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Foliar sprays of concentrated urea at maturity of pigeonpea to induce defoliation and increase its residual benefit to wheat

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Abstract

The pigeonpea (*Cajanus cajan* (L.) Millsp.) crop retains appreciable amounts of green foliage even after reaching physiological maturity, which if allowed to defoliate, could augment the residual benefit of pigeonpea to the following wheat (*Triticum aestivum* L.) in a pigeonpea–wheat rotation. The effect of addition of leaves present on mature pigeonpea crop to the soil was examined on the following wheat during the 1999/2000 growing season at Patancheru (17°4′N, 78°2′E) and during the 2001–2003 growing seasons at Modipuram (29°4′N, 77°8′E). At Patancheru, an extra-short-duration pigeonpea cultivar ICPL 88039 was defoliated manually and using foliar sprays of 10% urea (30 kg/ha) and compared with a millet (*Pennisetum glaucum* (L.) R.Br.) crop, naturally senesced leaf residue and no-leaf residue controls. At Modipuram, the effect of 10% urea spray treatment on mature ICPL 88039 was compared with the unsprayed control. At both locations, the rainy season crops were followed by a wheat cultivar UP 2338 at four nitrogen levels applied in a split plot design, which at Patancheru were 0, 30, 90 and 120 kg N ha^{-1} and at Modipuram 0, 60, 120 and 180 kg N ha^{-1}. At Patancheru, urea spray added 0.5 t ha^{-1} of extra leaf litter to the soil within a week without significantly affecting pigeonpea yield. This treatment, however, increased mean wheat yield by 29% from 2.4 t ha^{-1} in the no-leaf residue pigeonpea or pearl millet plots to 3.1 t ha^{-1}. At Modipuram, the foliar sprays of urea added more leaf litter to the soil than at Patancheru. Here, increase in subsequent wheat yield due to additional pigeonpea leaf litter was 7–8% and net profit 21% more than in the unsprayed control. The addition of pigeonpea leaf litter to the soil resulted in a saving of 40–60 kg N for the following wheat crops in both the environments. The results demonstrated that pigeonpea leaf litter could play an important role in the fertilizer N economy in wheat. The urea spray at maturity of the standing pigeonpea crop significantly improved this contribution in increasing wheat yield, the effect of which was additional to the amount of urea used for inducing defoliation. The practice, if adopted by farmers, may enhance sustainability of wheat production system in an environmentally friendly way, as it could reduce the amount of fertilizer N application to soil and enhance wheat yield.

Keywords: Pigeonpea–wheat rotation; Foliar urea spray; Extra-short-duration pigeonpea; Nitrogen; N fertilizer; Residual benefit

1. Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a perennial legume cultivated as an annual crop in Asia and Africa not only for its seeds which are rich source of dietary protein but also because it improves soil

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fertility to benefit the following cereal crops (Faroda and Singh, 1983; Kumar Rao et al., 1983; Singh and Verma, 1985). However, in intensively managed agricultural systems, cultivation of pigeonpea as well as other legumes is declining as farmers are able to improve soil fertility by applying fertilizers. For example, farmers in the Indo-Gangetic Plain region now grow high yielding rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) crops that are providing farmers with substantially higher returns from applied N fertilizer investments. However, lately returns from these cereal crops have begun to decline and a need to diversify cropping systems is increasingly being realized (Kumar et al., 1999). Being a legume, pigeonpea can be reintroduced into the rice–wheat system to diversify it provided it can be shown that cultivation of pigeonpea not only makes economic sense but also enhances sustainability of other crops grown in the system. This essentially involves developing new pigeonpea types that can fit well in rotation with the cereals, as well as finding new ways to enhance the residual benefit of the crop to following crops.

Alongside the development of high yielding rice and wheat crops that contributed to the green revolution in many countries, pigeonpea has also been transformed from a slow maturing perennial crop that was largely suited to subsistence agriculture into a quick maturing high yielding annual crop suitable for commercial cultivation (Singh, 1996). Dahiya et al. (2002) recently demonstrated greater farmer acceptability of this new pigeonpea for cultivation in rotation with wheat because of its higher yield and more timely maturity. However, this new pigeonpea still has a fair degree of perennial characteristic as reflected in substantial amount of green foliage retained at maturity. The perenniality trait has been considered as undesirable in pigeonpea as it tends to limit pod set and reduce harvest index (Sheldrake, 1979). Nevertheless, this trait could also be useful, as it ensures that not all the nitrogen fixed by the crop is partitioned into grain and a part is retained in vegetative structures, which could supply valuable nutrients to the following cereals if returned to soil. As much of the nitrogen retained in the non-grain portion of the crop remains confined to green leaves, which contain about 4% nitrogen (Sheldrake and Narayanan, 1979), defoliation and subsequent incorporation of these retained leaves at maturity may be necessary for maximizing residual benefit to a subsequent cereal crop.

Defoliation to assist in mechanical harvesting of crops such as cotton through a variety of chemical defoliants is a commercially accepted practice in developed countries. In the developing countries, such defoliants are less likely to be accepted due to their prohibitive costs as well as potential environmental concerns in using them. Hence, a suitable defoliant, which is both eco-friendly and economical, would be desirable for this purpose. In guava (*Psidium guajava*), urea has been successfully used as a defoliant in Hawaii, USA (Sigeura, 1973) and in Queensland, Australia (Chapman et al., 1979). It has, however, not been used as a defoliant in field crops. Its use in agricultural crops has by and large been as a fertilizer to meet soil N requirement, and to some extent foliar nutrition in an aqueous (1–2%) solution when N deficiency occurs. The objectives of this investigation were, therefore, to examine the contribution of pigeonpea leaf litter in providing residual benefit to the following wheat crop, explore the possibility of inducing defoliation of leaves retained at maturity using foliar sprays of concentrated urea (to increase the amount of leaf litter), and quantify its effect on the subsequent wheat crop in diverse environments.

2. Materials and methods

The experiments were conducted at two locations, one representing a tropical and another sub-tropical environment. The experiment in the tropical environment was conducted on an Alfisol field (with about 1 m deep soil and 100 mm plant available water holding capacity) at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru (17°4′N, 78°2′E) research farm during the 1999/2000 cropping season. The experiment in the sub-tropical environment was conducted on an Inceptisol field (>1.5 m deep soil with >200 mm plant available water holding capacity) at the Project Directorate for Cropping Systems Research, Modipuram (29°4′N, 77°8′E), Meerut research farm during the 2001–2003 cropping seasons. The details of experiments conducted at both the locations are given below.

2.1. Pantancheru experiment

An extra-short-duration pigeonpea cultivar ICPL 88039 was sown on 5 July 1999 at 60 cm row-to-row and 5 cm plant-to-plant spacing, giving about 30 plants m^{-2}. An additional treatment was planted to millet (*Pennisetum glaucum* (L.) R.Br.) cultivar BJ 104 grown at 60 cm × 10 cm spacing on the same day. Both rainy season crops were raised as rainfed. At maturity of ICPL 88039, which occurred on 23 October 1999, the following treatments were imposed:

- T_1 = no-leaf residue (NLR) incorporated into the soil − control;
- T_2 = leaf residue attached on the plant at maturity manually removed and incorporated into the soil (ATTLR);
- T_3 = naturally senesced leaves (NSL) incorporated into the soil;
- T_4 = NSL + ATTLR leaves (NSLAR) incorporated into the soil;
- T_5 = NSL + canopy leaves defoliated using foliar sprays of 10% urea (NSLARD) incorporated into the soil;
- T_6 = millet − control.

In T_1 plots, all the naturally senesced leaves were removed from the plots while in T_2, only canopy leaves were manually defoliated and incorporated into the soil. In T_3 plots, only naturally senesced leaves were incorporated into the soil. In T_4 plots, attached leaves were manually defoliated at harvest and incorporated into the soil along with naturally senesced leaves, while in T_5 plots, a 10% aqueous solution of urea (equivalent to 30 kg ha^{-1}) was sprayed on the crop a week prior to the harvest of the crop. The urea concentration for the effective defoliation was standardized in an adjacent bulk plot (results not reported). Foliar sprays of urea were given using a hand operated knap-sack sprayer. The defoliated leaves were incorporated into soil along with naturally senesced leaves. In T_6, the millet crop served as a cereal control. The plot size was 6 m × 4 m, and there were three replications. The experimental design was a randomized block design. After maturity the pigeonpea and millet crops were harvested at the ground level and their shoots removed from the plots. Pigeonpea leaf residue in each plot was weighed in a 1 m^2 sample area and returned again to the respective plots. The entire leaf residue in each plot was incorporated into the soil as per the treatments with the help of a spade followed by a general disc cultivation. Yields of pigeonpea and millet were estimated after threshing the Entire net plot of 14.4 m^2. The contents of soil nitrate and ammonium nitrogen were determined before and after the pigeonpea harvest using the method described by Keeney and Nelson (1982), and that of phosphorus by the method described by Olsen and Sommers (1982) and organic carbon by the method described by Nelson and Sommers (1982).

A wheat crop (cultivar UP 2338) was sown on 15 November 1999 at 20 cm row-to-row and 5 cm plant-to-plant spacing. Each of the main plots of the rainy season crops (pigeonpea and millet) in the undisturbed layout was further subdivided into four subplots of 1.5 m × 4 m to which four treatments of 0, 30, 90 and 120 kg N ha^{-1} were applied at the time of sowing. The wheat crop was uniformly irrigated at about 10-day intervals with about 50 mm application of water each time. It was harvested on 28 February 2000 and its grain yield recorded. The data of wheat yield were analyzed as split plot design experiment with the rainy season crops as main plot and the nitrogen treatments as subplots.

2.2. Modipuram experiment

Pigeonpea cultivar ICPL 88039 was grown on ridges on 2 June 2001 and on 28 May 2002. A fertilizer dose of 18 kg N ha^{-1} and 20 kg P ha^{-1} was applied at the time of sowing. The crop was raised as rainfed. Plots were randomly earmarked as control and those to be given 10% urea (equivalent to 30 urea ha^{-1}) spray at the physiological maturity. Foliar sprays of urea were applied at the physiological maturity of the crop. N recycling through pigeonpea leaf litter was measured by quantifying the amount of leaf litter and its nitrogen content. The leaf litter samples collected before and after urea spray from each plot were dried at 70 °C in a hot-air oven. The dried samples were ground in a stainless steel Wiley mill, and wet-digested in concentrated H_2SO_4 for determining total N and in di-acid mixture (HNO_3 and $HClO_4$ mixed in 4:1 ratio) for determining total P. The N content was determined by Kjeldahl method using Kjeltec auto-analyzer, and P by vanadomolybadate yellow color method (Piper, 1966) using a UV-Vis spectrophotometer.

Wheat (cv. UP 2338) was sown on 14 November 2001 and on 11 November 2002 on the undisturbed layout of the pigeonpea crop. Each plot was further subdivided into four subplots of 0, 60, 120 and 180 kg N ha^{-1}. The subplot size was 6 m × 5 m. There were four replications. The wheat crop received five irrigations (about 50 mm each) starting at the crown root initiation (21 DAS), maximum tillering (45 DAS), jointing (65 DAS), ear emergence (85 DAS), and milking (105 DAS) stages. At maturity, wheat was harvested manually at ground level using sickles, and the harvested above ground biomass was removed from plots. The net profit from wheat cultivation in the Modipuram experiment was calculated after subtracting the cost of cultivation at US$ 329 ha^{-1}, from the gross profit. In the urea spray treatment, only additional expenditure computed was for 30 kg urea ha^{-1} and a person day used in spraying, both of which valued US$ 4.30 ha^{-1}. The trial was analyzed as a split-plot designed experiment with the pigeonpea treatments assigned to main plots and the wheat treatments assigned to subplots.

3. Results

3.1. Weather

The rainy season (June–September) at Patancheru was characterized by a less than the normal (690 mm) rainfall (Table 1). While this favored disease-free development of pigeonpea, it also exposed the crop to mild stress allowing less than expected growth. Growing temperatures at this location were slightly above normal due to many rain-free days. The pigeonpea crop with a similar rainfall did not experience any stress at Modipuram (Table 1) in spite of less than the normal rainfall (600 mm) due to greater water holding capacity of the soil. Due to a lack of significant rainfall during the wheat-growing seasons in both the environments, the wheat crop needed frequent irrigations.

3.2. Urea effect on pigeonpea defoliation and yield

Mean total dry matter produced by pigeonpea (including the senesced leaves at Patancheru) was about 3 t ha^{-1}, of which leaves constituted about 1.08 t ha^{-1} (Table 2). In spite of being exposed to mild stress, only about half of the leaves senesced and about half remained attached to stems at maturity. Urea spray induced about 80% of these leaves to fall off within a week from physiological maturity. The total fallen plant material (1.26 t ha^{-1}) contained 28.4 kg N ha^{-1} and 2.16 kg P ha^{-1}. The total N contained in the attached leaves was 16.9 kg ha^{-1} and total P 1.14 kg ha^{-1}. The N content of the naturally senesced leaves was 1.85% compared to 3.3% of the attached leaf residue. Urea spray did not affect pigeonpea yield significantly (Table 2).

Table 1
Average monthly maximum and minimum temperatures (°C), and total monthly rainfall (mm) at Patancheru during the 1990/2000 and at Modipuram during the 2001/2002 growing seasons

Month	Patancheru (1999/2000)			Modipuram (2001/2002)		
	Temperatures		Rainfall	Temperatures		Rainfall
	Maximum	Minimum		Maximum	Minimum	
June	32.1	22.1	62.2	35.2	24.1	149.4
July	30.7	21.0	183.2	35.7	26.9	179.3
August	29.1	20.5	129.3	36.2	26.1	64.8
September	29.1	20.4	80.1	37.7	23.9	17.3
October	30.6	18.4	38.4	34.7	19.7	0.0
November	29.9	12.7	5.0	30.1	12.6	9.0
December	28.1	9.9	0.0	23.6	8.1	0.0
January	29.8	11.4	0.0	22.7	6.7	14.5
February	31.2	15.7	57.8	26.5	9.2	35.0
March	35.0	15.8	0.0	32.0	14.8	2.0
April	39.3	20.5	0.0	38.9	21.2	0.0
May	36.7	21.8	122.6	40.4	26.7	68.0

Table 2
Pigeonpea total dry matter (t ha^{-1}), grain yield (t ha^{-1}), leaf mass (t ha^{-1}) and contribution of N and P (kg ha^{-1}) to soil in different leaf residue treatments at Patancheru Alfisol, 1999/2000 rainy season

Treatment[a]	Total dry matter	Grain yield	Leaf-mass		Contribution of	
			Attached	Senesced	N	P[b]
NOLFR	3.58	1.27	0.48	–	–	–
ATTLR	3.73	1.32	0.48	0.56	16.9	1.1
NSL	4.32	1.32	0.58	0.56	28.5	2.2
NSLAR	4.11	1.34	0.52	0.56	45.4	3.3
NSLARD	3.63	1.21	0.11	0.56	73.9	3.3
±S.E.M.	0.172	0.061	0.042			

[a] NOFLR = no fallen leaf residue; ATTLR = attached leaf residue; NSL = naturally senesced leaves; NSLAR = naturally senesced leaf residue + attached leaf residue removed manually; NSLARD = naturally senesced leaf residue + attached leaf residue returned to soil through defoliation by urea spray.

[b] Calculated at N content at 1.85% in the naturally senesced leaves and 3.25% in attached leaf residue and P content at 0.19% in the naturally senesced leaves and 0.2% in the attached leaves. The average weight of the attached leaf residue was 0.52 t ha^{-1}.

The NO_3-N content of soil at Patancheru declined from sowing time to after the harvest of crop under all treatments, indicating that both millet and pigeonpea scavenged soil nitrogen (Table 3). However, in the urea treatment, nitrate-N content was higher than the other treatments. Ammonium-N, available P, and organic matter content were unaffected by different treatments.

In the Modipuram experiment of 2001/2002, natural senescence contributed to about 1.3 t ha^{-1} of leaf litter, whereas urea spray added a further 1.25 t ha^{-1} of leaf litter (Table 4). Little adverse effect of urea spray on pigeonpea yield was observed. The N content of fallen leaves in urea spray plots was about 2.35%, whereas naturally senesced leaves in the unsprayed treatment contained about 1.6% N. This leaf litter of pigeonpea contributed to about 29.4 kg additional N ha^{-1}, which was equivalent to the amount of nitrogen in urea, applied as foliar spray. In the second season, nearly identical leaf-fall and corresponding N recycling was observed.

3.3. Effect on wheat yield

At Patancheru, wheat grain yield was significantly more in the treatments receiving pigeonpea leaf litter

Table 3
Nitrate, ammonium-N, available P (mg kg^{-1} soil), and organic carbon content (%) in 0–15 and 15–30 cm soil layers before and after the harvest of pigeonpea and millet

Treatment[a]	Nitrate-N		Ammonium-N		Olsen-P		Organic carbon	
	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30
Before pigeonpea	15.8	5.9	3.7	3.6	20.9	3.6	0.60	0.39
NOFLR	6.9	4.3	2.2	1.9	18.3	4.7	0.58	0.37
ATTLR	7.2	5.3	2.2	2.0	21.0	7.1	0.61	0.46
NSL	7.0	4.5	2.3	1.9	20.7	5.4	0.62	0.38
NSLAR	6.4	4.5	2.4	1.9	18.2	3.9	0.59	0.42
NSLARD	12.1	7.8	2.6	2.4	19.2	6.5	0.61	0.44
Millet	6.2	3.8	2.2	2.0	17.8	5.0	0.58	0.37
±S.E.M.[b]	0.90	0.90	0.10	0.10	1.10	1.10	0.020	0.020

[a] NOFLR = no fallen leaf residue; ATTLR = attached leaf residue; NSL = naturally senesced leaves; NSLAR = naturally senesced leaf residue + attached leaf residue removed manually; NSLARD = naturally senesced leaf residue + attached leaf residue returned to soil through defoliation by urea spray.

[b] S.E. only for comparing treatments after the harvest of pigeonpea and millet.

Table 4
Effect of urea spray at physiological maturity of pigeonpea on the leaf-fall, N recycling, and grain yields of pigeonpea and wheat on a sandy loam soil, 2001–2003 growing seasons, Modipuram

Treatment	Total leaf-fall ($t\ ha^{-1}$)	N recycling through leaves ($kg\ ha^{-1}$)	Pigeonpea yield ($t\ ha^{-1}$)	Wheat yield ($t\ ha^{-1}$)	Net return from wheat (US$ ha^{-1})
2000/2001 rainy season					
Control	1.73	27.5	1.99	4.01	223
10% urea spray	2.58	56.9	2.03	4.36	271
±S.E.M.	0.19	7.84	0.02	0.101	
2002/2003 rainy season					
Control	1.76	40.3	2.07	3.79	193
10% urea spray	2.76	78.5	2.09	4.10	231
±S.E.M.	0.22	9.84	0.01	0.086	

compared with those without leaf litter (Table 5). Wheat yield was lowest after the millet crop, although the interaction between the different leaf litter treatments and fertilizer application to wheat was not significant. Maximum yield ($4.23\ t\ ha^{-1}$) was obtained at $120\ kg\ ha^{-1}$ of N applied in the treatments where pigeonpea was defoliated with urea (T_5), followed by the treatments where naturally senesced leaves and attached leaf residue were incorporated into the soil, and in the treatment where only naturally senesced leaves (T_4) were incorporated. Incorporation of only attached leaf residue (T_2) resulted in a lower yield of wheat than the other leaf residue treatments, but higher than the no residue or millet plots which gave the lowest yield ($3.3\ t\ ha^{-1}$). Wheat yield response tended to level off after $90\ kg\ N\ ha^{-1}$ in the treatments having millet in the preceding season, whereas continued to increase in the urea spray treatment even at the highest level of N application. Thus with an application of 30 kg N for defoliating pigeonpea, it was possible to increase responsiveness of wheat beyond its optimum fertilizer level. Even the incorporation of naturally senesced leaf litter (T_3) resulted in a significantly greater wheat yield over the millet treatment (Table 5), indicating beneficial effects of recycling pigeonpea leaf litter in a wheat production system. The increase in wheat yield was largely attributable to increases in wheat biomass

Table 5
Effect of different leaf residue treatments imposed at the maturity of pigeonpea and millet on yield ($t\ ha^{-1}$) of following wheat grown at different N levels at Patancheru, Alfisol, 1999/2000 rainy season

Main plot treatments[a]	0	30	90	120	Mean
NOLFR	1.31	1.95	3.06	3.36	2.42
ATTLR	1.47	2.40	3.37	3.63	2.72
NSL	1.53	2.34	3.58	3.80	2.81
NSLAR	1.57	2.46	3.58	3.63	2.81
NSLARD	1.69	2.66	3.94	4.23	3.13
Millet	1.38	1.90	3.09	3.07	2.36
Mean	1.49	2.29	3.44	3.62	
±S.E.M. (interaction)	0.186				
±S.E.M. (main plot treatments)	0.109				
±S.E.M. (nitrogen treatments)	0.071				

0, 30, 90 and 120 are the amount of nitrogen ($kg\ ha^{-1}$) applied to wheat.

[a] NOFLR = no fallen leaf residue; ATTLR = attached leaf residue; NSL = naturally senesced leaves; NSLAR = naturally senesced leaf residue + attached leaf residue removed manually; NSLARD = naturally senesced leaf residue + attached leaf residue returned to soil through defoliation by urea spray.

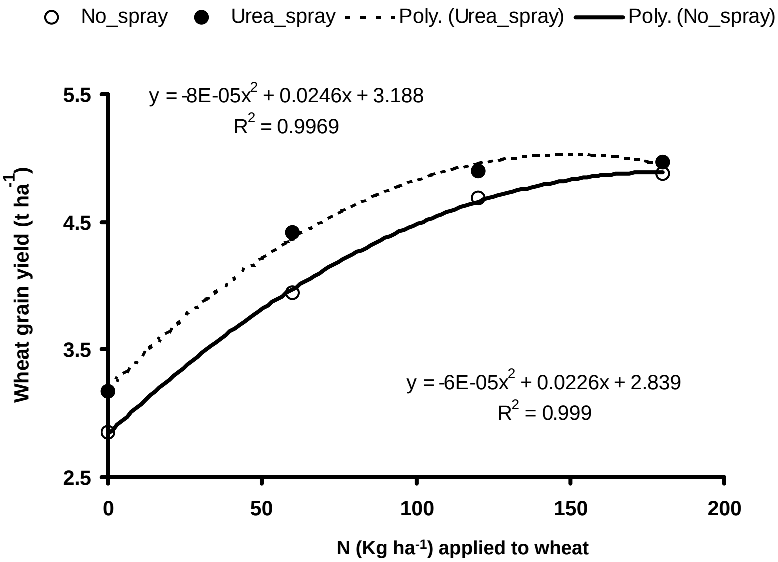

Fig. 1. Effect of 10% urea spray at physiological maturity of pigeonpea on the yield of following wheat crop grown with different levels of nitrogen, 2001/2002 rainy season, Modipuram.

arising from better tillering and to a marginal increase in 100-seed mass and grain number per spikelet (data not reported). The net N saving after subtracting the N applied for spray in urea sprayed treatment was about 25 kg ha^{-1} compared to T_1 and T_6 treatments and 10–15 kg ha^{-1} compared T_2–T_4 treatments.

At Modipuram, grain yields of the succeeding wheat crop varied significantly due to incremental rates of N, and the extent of increase was modulated by the urea spray treatment (Fig. 1). Wheat yield increased significantly up to 120 kg N ha^{-1}, producing a yield response of 1.79 t ha^{-1} over the no N-control that gave 3.01 t ha^{-1}. The average wheat yield advantage due to the urea spray in the preceding pigeonpea was 0.28 t ha^{-1}, about 7% more than in the no-spray treatment. Interestingly, wheat yield with 180 kg N ha^{-1} in the no-urea spray treatment was comparable to 120 kg N ha^{-1} in the urea spray treatment, thus indicating a possible saving of 60 kg N. In the second season (2002/2003), mean wheat yield was 3.79 ha^{-1} in the unsprayed control and 4.10 t ha^{-1} in the urea sprayed treatment, representing a 8.23% increase due to urea spray (detailed results not presented).

The net profit from wheat cultivation after urea spray was 21.5% more in 2001/2002 and 20% more in 2002–2003 seasons than in the unsprayed controls (Table 4).

4. Discussion

Sustaining productivity of wheat and rice crops in South Asia, which is crucial to food security of the region, is receiving high priority as negative trends in the productivity of these crops have been noticed in some parts (Pathak et al., 2003). Such negative trends have been attributed to changes in climate as well as to decrease in availability of some nutrients (Ladha et al., 2003). In order to maintain wheat productivity, farmers, especially in South Asia are resorting to higher doses of nitrogenous fertilizers and less so on traditional means of ameliorating soils with alternative cropping systems due to the economic risks of losing profits from higher yielding crops. The results of this study demonstrated that it is possible to increase wheat yields by adding a pigeonpea component into the system and augmenting its residual benefit by foliar applications of urea upon maturity to increase addition of its leaf residue to soil. In both Patancheru and Modipuram environments investigated in this study, urea spray nearly doubled the amount of leaf litter, although the quantity of additional leaf litter was more in Modipuram environment. The exact mechanism of induction of defoliation by urea is not clear as yet. However, urea spray was not detrimental to pigeonpea yield suggesting that leaves present in the canopy were no longer required for supporting the existing pods because they were already mature.

In the present study, concentrated urea spray on a mature pigeonpea crop assisted not only in increasing the amount of leaf litter but also increasing nitrogen concentration in its defoliating leaves compared to that in the naturally senesced leaves. Almost all the nitrogen applied as urea could be accounted for in additional nitrogen present in the defoliated leaf residue. The increased nitrogen in the defoliating leaves could lower their carbon to nitrogen ratios and thus make them more easily decomposable facilitating release of not only nitrogen into soil but other nutrients as well. Some of the nitrogen could have also been remobilized to stems and roots during the defoliation process, which could have been additional to the amount of N recovered in fallen leaves.

At Patancheru, a comparison of wheat yield in different treatments of the preceding rainy season crops suggested that in general incorporation of pigeonpea leaf residue was beneficial to wheat compared to the no-leaf residue or millet crop treatment. Pigeonpea leaf residue quantity as less as 0.5 t ha^{-1} seemed to have helped in recycling some of the nitrogen it may have fixed and other nutrients it may have removed from soil during its growth. This benefit to wheat crop was significantly increased when additional leaf residue defoliated by urea spray with higher nitrogen content than naturally senesced leaves was added to the soil. Foliar spray of urea not only increased yields of wheat in general but also its N responsiveness. With an application of 30 kg N for defoliating pigeonpea, N responsiveness of wheat observed was up to the maximum N level applied whereas in the millet control, leveling off of response was seen at a lower N level. A greater response to applied nitrogen in the urea induced defoliation treatment suggests a possible increase in N requirement of the wheat crop, perhaps owing to the increased recycling of nutrients other than N that may be limiting wheat yield. This is consistent with observation made in long-term experiments with rice and wheat grown with recommended rates of NPK where a decline in wheat yield has been attributed to depletion of nutrients other than N in soil (Ladha et al., 2003). Though not measured in this study, an assessment of increase in availability (in soil) and uptake in wheat crop of nutrients other than N in urea spray treatment may help explaining the N response of wheat.

At Modipuram, the average wheat yield due to urea spray on the preceding pigeonpea crop was up to 7–8% more than in the no-spray treatment, needing up to 60 kg less fertilizer N application to reach peak yield levels. The locally recommended dose of N application to wheat is 120 kg ha^{-1} in this region (Dwivedi et. al., 2001) suggesting that if farmers were to use the recommended dose of fertilizer N and adopted urea spray, they would harvest greater yields of wheat with just a little extra cost. The additional net profit from urea application was about 21% more than the no-urea spray treatment, which should make it attractive enough to invest in the additional extra cost of urea and its application.

The extent of increase in wheat yield due to defoliation was far more in Patancheru environment than in Modipuram, although leaf litter addition was more in the latter environment. This could be because Modipuram seems to provide a more favorable environment for wheat growth as was evident from higher yield at this location even in the no-N treatment than at Patancheru. A larger response to defoliation using urea at Patancheru suggests its greater benefit in more marginal environments for wheat production. Even in more favorable environment of Modipuram, a 7–8% increase in wheat yield although may not represent a large increase in absolute terms, but it may require a significant breeding effort to achieve similar increases through genetic means. Moreover, such response was obtained with only 1 year of pigeonpea leaf residue incorporation. Several cycles of such incorporation may enhance the fertility to result in even better responsiveness of wheat and restore negative trends in its productivity. As well as some N fertilizer savings, the urea spray treatment would be likely to increase overall organic matter, hence larger responses could be expected over a longer term. The practice of defoliating pigeonpea leaves at maturity using foliar sprays of urea, therefore, if adopted by farmers may enhance sustainability of wheat production systems in an environmentally friendly way, as it could reduce the amount of direct N application to soil and enhance wheat yield. Urea being a common fertilizer and easily available, should not be difficult to procure and apply.

References

Chapman, K.R., Saranah, J., Paxton, B., 1979. Induction of early cropping of guava seedlings in a closely planted orchard crop using urea as a defoliant. Aust. J. Agric. Anim. Husb. 19, 382–384.

Dahiya, S.S., Chauhan, Y.S., Johansen, C., Waldia, R.S., Sekhon, H.S., Nandal, J.K., 2002. Extra-short-duration pigeonpea for diversification of wheat based cropping systems in the sub-tropics. Exp. Agric. 38, 1–11.

Dwivedi, B.S., Shukla, A.K., Singh, V.K., Yadav, R.L., 2001. Results of participatory diagnosis of constraints and opportunities (PDCO) based trials from the state of Uttar Pradesh. In: Subba Rao, A., Srivastava, S. (Eds.), Development of Farmers' Resource-based Integrated Plant Nutrient Supply Systems: Experience of an FAO–ICAR–IFFCO Collaborative Project and AICRP on Soil Test Crop Response Correlation. IISS, Bhopal, India, pp. 50–75.

Faroda, A.S., Singh, R.C., 1983. Effect of preceding crops on the nitrogen need of succeeding wheat crop. Indian J. Agric. Sci. 53, 123–128.

Keeney, D.R., Nelson, D.W., 1982. Nitrogen inorganic forms. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. American Society of Agronomy, Madison, WI, pp. 651–658.

Kumar Rao, J.V.D.K., Dart, P.J., Sastry, P.S.S., 1983. Residual effect of pigeonpea (*Cajanus cajan*) on yield and nitrogen response of maize. Exp. Agric. 19, 131–141.

Kumar, P., Joshi, P.K., Johansen, C., Ashoken, M., 1999. Sustainability of rice wheat systems in India: socio-economic and policy issues. In: Pingali, P.L. (Ed.), Sustainability of Rice–Wheat Productions Systems: Socio-economic and Policy Issues. Rice Wheat Consortium Paper Series 5. Rice–Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India, pp. 61–77.

Ladha, J.K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R.L., Singh, B., Singh, Y., Singh, P., Kundu, A.L., Sakal, R., Ram, N., Regmi, A.P., Gami, S.K., Bhandari, A.L., Amin, R., Yadav, C.R., Bhattarai, E.M., Das, S., Aggarwal, H.P., Gupta, R.K., Hobbs, P.R., 2003. How extensive are yield declines in long-term rice–wheat experiments in Asia? Field Crops Res. 81, 159–180.

Nelson, D.W., Sommers, L.E., 1982. Total organic carbon, and organic carbon, and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. American Society of Agronomy, Madison, WI, pp. 539–579.

Olsen, S.R. Sommers, L.E., 1982. Phosphorus. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. American Society of Agronomy, Madison, WI, pp. 421–422.

Pathak, H., Ladha, J.K., Aggarwal, P.K., Peng, S., Das, S., Singh, Y., Singh, B., Kamra, S.K., Mishra, B., Sastri, A.S.R.A.S., Aggarwal, H.P., Das, D.K., Gupta, R.K., 2003. Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. Field Crops Res. 80, 223–234.

Piper, C.S., 1966. Soil and Plant Analysis. University of Adelaide, Australia.

Sheldrake, A.R., 1979. A hydrodynamical model of pod-set in pigeonpea (*Cajanus cajan*). Indian J. Plant Physiol. 22, 137–143.

Sheldrake, A.R., Narayanan, A., 1979. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). J. Agric. Sci. Camb. 92, 513–526.

Sigeura, G.T., 1973. Culture and management of guava. In: Proceedings of the CTA Statewide Guava Industry Seminar. Hawaii Agricultural Experiment Station Miscellaneous Publication 111, p. 10.

Singh, L., 1996. The development of and adoption prospects of extra-short-duration pigeonpea. In: Singh, L., Chauhan, Y.S., Johansen, C., Singh, S.P. (Eds.), Prospects for Growing Extra-short-duration Pigeonpea in Rotation with Winter Crops: Proceedings of the IARI/ICRISAT Workshop and Monitoring Tour, October 16–18, 1995, New Delhi, India. Indian Agricultural Research Institute/ICRISAT, New Delhi/Patancheru, Andhra Pradesh, India, pp. 1–5.

Singh, S.B., Verma, B.S., 1985. Effect on kharif grain legumes on nitrogen economy in succeeding crop of wheat. Indian J. Agron. 30, 397–400.