_1 = 60000 plants ha^{-1}, D_2 = 1000000 plants ha^{-1}, N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 = 180 kg N ha^{-1}
T_1= Two equal N-slits (50-50%), T_2 = Three un-equal N-splits (50-25-25%), T_3 = Three equal N-splits (33-33-33%),
T_4 = Four equal N-splits (25-25-25-25%), T_5 = Five equal N-splits (20-20-20-20-20%) and T_6 = Five un-equal N-splits (8-17-25-33-17%)

Table 4. Interactive impacts of plant density and N timing (D x T) on the partial factor productivity, agronomic efficiency and economic analysis of maize in Northwest Pakistan

D x T	(1) GY	(2) PFP_N	(3) GY_{IOC}	(4) AE_N	(5) GY_V	(6) SY_V	(7) GR	(8) GR_{IOC}	(9) $Cost_V$	(10) NR	(11) VCR	(12) MR
D_1 x T_1	3678	30.65	1983	16.53	88272	6682	94954	47454	28270	19184	3.36	0.68
D_1 x T_2	3723	31.03	2028	16.90	89352	6768	96120	48620	28670	19950	3.35	0.70
D_1 x T_3	3931	32.76	2236	18.63	94344	7364	101708	54208	28670	25538	3.55	0.89
D_1 x T_4	4302	35.85	2607	21.73	103248	7672	110920	63420	29070	34350	3.82	1.18
D_1 x T_5	4496	37.47	2801	23.34	107904	7764	115668	68168	29470	38698	3.92	1.31
D_1 x T_6	4345	36.21	2650	22.08	104280	8172	112452	64952	29470	35482	3.82	1.20
D_2 x T_1	4071	33.93	2376	19.80	97704	9436	107140	59640	28270	31370	3.79	1.11
D_2 x T_2	4059	33.83	2364	19.70	97416	9738	107154	59654	28670	30984	3.74	1.08
D_2 x T_3	4471	37.26	2776	23.13	107304	10212	117516	70016	28670	41346	4.10	1.44
D_2 x T_4	4852	40.43	3157	26.31	116448	11082	127530	80030	29070	50960	4.39	1.75
D_2 x T_5	5043	42.03	3348	27.90	121032	11336	132368	84868	29470	55398	4.49	1.88
D_2 x T_6	5121	42.68	3426	28.55	122904	11436	134340	86840	29470	57370	4.56	1.95

Where:
D_1 = 60000 plants ha^{-1}, D_2 = 1000000 plants ha^{-1}, N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 = 180 kg N ha^{-1}
T_1= Two equal N-slits (50-50%), T_2 = Three un-equal N-splits (50-25-25%), T_3 = Three equal N-splits (33-33-33%),
T_4 = Four equal N-splits (25-25-25-25%), T_5 = Five equal N-splits (20-20-20-20-20%) and T_6 = Five un-equal N-splits (8-17-25-33-17%)

Table 5. Interactive impacts of N rates and its application time (N x T) on the partial factor productivity, agronomic efficiency and economic analysis of maize in Northwest Pakistan

N x T	(1) GY	(2) PFP_N	(3) GY_{IOC}	(4) AE_N	(5) GY_V	(6) SY_V	(7) GR	(8) GR_{IOC}	(9) $Cost_V$	(10) NR	(11) VCR	(12) MR
N_1 x T_1	2758	45.97	1063	17.72	66192	7724	73916	26416	26590	-174	2.78	-0.01
N_1 x T_2	2756	45.93	1061	17.68	66144	7890	74034	26534	26990	-456	2.74	-0.02
N_1 x T_3	3170	52.83	1475	24.58	76080	7784	83864	36364	26990	9374	3.11	0.35
N_1 x T_4	3612	60.20	1917	31.95	86688	8640	95328	47828	27390	20438	3.48	0.75
N_1 x T_5	3879	64.65	2184	36.40	93096	8588	101684	54184	27790	26394	3.66	0.95
N_1 x T_6	3982	66.37	2287	38.12	95568	9078	104646	57146	27790	29356	3.77	1.06
N_2 x T_1	4005	33.38	2310	19.25	96120	7672	103792	56292	28270	28022	3.67	0.99
N_2 x T_2	4164	34.70	2469	20.58	99936	8056	107992	60492	28670	31822	3.77	1.11
N_2 x T_3	4382	36.52	2687	22.39	105168	8480	113648	66148	28670	37478	3.96	1.31
N_2 x T_4	4653	38.78	2958	24.65	111672	9156	120828	73328	29070	44258	4.16	1.52
N_2 x T5	4933	41.11	3238	26.98	118392	9814	128206	80706	29470	51236	4.35	1.74
N_2 x T_6	4820	40.17	3125	26.04	115680	9694	125374	77874	29470	48404	4.25	1.64
N_3 x T_1	4860	27.00	3165	17.58	116640	8782	125422	77922	29950	47972	4.19	1.60
N_3 x T_2	4753	26.41	3058	16.99	114072	8814	122886	75386	30350	45036	4.05	1.48
N_3 x T_3	5052	28.07	3357	18.65	121248	10100	131348	83848	30350	53498	4.33	1.76
N_3 x T_4	5466	30.37	3771	20.95	131184	10336	141520	94020	30750	63270	4.60	2.06
N_3 x T_5	5497	30.54	3802	21.12	131928	10248	142176	94676	31150	63526	4.56	2.04
N_3 x T_6	5396	29.98	3701	20.56	129504	10640	140144	92644	31150	61494	4.50	1.97

Fig 1. Impacts of N rates and cost on the net benefit curve of maize

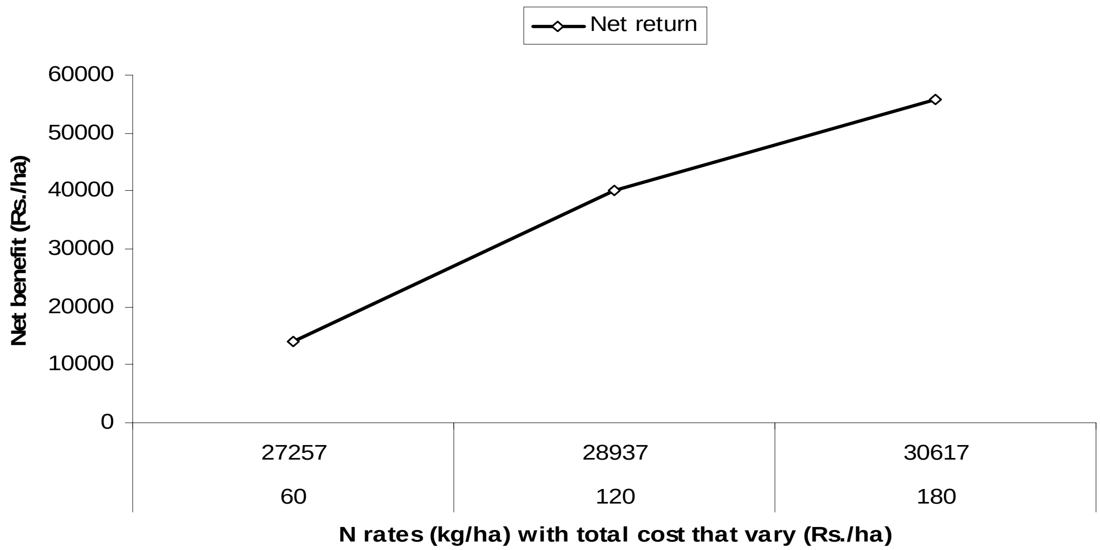


fig 2. Impacts of N timing and cost on the net benefit curve of maize

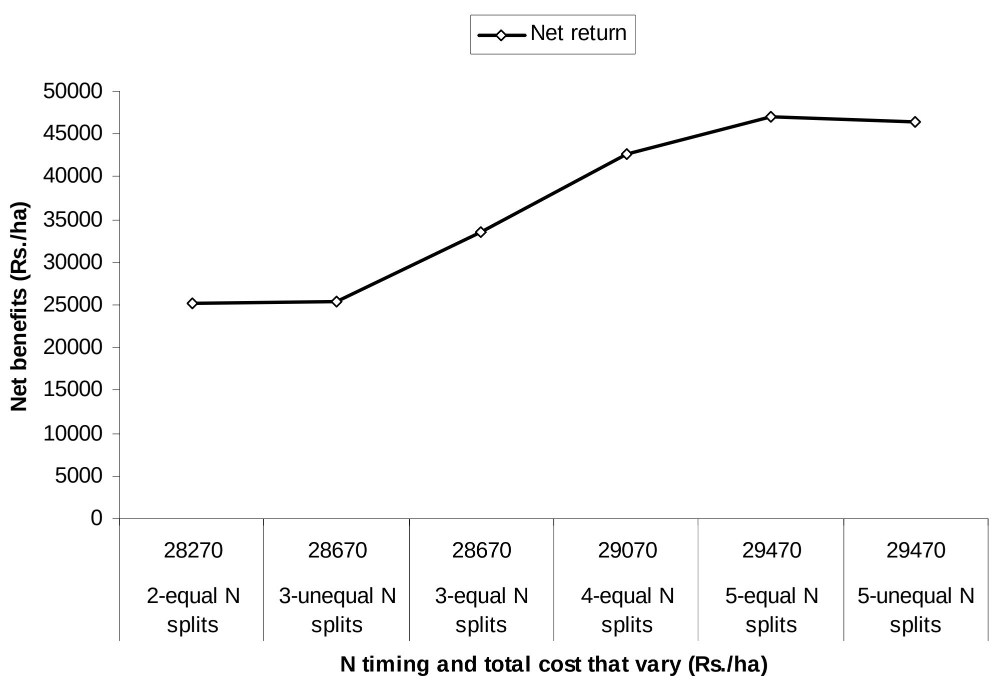


Fig 3. Impacts of N rates applied at low and high densities of maize

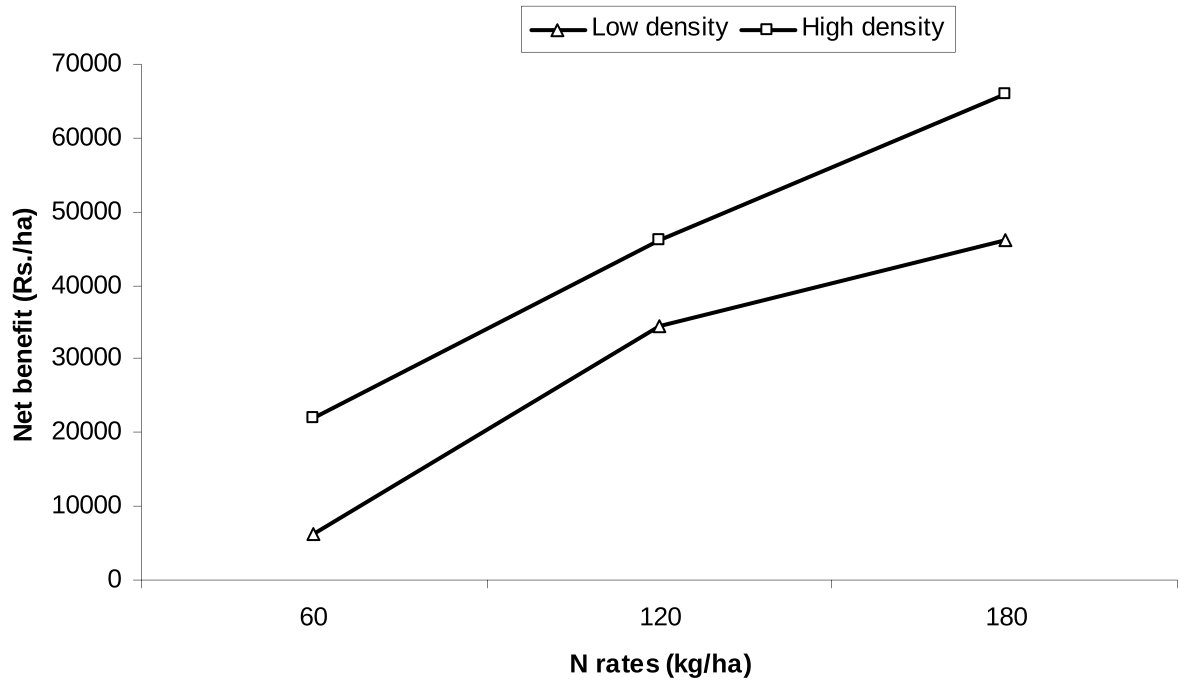
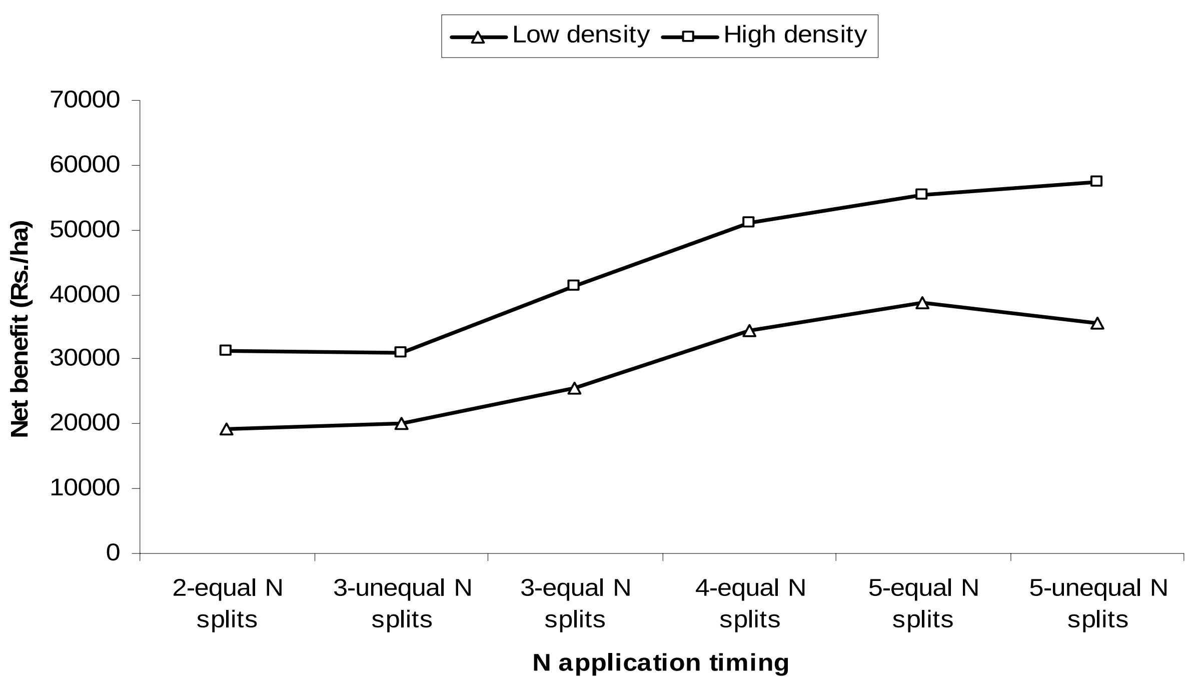


Fig 4. Impacts of N timing on net benefit curve at low and high densities of maize



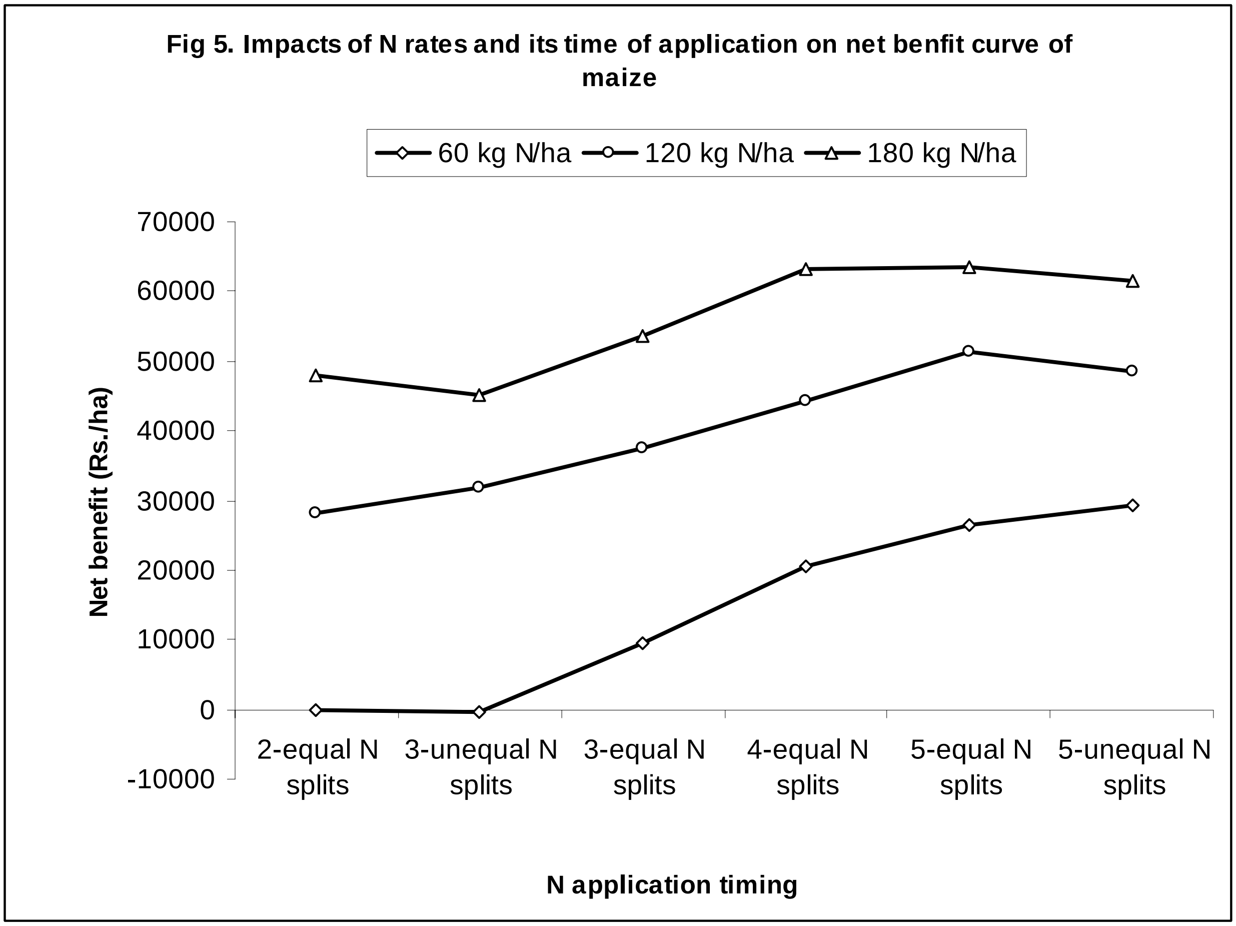


Fig 5. Impacts of N rates and its time of application on net benfit curve of maize
60 kg N/ha
120 kg N/ha
180 kg N/ha
70000
60000
50000
40000
30000
20000
10000
0
-10000
Net benefit (Rs./ha)
2-equal N splits
3-unequal N splits
3-equal N splits
4-equal N splits
5-equal N splits
5-unequal N splits
N application timing