

CHICKPEA NITROGEN FIXATION INCREASES PRODUCTION OF SUBSEQUENT WHEAT IN RAIN FED SYSTEM

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Abstract

A three-year chickpea-wheat rotation study was carried in a well-drained sandy soil at National Agricultural Research Centre, Islamabad, to quantify nitrogen fixation by chickpea and determine its residual N effects on soil N-fertility and yield of following wheat crop. The treatments were; continuous wheat without N, continuous wheat with N, chickpea wheat rotation without N (to wheat), chickpea wheat rotation with N (to following wheat), and continuous chickpea. In N treatments, nitrogen was applied to wheat @ 100 kg ha⁻¹. The $\delta^{15}\text{N}$ of shoot of chickpea and non-nitrogen fixing reference crop (wheat) was used to determine the percentage of chickpea N derived from nitrogen fixation (pfix). The pfix values by chickpea ranged from 70-98%. The total N fixed by chickpea ranged from 64-103 kg N ha⁻¹ in 996/97 and 138 kg ha⁻¹ in 1997/98. After removal of above ground biomass of chickpea at harvest, the average N balance in our study was 38 kg N ha⁻¹ and 35kg N ha⁻¹ after first and second years. Continuous wheat grown without N fertilizer (control) exhausted soil N fertility and produced the least grain yield. Wheat sown after chickpea with N application produced the highest grain yield followed by continuous wheat with N. Chickpea rotation also increased significantly the yield by 11% of following wheat without N treatment. Continuous chickpea crop and its rotation with wheat enhanced N fertility level of the soil. Our results support the strategy of using legumes in rotation with wheat in the arid region for enhancing soil N-supply and increasing wheat yield.

Introduction

Chickpea is a crop that provides cash income from its grain. It requires no N fertilizers owing to its ability to fix atmospheric N, and in rotation can improve the N nutrition and yield of subsequent cereals. Aslam *et al.*, (1997) observed 81% pfix and 74 kg ha⁻¹ total nitrogen fixed in 1995. Legumes are grown on an area of 1.6 million hectares that is 1.9% of total cultivated land of Pakistan (Aslam *et al.*, 2000). Almost all of this is in Punjab and the North Western Frontier Province, concentrated in *Thal* and *Potohar* area (Aslam *et al.*, 1994). The yield of pulse legumes in Pakistan is 0.5 -0.6 t ha⁻¹, which is lower than most other countries of the world. At time's country has to spend a lot of foreign exchange to import pulses (especially chickpea) to meet national food requirement. Therefore, there is a strong need to increase yield of pulse legumes in Pakistan.

Legumes grown in rotation with the cereals are the great source of N. The grain legumes are a definite part of Pakistani agriculture, which reflects the long-standing vegetarian traditions of country. Hence rotation is a key strategy for improving production and maintaining fertility of the soil, and this practice has to be encouraged among farmers to retain the traditional pulse legumes, chickpea and lentil, as a basis for rotational cropping systems. Growing cereals continuously in low input dry land conditions is likely to be an unsustainable system in the long run, with high probability of

declining profit margins due to depletion in soil fertility and development of unfavorable soil physical and biological conditions (Jones 1989, Harris 1990; Karaca *et al.*, 1991).

There was a tendency to related nitrogen fixation to just one factor. Evans *et al.*, (1991) relates N₂ fixation of pea and narrow – leafed lupine only to crop yield; Doughton *et al.*, (1993) related N₂ fixation of chickpea only to soil nitrate. We consider that both of these factors i.e., total crop yields, soil nitrate, total N are fixed through δ¹⁵N method. There is a strong need to introduce crop rotation practices in these areas, to increase N supply for cereals, particularly wheat. Annual crop legumes, grown in rotation with cereal crops, can improve yields of the cereals and contribute to the total pool of N in the soil. Benefits of legumes have been attributed to control of cereal diseases and insect pests, and improvements of soil structure. In rain fed areas of Pakistan this would be the first study to determine the effects of legume cereal rotation system on scientific lines.

Therefore, the specific objectives of this study were to quantify nitrogen fixation by field-grown chickpea, and determine its effects on increasing soil N - fertility and yield of following wheat crop.

Materials and Methods

Treatments and experiment design: A three-year chickpea-wheat (legume-cereal) field study was carried out in a sandy loam soil at the National Agricultural Research Centre, Islamabad. The initial fertility status of soil was; OM = 0.4 %, nitrate-N = 6mg/kg, phosphorus (Olsen/ available i.e. P₂O₅) = 0.34 mg /kg and total-N = 0.01%. In order to exhaust / and or uniform soil fertility wheat was grown with no fertilizer application during first year in 1995/96. In the following two years i.e., 1996/97 and 1997/98, the treatments were; (T₁) continuous wheat without N, (T₂) continuous wheat with N, (T₃) chickpea wheat rotation without N (to wheat), (T₄) chickpea wheat rotation with N (to following wheat), and (T₅) continuous chickpea.

Wheat variety Chakwal-86 and chickpea variety CM - 88 were grown as test crops. The seed rates used were 100 kg ha⁻¹ for wheat and 60 kg ha⁻¹ for chickpea. During 2nd and 3rd year fertilizer doses applied were P₂O₅ = @ 80 kg ha⁻¹ (as single super phosphate, SSP) as a basal dose to all plots and N (to wheat only where required) = @ 100 kg ha⁻¹ (as urea) by broadcast method.

The treatments were replicated four times in a Randomized Complete Block Design (RCBD). The plot size was 4x10 m².

Assessment of N₂ fixation by ¹⁵N natural abundance techniques: The estimation of nitrogen fixation (by chickpea) was done by ¹⁵N Natural Abundance technique (Peoples *et al.*, 1996). The δN values of chickpea and wheat (as non-N₂ fixing reference) plants were taken before harvest, at maximum biomass stage (spectrometer (Bergersen *et al.*, 1985) and percent N₂ fixed (%pfix) was calculated as follows:

$$\% \text{ pfix} = \frac{100 \times \delta^{15}\text{N} (\text{soil N}) - \delta^{15}\text{N} (\text{legume N})}{\delta^{15}\text{N} (\text{soil N}) - \text{B}}$$

The total N₂ fixed by chickpea was calculated by multiplying %fix with total crop N (plant biomass x crop N-content).

$$\text{Kg N fixed /ha} = \frac{\text{*Legume N kg /ha} \times \% \text{ pfix}}{100}$$

Crop yield: At harvest the grain yields, straw yields and total biomass of both chickpea and wheat crops were taken.

Nitrate-nitrogen content of soil: The nitrate nitrogen content of soil was recorded at harvesting following the method Winkleman *et al.*, (1985).

The data were analyzed statistically by Analysis of Variance technique and comparison among treatment means was made by “Duncan’s Multiple Range test” (DMRT) using MSTAT-C version 1.4.2.

Results

In the year 1995-96 wheat was grown in all five treatments and there was no difference in plant population in all the treatments (Table 1). During second year (1996-97) there was no difference in population of three chickpea treatments. However, among two-wheat treatment plant population in case of continuous wheat with fertilizer N (T3) was significantly greater as compared to continuous wheat with no fertilizer N (T1). In the third year (1997-98), among four wheat treatments, the plant population was the highest in case of wheat with fertilizer N after chickpea followed by wheat after wheat with fertilizer-N, and followed by two other treatments of wheat with no fertilizer-N. The lowest plant population was in case of continuous wheat without fertilizer- N.

Table 1. Yield data in a three years chickpea - wheat rotation experiment conducted at NARC during 1995-98.

Treatments	Plant population (m ⁻²)	Straw yield (t. ha ⁻¹)	Grain yield (t. ha ⁻¹)	Total biomass (t. ha ⁻¹)
1995-96				
Wheat	37	1.38	0.93	2.30
Wheat	42	1.60	1.13	2.72
Wheat	38	2.05	1.70	3.75
Wheat	47	1.65	1.55	3.45
Wheat	36	1.83	1.30	3.12
1996-97				
Wheat	64	3.26	1.56	4.82
Chickpea	40	2.24	1.12	3.36
Wheat +N	76	4.64	2.23	6.86
Chickpea	38	2.27	1.17	3.43
Chickpea	37	2.00	1.11	3.10
1997-98				
Wheat	46	5.08	1.41	6.49
Wheat	52	7.16	1.57	8.74
Wheat +N	60	8.04	2.69	10.73
Wheat +N	70	8.39	2.79	11.19
Chickpea	26	4.48	0.75	5.23

The results showed that in the second year, total above ground biomass yield of wheat was highest (6.86 t ha^{-1}) in plots with fertilizer-N (Table 1). This yield was 42 % more as compared to biomass yield (4.82 t ha^{-1}) of continuous wheat with no fertilizer-N i.e., control (T1). Total biomass yield of three chickpea plots was similar ranging $3.1\text{--}3.43 \text{ t ha}^{-1}$. In third year (1997/98) the maximum biomass of 11.19 t ha^{-1} (72% increase over control) was recorded in wheat followed by chickpea with fertilizer-N (T4). After that was continuous wheat with fertilizer-N (10.73 t ha^{-1}), having 65% increases over control. Wheat after chickpea without fertilizer-N (T2) had a biomass yield of 8.74 t ha^{-1} that was 35% more compared with control (6.49 t ha^{-1}). Among chickpea plots, in the second year there was slight difference in yield, which was non-significant.

During 1996/97 maximum grain yield of 2.23 t ha^{-1} was recorded in the treatment of wheat with fertilizer-N, which had 43% increase over control i.e., continuous wheat with no fertilizer N in second year. All three chickpea plots had same yield that was slightly more than 1.0 t ha^{-1} .

In the third year (1997/98) continuous wheat with no fertilizer-N treatment (i.e. control) had the lowest grain yield. The maximum grain yield (2.79 t ha^{-1}) was recorded in wheat after chickpea with fertilizer-N treatment which was 98% higher than control (1.41 t ha^{-1}), followed by continuous wheat with fertilizer- N (2.69 t ha^{-1}) having 91% increase over control. Wheat followed by chickpea but with no fertilizer-N (1.57 t ha^{-1}) had only 11% increase in yield over control. Yield of chickpea showed no significant difference among treatments in second year.

The differences in straw yields of various treatments were similar show to those of grain yields. In the second year, the wheat straw yield was highest (4.64 t ha^{-1}) in the treatment where fertilizer-N was applied to continuous wheat that was 42% more than that of continuous wheat with no fertilizer-N (3.26 t ha^{-1}) higher. The straw yields of three chickpea plots were similar ranging $2.0\text{--}2.27 \text{ t ha}^{-1}$. In the third year the highest wheat straw (8.39 t ha^{-1}) was again in wheat after chickpea with fertilizer-N treatment that was (65% more than that of continuous wheat without fertilizer-N (5.08 t ha^{-1})). This was followed by continuous wheat with fertilizer-N treatment (8.04 t ha^{-1}) that was 58% more than that of control. The chickpea rotation without fertilizer-N increased wheat yield (7.16 t ha^{-1}) by 41% over continuous control.

The data revealed that the chickpea in T2 fixed highest proportion of nitrogen from air (Table 2). The lowest proportion of fixed nitrogen was in case of T5, whereas, T4 had medium value. The results of total N_2 fixation have shown that about 100-kg N ha^{-1} was fixed by chickpea crop in treatments T2 and T4. This quantity was significantly higher than in case of T5, which was 64 kg ha^{-1} . In the third year, chickpea fixed 138 N kg ha^{-1} .

The soil $\text{NO}_3\text{-N}$ values were generally very low (Table 3). These results have shown that there was no significant difference in soil nitrate content of all the plots in first year. However, in the second and third years the $\text{NO}_3\text{-N}$ values were generally higher in treatments where chickpea was grown in rotation.

Discussion

Legumes are considered to be an important component of subsistence cropping systems of the semi-arid tropics because of their ability to convert atmospheric nitrogen into the assimilable form of ammonia, to add substantial amounts of organic matter to the soil and to grow better than many other crops with low inputs under harsh climatic and edaphic conditions. In grain legumes, however, usually the aboveground plant parts are

Table 2. Percent (pfix) and total N₂ (kg.ha⁻¹) fixed by *Cicer arietinum* L. cv. CM 88 in a crop rotation experiment at NARC during 1996-97.

	T ₂	T ₄	T ₅
Concentration (%)	1.56	1.64	1.47
Total above ground biomass (t. ha ⁻¹)	3.36	3.43	3.10
Above ground crop N (kg ha ⁻¹)	50.3	55.6	45.7
Total crop N (kg ha ⁻¹)	100.7	111.2	91.5
% pfix	98	93	70
Total N fixed (kg ha ⁻¹)	98.8	103.4	64.0

Treatments

T₂ = Wheat - Chickpea - Wheat, T₄ = Wheat - Chickpea - Wheat_{-N}, and T₅ = Wheat - Chickpea - Chickpea**Table 3. Nitrate nitrogen of soil in a two years chickpea - wheat rotation experiment conducted at NARC during 1996-98.**

Treatments	1995-96		Treatments	1996-97		Treatments	1997-98	
	0-15 cm	15-90 cm		0-15 cm	15-90 cm		0-15 cm	15-90 cm
Nitrate-nitrogen content of soil (mg kg⁻¹)								
Wheat	6.43	2.79	Wheat	1.69	0.22	Wheat	2.18	0.18
Wheat	7.43	3.17	Chickpea	2.88	0.34	Wheat	2.87	0.34
Wheat	6.42	2.07	Wheat _{+N}	2.23	0.27	Wheat _{+N}	2.23	0.21
Wheat	6.33	2.87	Chickpea	2.38	0.41	Wheat _{+N}	2.38	0.39
Wheat	6.78	3.07	Chickpea	2.80	0.39	Chickpea	2.63	0.37

harvested and removed and therefore the residual effect must largely be derived from the under ground plant biomass and the leaf fall during crop growth. Several researchers have shown that in most cases legumes generally leave 17 - 23 kg N ha⁻¹ in the form of nitrate in soil (Rao *et al.*, 1987; Herridge, 1993). This positive N balance results from "sparing of nitrate" i.e., reduced use of soil N associated with N₂ fixing activity of legumes (Herridge, 1993). However, in certain other cases where significant amount of atmospheric N₂ is not fixed by a grain legume it takes relatively more N from soil. With the harvest of such grain legume(s) the soil N fertility is generally depleted and the following crops do not get any benefit.

During first year of our study all yield parameters of wheat in all the plots were same which meant that the fertility gradient of the soil of the study was same. Growing wheat without any fertilizer lowered the fertility status of soil that helped in the projection of treatment differences in the following years.

During second year of study (first year of rotation i.e., 1996-97) no significant difference was observed in plant population of three chickpea treatments. However among two - wheat treatments, plant population in case of continuous wheat with fertilizer-N (T3) was significantly higher as compared to continuous wheat without fertilizer-N (T1). In third year of study (second year of rotation i.e., 1997-98) among four wheat treatments plant population was highest in case of wheat with fertilizer N after chickpea (T4), followed by two other treatments. The increase in plant population of wheat grown after chickpea (during third year) might have been because of increased soil N as a result of N₂ - fixation by the previous year's chickpea.

Total biomass: The second year results have shown that biomass yield of wheat with fertilizer-N was significantly increased (42. %) over control (T1). During third year the +N treatments (T3 & T4) produced almost same biomass showing that chickpea

rotational effect was masked by the addition of 100kg N ha⁻¹. However, where fertilizer N was not added chickpea rotation (T2) increased yield of following wheat by 35% as compared to wheat after wheat (T1). These results are supported by Nair *et al.*, (1979) who found that as compared to wheat sown after sole maize the yield of wheat sown after maize/soybean and maize/cowpea was increased by 30% and 34%, respectively. Evans *et al.*, (1991) defined that legume N fixation (as additional N) increases wheat biomass following legumes compared with wheat after wheat.

Straw yield: In the second year, fertilized (N) wheat produced 42% more straw than unfertilized one. The straw yield of all three chickpea plots was same. In third year the application of N-fertilizer increased wheat yield by 58%. Chickpea rotation produced 2.08 tons more straw of following wheat in case of no fertilizer treatments; equivalent to 41% increase. When 100kg N ha⁻¹ was added to wheat, the rotational effect of chickpea vanished as both +N treatments produced almost same wheat straw. Perhaps 100kg N ha⁻¹ applied through fertilizer fulfilled the crop need and additional through N₂ fixation by previous chickpea did not have any effect.

Grain yield: In the second year the maximum grain yield of wheat was recorded in wheat with fertilizer-N treatment, which had 42% increases over control (continuous wheat with no fertilizer N). In the third year maximum grain yield was recorded in wheat with fertilizer following chickpea, having 98% increases over control. This yield was slightly more than wheat after wheat with fertilizer-N, but difference was insignificant. The benefits of chickpea rotation were masked probably due to high (100 kg N ha⁻¹) dose of fertilizer N applied. Nevertheless, 11% increases in wheat grain yield was recorded in case of wheat after chickpea with no fertilizer N as compared to continuous wheat without fertilizer N. These benefits were purely due to chickpea rotation i.e. N balance (ranged 18-98kg ha⁻¹) due to previous year's chickpea crop. Chalk *et al.*, (1993) found that the N benefit of 34 kg N ha⁻¹ conferred by lupine to following barley crop, could be partitioned almost equally between spared N (18 kg N ha⁻¹) and fixed N (16 kg N ha⁻¹, by lupine residue).

The rotational benefits in terms of increased wheat grain yield were lower than expected. The reason of this might be leaching of nitrate – N (converted from fixed N) from soil profile during fallow period of monsoon rains, especially in our case since soil of our experimental site was a loamy sand, with a slope gradient. These results are supported by Aslam *et al.*, (2000). Many other researchers have reported cereals produce more grains when grown after a legume or fallow than that after a non-legume or after a fallow. Dalal *et al.*, (1998) observed that wheat yields were significantly higher in the chickpea-wheat rotation than in the wheat - wheat rotation. The treatments aimed at enhancing the nitrogen nutrition of cereal crops through N fertilizer plus crop rotation produced consistently positive benefits on grain yield and grain protein.

Chickpea N₂ fixation: Our results show that during second year pfix (proportion of N derived by chickpea plants through N₂ fixation) values of chickpea of treatments T2 and T4 were slightly higher than that of treatment T1. These differences could be attributed to variations of field studies. Nevertheless the proportion of fixed N ranged between 70 - 98%, which is quite high. The obvious reason for this is low soil nitrate at experimental site. These results have shown that chickpea has fixed high proportions of its requirements for N. However this was limited in terms of total N₂ fixed (kg ha⁻¹) due to low biomass production. The maximum pfix recorded in this study were 98% and 93% in treatments T2 and T4, respectively. In similar studies, Schwenke *et al.*, (1997) has reported similar findings.

The amount of nitrogen fixed by chickpea is regulated by two factors: the amount of N accumulation during growth and proportion of that N derived from symbiotic N₂ (pfix) of total N fixed. The results have shown that about 100 kg N ha⁻¹ was fixed by chickpea crop in treatments T2 and T4. In third year chickpea fixed 138 kg N ha⁻¹. These findings proved that total nitrogen fixed was highly correlated with shoot biomass, but not with pfix. Rupela (1997) also has supported this view. In the present study, the N - balance due to previous chickpea crop was 48 kg N ha⁻¹ during second and year 35kg N ha⁻¹ during third year.

In grain legumes, nitrogen (N) accumulation is closely linked to biomass accumulation and seed growth, but there is need for quantitative information specific to chickpea in arid region. Evidence suggests that the soil nitrate (NO₃) level is critical to the initiation of chickpea nodulation and affects dry matter accumulation and distribution, and N₂ fixation; with N₂ fixation decreasing as soil nitrate - nitrogen increases (Doughton *et al.*, 1993, Herridge *et al.*, 1995). In our studies there was no significant difference in soil nitrate content in second year but in third year the maximum value was recorded in wheat after chickpea (T2). This is because legumes increase plant-available nitrate - N in the soil. Aslam *et al.*, (2000) reported that chickpea crop enhanced N fertility level of the soil. The results of this experiment suggest that nitrate contents in third year increased significantly in T2 treatment where sequence was wheat - chickpea-wheat. In this way chickpea can be seen as a crop that provides a cash income from grain, requires no N fertilizer owing to its ability to fix atmospheric nitrogen, and in rotation can improve the N nutrition and yield of subsequent cereals (Doughton *et al.*, 1993). These finding were supported by Aslam *et al.*, (2003).

There was no effect on chickpea grain yield with increased total N in chickpea under high soil nitrate, this shows that grain yields were not limited by N nutrition and that the source of N, whether soil derived or fixed, was of no consequence to grain yield. Therefore chickpea has the ability of providing the entire N required for grain yield even at the lowest soil nitrate levels (Doughton *et al.*, 1993). The major benefit expected from chickpea is that it will add N to the soil through N₂ fixation. If the total N₂ fixed by chickpea is greater than that removed in harvested grain, then this expectation will be met.

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