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Ridge Planted Pigeonpea and Furrow Planted Rice in an Intercropping System as Affected by Nitrogen and Weed Management

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1. Introduction

Producing more food to feed the burgeoning population from shrinking agricultural land and water resources will be a challenge. Recently, intercropping has received more attention as a means to increase productivity of crops in per unit area and per unit time.

Intercropping is a crop management system involving the growing of two or more dissimilar crops in distinct row combinations simultaneously on the same land area. In intercropping, the component crop species are usually sown in parallel lines enabling mechanical crop production, maintenance, and harvest. Intercropping involves crop intensification in respect to both time and space dimensions (Ahlawat and Sharma, 2002). Conceptually, an intercropping system helps for risk avoidance from epidemic of insect-pest and diseases and overcome adverse environmental conditions in agro-climatologically unstable regions along with increasing solar radiation utilization and inputs including fertilizer and water utilization compared to monoculture crops. Intercropping not only reduces the risk associated with input costs but also increases profit potential (Rathi and Verma, 1979). Moreover, it provides several major advantages namely, diversification reduces risk associated with crop failure, increased productivity per unit area and time, offers greater yield stability and utilizes the available growth resources more efficiently and sustainably. Furthering rationales of this practice, it caters to the multiple needs of the farmer, is a self-provisioning device, is a mechanism to spread labour peaks, and keeps weeds under check (Singh and Jha, 1984). A number of researchers (Enyi, 1973; Sengupta et al., 1985) reported greater land use efficiency utilizing intercropping and reductions of weed growth through competition. The yield advantage obtained through intercropping has been reported mainly due to efficient utilization and optimization of available natural growth

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resources including water (Donald, 1963; Singh and Gupta, 1994), nutrients (Donald, 1963; Dalal, 1974); light (Donald, 1963; Nelliet et al., 1974; Singh and Gupta, 1994) as well as air and space (Singh and Gupta, 1994). In addition, intercropped species can be selected that produce allelopathic effect (Risser, 1969; Rice, 1974). Similarly, Willey (1979) made critical analysis of the yield advantages accrued from the intercropping. He explained that yield advantage occurs because the component crops differ in their use of growth resources in such a way that when they are grown in combination they are able to complement each other to make better overall use of resources than when grown separately. Annidation is the complementary use of resources by exploiting the environment in different ways by the components of a community. Maximizing intercropping advantage is a matter of maximizing the degree of complementarity between the components and minimizing intercrop competition.

Pigeonpea (*Cajanus cajan* L. Millsp.) is seldom or never grown in monoculture except on a very small scale, and mixed cropping is standard on field scale (Aiyer, 1949). Pigeonpea is commonly intercropped with cereals such as sorghum (*Sorghum bicolor* L. Moench), maize (*Zea mays* L.), pearl millet (*Pennisetum typhoides* L.), finger millet (*Eleusine coracana* Gaertn) and rice (*Oryza sativa* L.); grain legumes like black gram (*Vigna mungo* L. Hepper), green gram (*Vigna radiata* L. Wilczek), soybean (*Glycine max* L. Merrill) and oilseed such as sesamum (*Sesamum indicum* L.), groundnut (*Arachis hypogaea* L.) (Jena and Misra, 1988; Parida et al., 1988; Gouranga Kar, 2005; Behera et al., 2009; Ashok et al., 2010).

Practice of intercropping of pigeonpea with different short duration companion crops in India is very common. Being deep rooted, pigeonpea is very well suited for intercropping with the shallow rooted ones. Intercropping besides offering an insurance against failure of the crop due to disease, pests and frost, enables the farmers to obtain a variety of crops of their needs from the same piece of land. Pigeonpea is generally grown with wide row spacing of about 75-80 cm. However, the initial growth is quite slow and the grand growth period starts after 60-70 DAS. A lot of inter-row spaces, therefore, remain vacant during the early stages and get infested by weeds. The space between the rows could be profitably utilised by growing short duration crops such as black gram, green gram, cowpea, rice etc. The row arrangement that utilises a high proportion of the early crop to maximise its yield and allows the late maturing component to fully cover the ground should normally give the highest productivity. Based on the per cent of plant population used for each crop in intercropping system, it is divided into two types *viz.* additive and replacement series. In additive series, one crop is sown with 100% of its recommended population in pure stand which is known as the base crop. Another crop known as intercrop is introduced into base crop by adjusting or changing crop geometry. The population of intercrop is less than its recommended population in pure stand. In replacement series, both the crops called component crops. By scarifying certain proportion of population of one component, another component is introduced. Soybean+pigeonpea (4:2) is one of the example of intercropping in replacement series (Kasbe et al., 2010) and pigeonpea+greengram (1:2) is in additive series (Arjun Sharma et al., 2010).

A new concept of pigeonpea +rice intercropping system under ridge-furrow method of planting has been developed for rice ecosystem of Varanasi in India in additive series (Singh, 2006a). Since both upland rice and pigeonpea are sensitive to moisture regime (rice to drought and pigeonpea to excess soil moisture); however in this system, pigeonpea and rice both receive their favourable micro-climate at field level. The major advantage of rice intercropping in furrow with ridge planted pigeonpea is that it can give greater yield stability compared to other intercropping choices because they are either adversely affected due to higher soil moisture or waterlogging at initial growth stage, thus the risk of a total crop failure is halved.

Weed infestation reduces grain yield directly and indirectly. Many crop and weeds have evolved with similar requirements for growth and development (Pujari et al., 1989; Yadav and Singh, 2009). Competition occurs when one of the resources (nutrients, light, moisture and space) fall short of total requirement of the crop and/or weeds. Weeds, by virtue of their high adoptability and faster growth, usually dominate the crop habitat and reduce the yield potential. Due to slow initial growth, wide crop row spacing is inefficient in fully utilizing light and moisture resources at initial growth stages and subsequently yield is reduced through competition with weeds. The inclusion of additional intercrop species can overcome this limitation. The presence of weeds is one of the major constraints to increase the seed yield in grain crops. Weeds are also an important factor responsible for low fertilizer use efficiency. Effective weed control measures are one of the several ways of increasing fertilizer use efficiency in crops in monoculture as well intercropping systems.

The nature and magnitude of crop-weed competition differs considerably between monoculture and intercropping systems. The crop species, population density, sowing geometry, duration and growth rhythm of the component crops, the moisture and fertility status of soil and tillage practices all influence weed flora in intercropping system (Moody and Shetty, 1981).

Since weeds are the main concern in many cultivated crops they should be controlled at the proper time. The most critical stage of crop-weed competition was observed between 15 to 45 days after sowing for the pigeonpea based intercropping system (Singh and Singh, 1995). Hand weeding, which is common practice, is very effective if repeated, though it is tedious, time consuming and costly. Moreover, present labour availability for such operations has decreased due to rapid industrialization, increased literacy and migration of labour to urban areas. Further, manual weed control methods are usually initiated after weeds have attained size and thus already competed for some time with the crop. Continuous rains in the rainy season make weed control by hand more difficult due to improper field conditions. In such situations, herbicide use likely will control weeds from the beginning of crop growth and can increase the crop yields. Herbicides not only control weeds and reduce labour cost, but also allow coverage of more area in a relatively shorter time period thus protecting yield potential (Ampong-Nyarko and De Datta, 1993). Many herbicides are crop specific; a herbicide that does not harm both the component crops, usually does not control a broad spectrum of weed species. The herbicides used in intercropping are selective in action for both component crops, but likely have narrow spectrum of weed control, leaving the other weeds to develop and compete with the crop. In addition, herbicidal soil activity expires before the critical period of crop-weed competition. A long duration crop of pigeonpea responded positively to two manual weeding and a pre-emergence herbicide likely substitute first one out of these two (Maheswarappa and Nanjappa, 1994). Higher yield attributes and yield of pigeonpea were also observed in different intercropping system under two sequential hand weedings or by integrated use of herbicides and hand weeding (Dwivedi et al., 1991; Rafey and Prasad, 1995; Rana et al., 1999).

The objectives of our present investigation entitled "Ridge Planted Pigeonpea and Furrow Planted Rice in an Intercropping System as Affected by Nitrogen and Weed Management" were to study the growth pattern and yields and nutrient uptake as affected by nitrogen and weed management in pigeonpea+ rice intercropping system.

2. Materials and methods

2.1 Physiographic situation

The Agricultural Research Farm is situated in the South eastern part of Varanasi city, India at an altitude of 125.93 meter above the MSL, 20^0 18′ north latitude and 80^0 36′ eastern longitude. The experiment was established at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University. The area accurately reflects the agro-climatic conditions of North Gangetic Alluvial Plains with annual rainfall of about 1100 mm.

2.2 Climatic condition

Varanasi's climate is sub-tropical and is subjected to extremes of weather conditions i.e. heat of summer (33.4-41.4 ^{0}C) and cold in winter (9.3-11.8 ^{0}C). The temperature increases from mid-February and reaches its maximum by May/June but has a tendency to decrease from July onwards reaching the minimum in December/January. The normal period for the onset of monsoon in the region is third week of June which lasts up to the end of September or sometimes into the first week of October. The area occasionally experiences some winter cyclonic rains during December/ February. The period between March and May is generally dry. The normal annual rainfall of the region is about 1081.4 mm. In terms of percentage of total rainfall, 88 per cent is received from June to September, 5.7 per cent from October to December, 3.3 per cent from January to February and 3 per cent from March to May as per monsoon rains. The mean relative humidity is 62 per cent which rises up to 82 per cent during July to September and fall down to 28 per cent during the end of April and early June.

2.2.1 Rainfall

The cumulative rainfall received during the period of investigation was 683.0 mm and 783.3 mm in the year 2004-05 and 2005-06, respectively. The distribution of rainfall was more uniform during second year as compared to first year during crop production. The month-wise distribution of the rainfall indicated that July and August of second year received more rain than the corresponding period of the first year.

2.2.2 Temperature

The weekly mean maximum temperature ranged from 20.0 to 38.6 ^{0}C with an average of 30.0 ^{0}C during 2004-05 and 18.8 to 44.1 ^{0}C with an average of 30.8 ^{0}C during 2005-06. The weekly mean minimum temperature ranged from 8.3 ^{0}C to 27.4 ^{0}C with an average of 19.1 ^{0}C during 2004-05 and 7.4 to 30.4 ^{0}C with an average of 18.7 ^{0}C during 2005-06. The mean fluctuation in maximum and minimum temperature was almost normal during both the years.

2.2.3 Relative humidity

The weekly mean maximum relative humidity varied from 62 to 95% with an average of 84% during 2004-05 and it varied from 37 to 92% with an average of 82% during 2005-06. The weekly mean minimum relative humidity varied from 18 to 81%-with an average of 55% during 2004-05 and it varied from 18 to 83% with an average of 52% during 2005-06. The relative humidity indicated considerable variation throughout the growing season during both the years. Data also indicated that the first year was comparatively more humid as compared to second year.

Soil Physical and Chemical Properties	Value	Analysis Method Employed
Soil separates 0 – 15 cm (%) Sand Silt Clay	 43.68 30.66 25.66	Hydrometer method (Bouyoucos, 1962)
Textural class	Sandy clay loam	Textural triangle (Black, 1967)
*p*H (1:2.5 soil water ratio)	7.3	Glass electrode *p*H meter (Jackson, 1973)
Electrical conductivity (d S/m at 25^0C)	0.29	Systronics electrical conductivity meter (Jackson, 1973)
Organic carbon (%)	0.35	Chromic acid rapid titration method (Walkley and Black, 1934)
Available nitrogen (kg N/ha)	208.5	Alkaline permanganate method (Subbiah and Asija, 1973)
Available phosphorus (kg P/ha)	18.21	0.5 M $NaHCO_3$ extractable Olsen's colorimetric method. (Olsen et al., 1954)
Available potassium (kg K /ha)	185.02	Flame photometric method (Ammonium acetate extract) (Jackson, 1973)

Table 1. Physio-chemical properties of the experimental field

2.2.4 Sunshine duration

The average duration of bright sunshine day was 6.9 and 7.2 hours in first and second year, respectively. The range of maximum and minimum mean weekly bright sunshine duration was ranged from 2.9 to 10.2 hours during 2004-05 and it ranged from 1.9 to 10.0 hours during 2005-06.

2.2.5 Evaporation

The evaporation data recorded from a United States Weather Bureau class A pan evaporimeter revealed that the weekly average evaporation per day varied from 6.4 to 1.4 mm/day in 2004-05 and 9.5 to 1.5 mm/day in 2005-06. The total evaporation during crop growing period was 942.2 mm in 2004-05 and 1061.9 mm in 2005-06.

2.3 Soil and soil analysis

In order to know the initial fertility status of the experimental plot, soil sample from 0-15 cm were collected and analysed for mechanical composition and chemical constituents. Data obtained are reported in Table 1. The experimental plot area soil was classified as sandy clay loam in texture, low in nitrogen, and medium in available phosphorus and potassium.

2.4 Technical programme

Considering the nature of factors evaluated and the convenience of agricultural operation, the experiment was laid out in split plot design with three replications. Six main plot treatments (consisting of all possible combinations of two nitrogen levels in pigeonpea including one control and another 25 kg N/ha as starter application with three nitrogen levels in rice i.e. 50, 75 and 100 kg N/ha) and four sub plot treatments(weed management) were established. Weed management treatments included: 1) a weedy check, 2) pendimethalin at 1.0 kg/ha, 3) pendimethalin at 1.0 kg/ha followed by one hand weeding at 45 days after seeding (DAS) or 4) two sequential hand weeding at 15 and 45 DAS. The whole field was divided into three blocks, each representing a replication. Each block was further divided in six main plots where main plots treatments were randomly allocated within them. Then each main plot was again divided into four equal sub plots and the sub plot treatments were again allocated randomly.

2.4.1 Field preparation

Proper field preparation is essential for a healthy pigeonpea and rice crop in intercropping. The experimental area was ploughed with tractor drawn mould board plough followed by two passes with a disc. Finally the field was levelled.

2.4.2 Ridge and furrow establishment

Ridges and furrows were established manually by spade.

2.4.3 Fertilizer application

The recommended doses of P_2O_5 and K_2O for pigeonpea were 40 and 30, and for rice were 40 and 40 kg/ha, respectively. Quantity of P_2O_5 and K_2O/ha were applied on row basis to each crop separately in the form of single super phosphate and muriate of potash, respectively. Full doses of phosphorus and potassium were applied to pigeonpea and rice as basal applications. Nitrogen was applied as per treatment through urea. Full nitrogen dose of pigeonpea and 75% nitrogen dose of rice were applied as basal and remaining nitrogen dose of rice was top dressed at it's tillering growth stage.

2.4.4 Seed and sowing

Seed rate for pigeonpea and rice were 20 and 60 kg/ha, respectively. Pigeonpea seeds were sown on top of the ridges and rice seeds were sown in two rows in each furrow at the same date. The crops were sown on 8th July in 2004 and 12th July in 2005 using full season pigeonpea variety 'Bahar' and early rice variety 'NDR 97'. Row to row spacing of pigeonpea was 75 cm and plant to plant spacing of pigeonpea and row to row spacing of rice were 20 cm.

2.4.5 Herbicide application

The required quantity (1.0 kg/ha) of pendimethalin was mixed in water and sprayed with a backpack sprayer using the spray volume of 600 litres of water/ha as per treatment. Pendimethalin was applied pre-emergence (1 DAS).

2.4.6 Thinning

The extra plants were thinned out at 30 days after sowing to maintain the plant to plant spacing of 20 cm for pigeonpea.

2.4.7 Hand weeding

Hand weeding was accomplished as per the treatment in the experiment. The weeds were removed from hand weeded plots twice at 15 and 45 DAS or once at 45 DAS in integration with herbicidal treatment as per treatment 3, respectively. Weedy check plots were kept weed infested condition until crop maturity.

2.4.8 Plant protection

There was no serious incidence of any major pest or disease during period of crop growth. However, as a preventive measure against leaf folder, pod borer attack, two applications of Endosulfan 35 EC at the rate of 2 litres/ha dissolved in 800 litres of water were applied at 65 DAS and at pod formation growth stage.

2.4.9 Harvesting

The crops were harvested at physiological maturity growth stage. Rice was harvested on 10th and 21st October in 2004 and 2005 respectively and pigeonpea on 20th and 28th March in 2005 and 2006 respectively. Firstly, the border rows were harvested and separated. Following border row harvest, crop from net plot was harvested and sun dried. The harvested material from each net plot was bundled, tagged and threshed separately.

2.4.10 Threshing, cleaning and weighing

The individual net plot's harvested crop bundles were weighed after drying prior to threshing. The grain yield was recorded separately after threshing, winnowing and cleaning. The straw/stalk yield was calculated by subtracting grain yield from the bundle weight and was converted to t/ha based on net plot size harvest.

2.5 Observation

The following observations were taken during the study periods which are described below:

2.5.1 Studies on pigeonpea and rice

2.5.1.1 Shoot dry matter/ plant or/meter row(g)

The five pigeonpea plants randomly selected from the sample row were cut carefully at the ground surface and then sun dried. After sun drying, plant samples were collected in paper bags after being cut into smaller pieces and placed in an electric oven at 70 ^{0}C for drying to obtain a constant dry weight. The dry weight of the samples then obtained was expressed in g/plant. For dry matter production by rice, all plant samples from 0.50 meter running row length were selected from the sampling rows (leaving aside one border row from the each side) at harvest. The plants were cut at the collar region. The collected sample tillers were oven dried at 60 ^{0}C for 48 hours and weighted. The weight of sample tillers thus obtained was converted into g/ running meter by multiplying with conversion factor.

2.5.1.2 Grain yield (t/ha)

The harvested crop from each net plot was threshed separately. After proper cleaning and drying, grain yield was recorded in kg/plot and finally converted into t/ha by multiplying with conversion factor.

2.5.1.3 Stalk/straw yield (t/ha)

Stalk/straw yield for each net plot was calculated by subtracting the grain yield from total biological yield and finally expressed in terms of t/ha.

2.5.2 Weed assessment

Weeds were collected from each individual plot during each year of the investigation for identification. Weed samples were collected by placing a quadrate (0.50 m x 0.50 m) randomly at two places in each plot at 60 DAS.

2.5.2.1 Weed population

Species wise weed counts were recorded at 60 DAS of crops from the two randomly place quadrates of 0.50 m x 0.50 m (0.25 m^2) in each net plot. Thus, weed population/m^2 was calculated from total number of all weed species of two quadrates multiplied with conversion factor.

2.5.2.2 Weed dry matter production/m^2 (g)

Weed enclosed in a quadrate of 0.25 m^2 (0.50 m x 0.50 m) were removed from the sampling rows at 60 DAS. After sun drying the samples were placed in an oven at 60 ^{0}C for 48 hours. The dry weight was multiplied with conversion factor to express in g/m^2.

2.5.2.3 Weed control efficiency (%)

Weed control efficiency (WCE) was calculated at 60 DAS using the formula USDA/ICAR (AICRPWC, 1994).

$$WCE=\frac{DMC\text{-}DMT}{DMC}X\ 100$$

Where,
DMC= Dry matter production of weeds/m^2 in weedy check.
DMT= Dry matter production of weeds/m^2 in the treatment to be compared.
WCE has been expressed in percentage.

2.6 Chemical analysis of crops and weeds

The plant samples from crops (pigeonpea and rice) and weed flora collected within each treatment at crop harvest and thus the maximum growth stage of weeds (60 DAS), respectively were washed with tap water followed by 0.1N HCl, distilled water and then with double distilled water. Plants were first dried under shade then in hot air oven at 60 ^{0}C for 48 hours. After recording oven dry weight, plant samples were individually grinded in Willey' Mill and stored in butter paper covers. The powder of plant samples was analysed for nitrogen, phosphorus and potassium as per the methods described in Table 2.

Element	Method employed
Total nitrogen	Modified Kjeldahl method (Jackson,1973)
Total phosphorus	Vanadomolybdo phosphoric yellow colorimetric method (Jackson,1973)
Total potassium	Flame photometric method (Jackson,1973)

Table 2. Methods used for determination of chemical composition of crops and weeds

2.6.1 Nutrient uptake (kg/ha)

Nutrient content (N,P and K) in grain and stalk/straw of each crop and in entire weed complex were analysed separately using procedure given in Table 2. Nutrient uptake by grain and straw of crops and that of by weeds were calculated in kg/ha by multiplying the corresponding dry matter and nutrient content (Black, 1967).

2.7 Pigeonpea grain equivalent yield (kg/ha)

Pigeonpea grain equivalent yield (PGEY) was calculated as follows:

$$PGEY=\sum_{i=1}^{n}(Yi.ei)$$

Where,
Yi= Grain yield i^{th} component
ei= equivalent price of i^{th} component
PGEY has been expressed in tonne/hectare

2.8 Statistical analysis

The data pertaining to each of the treatments and interactions were analyzed statistically by applying the procedure as described by Gomez and Gomez (1984).

3. Results and discussion

3.1 Weeds

The weed flora of the experimental field included: Jungle rice [*Echinochloa colona* (L.) Link.], barnyard grass [*Echinochloa crusgalli* (L.) Beauv.], bermuda grass [*Cynodon dactylon* (L.) Pers], goose grass [*Eleusine indica* (L.) Gaerth.], crab grass [*Digitaria sanguinalis*(L.) Scop.], crowfoot grass [*Dactyloctenium aegypticum* (L.) P. Beauv.], purple nutsedge *(Cyperus rotundus* Linn.), variable flatsedge (*Cyperus difformis* Linn.), ricefield flatsedge (*Cyperus iria* Linn.), grass-like fimbry [*Fimbristylis miliacea* (L.) Vahl.], goat weed (*Ageratum conyzoides* L.), dayflower (*Commelina benghalensis* Linn.), climbing dayflower (*Commelina diffusa* L.), hairy spurge (*Euphorbia hirta* Linn.), asian spiderflower (*Cleome viscosa* L.), wild carrot weed (*Parthenium hysterophorus* L.), pink node flower (*Caesulia axillaris* Roxb.), silver cock's comb (*Celosia argentea* L.), gale of the wind (*Phyllanthus niruri* Linn.), false daisy [*Eclipta alba*(L.) Hassk.] and wild jute (*Corchorus acutengulus* lamk).

Application of 25 kg N/ha in pigeonpea increased weed population and their dry weight/m^2 as compared to control (Table 3). Analysis further reveals that weed density and dry weight/m^2 increased with increasing levels of nitrogen to rice up to 100 kg N/ha (Table 3). This likely due to weeds utilizing a greater quantity of applied and available nutrients. Thus, higher dose of nitrogen accelerated weed emergence and growth. Weed control efficiency increased with increasing nitrogen levels for pigeonpea and rice. Similar findings were also reported by Pujari et al. (1989) and Yadav and Singh (2009).

Data presented in Table 3 also indicates that two hand weeding at 15 and 45 DAS resulted in the lowest density and dry weight of weeds/m^2 followed by pendimethalin + one hand weeding at 45 DAS; both treatments were superior over other weed management treatments. This result was likely owing to better indiscriminate control of all types of weeds by hand weeding. These findings were in close agreement with those of Shetty and Krantz (1976), Ampong-Nyarko and De Datta(1993) and Reddy et al. (2007). Reflecting minimum density and dry weight results, maximum weed control efficiency was obtained with two hand weeding at 15 and 45 DAS. This finding is in agreement with finding of Sinha et al. (1989a and b), Goyal et al. (1991), Parthi et al. (1991), Mahapatra (1991), Prasad and Srivastava (1991), Maheswarappa and Nanjappa (1994), Rafey and Prasad (1995), Patil and Pandey (1996), Mishra et al. (1998), Singh et al. (1998c), Singh et al. (1999), Rana and Pal (1999), Rana et al. (1999), Manickam et al. (2000), Reddy et al. (2007) and Singh (2007).

3.2 Growth, yields and pigeonpea grain equivalent yield

Dry matter production, grain and straw yield of pigeonpea and rice, and pigeonpea grain equivalent yield were increased with application of 25 kg N/ha to pigeonpea over control (Table 3 and 4). Similar findings have been reported earlier by Singh et al. (1978), Bhandhari et al. (1989), Chittapur et al. (1994), Patel and Patel (1994), Singh et al.(1998a and b), Mandal et al. (1999) and Singh (2006b). Dry matter production, grain and straw yield of rice were increased significantly up to 75 kg N/ha applied to rice (Table 3 and 4). The improvement in the dry matter production and yields of rice might be attributed to the adequate supply of photosynthate to sink under sufficient supply of nitrogen. These results were supported by the findings of Samui et al. (1979), Reddy et al. (1986), Abdulsalam and Subramaniam (1988), Purushotham et al. (1988), Raju et al. (1990), Dubey et al. (1991), Bhattacharya and Singh

(1992), Mazid et al. (1998), Panda et al. (1999) and Bindra et al. (2000). Many researchers also reported that cereal component in legumes based intercropping yielded more at higher levels of nitrogen application (Reddy et al. 1980; Ramesh and Surve 1984; Ofori and Stern 1986; Ezumah et al. 1987; Rao et al. 1987; Kaushik and Gautam 1987; Chowdhury and Rosario 1992; Rafey and Prasad 1992; Bhagat and Dhar 1995; Kushwaha and Chandel 1997; Mandal et al. 2000; Sarwagi and Tripathi 1999; Shivay et al. 1999; Shivay and Singh 2000; Singh, 2006b). Whereas, same were failed to show its effect on pigeonpea (Table 3 and 4). This might be due to the fact that localized placement of nitrogen made was first available to that crop for which it was applied. Forage area of pigeonpea at initial growth stage (50 DAS) was slow due their slow growth habit. Contrary to this, forage area of short duration rice was higher due to faster initial growth rate and planting in furrow between ridges, likely taking most of applied nitrogen easily by themselves in comparison to pigeonpea. Mahapatra et al. (1990) and Singh (2006b) were also find the similar result.

Treatment	Pigeonpea dry matter/ plant at harvest (g)	Rice dry matter /m row at harvest (g)	Weed number /m^2	Weed dry weight /m^2(g)	Weed control efficiency (%)
N level in Pigeonpea(kg/ha)					
0	151.4	187.3	256.9	193.9	76.4
25	168.0	209.9	286.7	225.0	77.9
CD(*P*=0.05)	7.6	11.9	13.9	10.9	0.5
N level in Rice(kg/ha)					
50	156.1	175.2	256.3	194.7	76.6
75	160.5	204.0	274.4	211.7	77.5
100	162.6	216.7	284.7	222.1	77.5
CD(*P*=0.05)	NS	14.6	17.0	13.4	0.6
Weed Management					
Weedy check	136.1	60.4	545.0	498.8	-
Pendimethalin@ 1kg / ha	159.0	178.6	266.1	205.2	58.7
Pendimethalin@ 1kg / ha +one hand weeding at 45 DAS	171.0	255.1	161.7	79.7	83.9
Two hand weedings at 15 and 45 DAS	172.9	300.4	114.3	54.3	89.0
CD(*P*=0.05)	3.2	6.5	8.0	7.7	0.3

Table 3. Effect of nitrogen levels and weed management practices on crop growth and weed and weed control efficiency under pigeon pea + rice intercropping system (mean of two years)

Treatment	Pigeonpea		Rice		Pigeonpea grain equivalent yield (t/ha)
	Grain yield (t/ha)	Stalk yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)	
N level in Pigeonpea(kg/ha)					
0	1.9	6.3	0.7	1.2	2.1
25	2.3	7.0	0.8	1.4	2.5
CD(*P*=0.05)	0.2	0.5	0.1	0.1	0.17
N level in Rice(kg/ha)					
50	2.0	6.4	0.7	1.2	2.2
75	2.1	6.7	0.8	1.3	2.3
100	2.1	6.9	0.8	1.4	2.4
CD(*P*=0.05)	NS	NS	0.1	0.1	0.21
Weed Management					
Weedy check	1.5	6.0	0.2	0.4	1.6
Pendimethalin@ 1kg / ha	2.0	6.6	0.7	1.2	2.2
Pendimethalin@ 1kg / ha +one hand weeding at 45 DAS	2.3	7.0	1.0	1.6	2.6
Two hand weeding at 15 and 45 DAS	2.4	7.1	1.2	1.9	2.7
CD(*P*=0.05)	0.1	0.2	0.1	0.1	0.07

Table 4. Effect of nitrogen levels and weed management practices on yields under pigeon pea +rice intercropping system (mean of two years). DAS: days after sowing

Among weed management practices, two sequential hand weeding recorded maximum dry matter accumulation and yields of pigeonpea and rice and minimum weed density and dry weight which was followed by pendimethalin + one hand weeding at 45 DAS (Table 3 and 4). This was likely owing to minimum weed competition for water, nutrient and space etc. (Fig. 1). Similar observations were seen by Dwivedi et al. (1991), Mahapatra (1991), Parthi et al. (1991), Dahama et al. (1992), Varshney (1993), Rafey and Prasad (1995), Mahalle (1996), Patil and Pandey (1996), Mishra et al. (1998), Rana and Pal (1999), Rana et al. (1999) and Reddy et al. (2007). The minimum yields were attained in the weedy check. This was again likely owing to higher weed competition for water, nutrient and space etc. (Fig. 1). Similar results were also reported by Ghobrial (1981), Dwivedi et al. (1991), Mahapatra (1991), Rafey and Prasad (1995) and Chandra Pal et al. (2000).

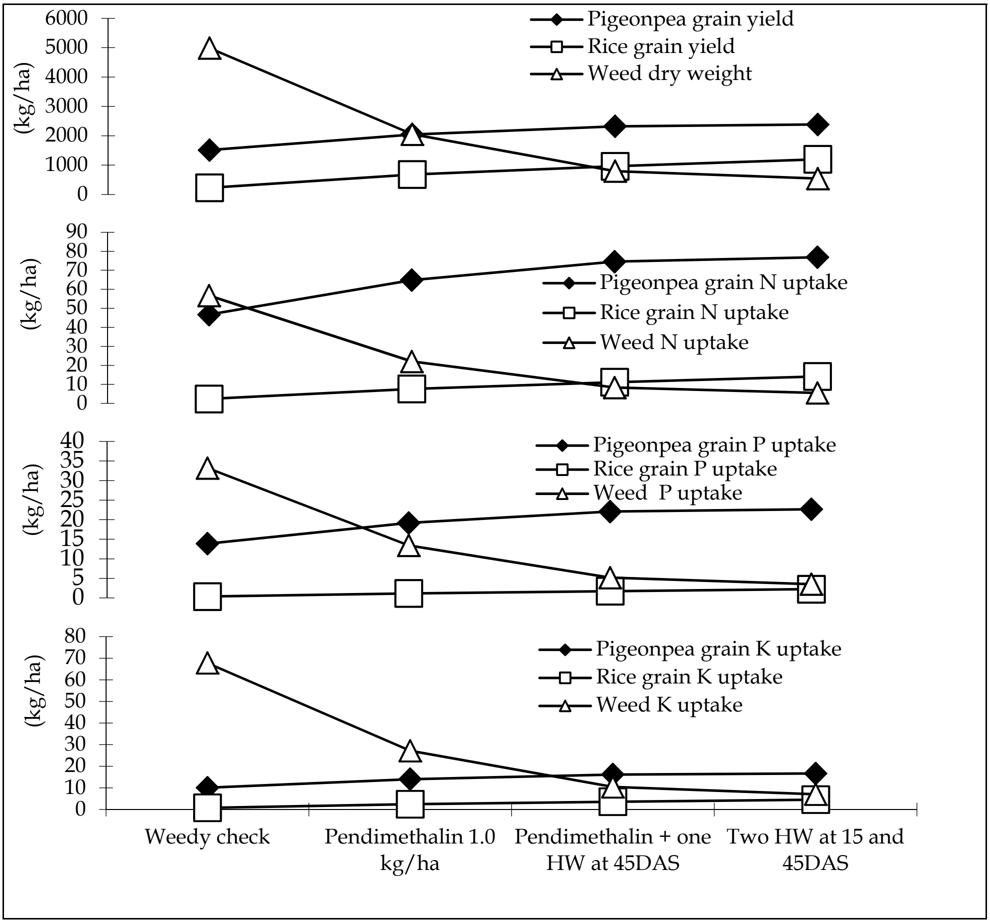

Fig. 1. Effect of weed management practices on weed dry weight, crop yield and nutrient uptake under pigeon pea + rice intercropping system (mean of two years).

3.3 Nutrient uptake

Application of 25 kg N/ha to pigeonpea increased NPK uptake by grain as well by stalk/straw of pigeonpea and rice over the control. Weed NPK uptake were also higher with 25 kg N/ha applied to pigeonpea. NPK uptake by rice grain and straw increased significantly with each successive increase in nitrogen level applied to them up to 75 kg N/ha (Table 5). Nitrogen levels applied to rice also increased weed NPK uptake up to 100 kg/ha. This is likely due to the optimum nitrogen application and ultimately resulted in subsequent uptake of other nutrients (phosphorus and potassium) due to increased growth. The maximum nutrient uptake under higher nitrogen dose might be due to better root establishment and thus enhanced translocation of absorbed nutrients from soil to plant ultimately resulting in higher growth and yield. Singh (2006b) and Yadav and Singh (2009) also observed similar results.

Among the weed management practices, two sequential hand weeding recorded higher NPK uptake by grain and straw of pigeonpea and rice and this treatment was followed by with pendimethalin + one hand weeding at 45 DAS (Table 5). Contrary to this, minimum NPK removals by weed were associated with these treatment and maximum with weedy check (Table 5). This might be due to applied inputs assimilated efficiently by weeds under weedy condition and by crops under weed free condition (Table 5 and Fig. 1). These results are in agreement with findings of Singh et al. (1980), Singh and Singh (1985), Sinha et al.(1989a and b), Goyal et al. (1991), Maheswarappa and Nanjappa (1994), Singh et al. (1998c) and Singh (2007).

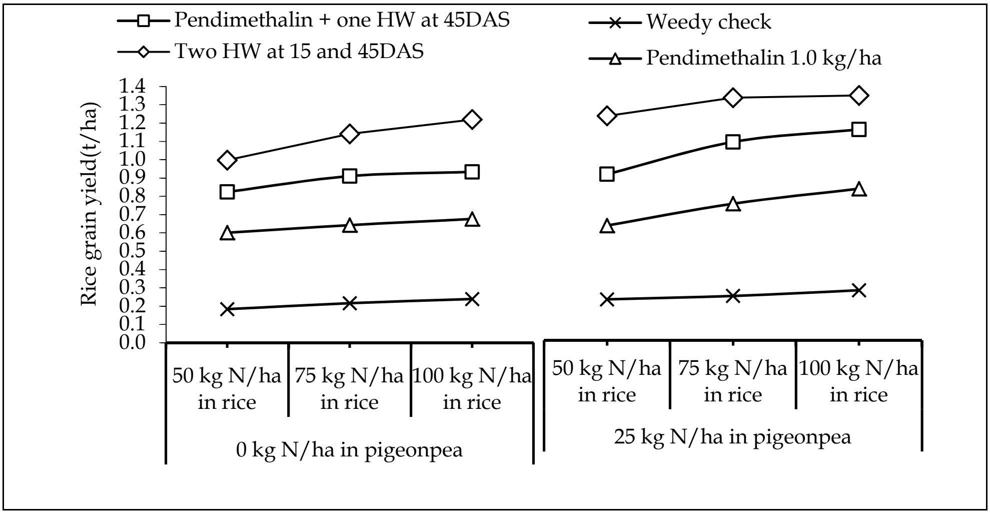

Fig. 2. Interaction effect of nitrogen levels and weed management practices on rice grain yield underpigeon pea + rice intercropping system (mean of two years).

3.4 Interaction effect

Interaction effect of nitrogen levels in pigeonpea and rice and weed management practices was significant in respect to grain yield of rice (Fig. 2). Grain yield of rice increased with increasing level of nitrogen applied to rice up to 100 kg N/ha with or without 25 kg N/ha applied to pigeonpea in combination with all weed management treatments except weedy check where all nitrogen level failed to show any significant increase in grain yield of rice. This might be due to fact that rice grew better even with lower nitrogen addition where weeds were controlled than weedy check. In case of weedy check, weeds were dominant competitor to applied nitrogen over crop. Soundara and Mahapatra (1978) found that the maximum grain yield of direct seeded rice with application of 100 kg N/ha along with two sequential hand weedings where weeds effectively controlled. Sharma (1997) observed that grain yield of rice increased significantly with N application up to 60 kg/ha when weeds were controlled. He also observed that grain yield of rice remained unaffected with N application under weedy conditions due to severe competition.

Treatment	Nitrogen uptake(kg/ha)					Phosphorus uptake(kg/ha)					Potassium uptake(kg/ha)				
	Pigeonpea		Rice		W	Pigeonpea		Rice		W	Pigeonpea		Rice		W
	G	S	G	S		G	S	G	S		G	S	G	S	
N level in Pigeonpea(kg/ha)															
0	58.4	43.3	8.1	5.2	21.1	17.4	7.0	1.3	1.4	12.2	12.7	57.6	2.6	18.1	25.6
25	73.1	49.8	9.5	5.8	25.2	21.5	8.0	1.5	1.6	15.4	15.8	65.2	3.1	20.4	30.7
C.D.(*P*=0.05)	6.2	5.0	0.5	0.3	2.0	1.7	1.0	0.1	0.2	1.1	1.5	6.0	0.3	1.9	2.3
N level in Rice(kg/ha)															
50	63.0	44.1	7.8	5.0	21.2	18.7	7.0	1.2	1.4	12.5	13.7	58.1	2.5	17.6	25.8
75	66.3	46.9	9.0	5.6	23.3	19.6	7.6	1.4	1.6	13.9	14.4	62.0	2.9	19.6	28.5
100	67.9	48.7	9.7	5.9	24.9	20.0	7.9	1.5	1.7	15.1	14.7	64.0	3.1	20.7	30.1
C.D.(*P*=0.05)	NS	NS	0.6	0.4	2.4	NS	NS	0.2	0.2	1.4	NS	NS	0.4	2.4	2.8
Weed Management															
Weedy check	46.7	39.6	2.3	1.7	56.7	13.9	5.8	0.4	0.4	33.2	10.1	53.1	0.8	6.1	67.8
Pendimethalin@ 1kg / ha	64.8	46.1	7.6	5.0	22.0	19.2	7.4	1.1	1.4	13.4	14.0	60.8	2.5	18.0	27.2
Pendimethalin@ 1kg / ha +one hand weeding at 45 DAS	74.6	49.8	11.2	6.9	8.3	22.1	8.3	1.7	1.9	5.2	16.2	65.2	3.6	23.9	10.5
Two hand weeding at 15 and 45 DAS	76.9	50.8	14.2	8.5	5.5	22.7	8.4	2.2	2.4	3.5	16.7	66.4	4.6	29.1	7.0
C.D.(*P*=0.05)	2.6	2.1	0.3	0.2	1.5	0.7	0.4	0.1	0.1	0.8	0.6	2.6	0.2	1.0	1.7

Table 5. Effect of nitrogen levels and weed management practices on nutrient uptake by component crops and weed under pigeon pea +rice intercropping system (mean of two years).G: Grain, S: Straw/Stalk, W: Weed, DAS: days after sowing

Interaction effect of nitrogen levels in pigeonpea and weed management practices was significant in respect to grain yield and grain nutrient uptake by pigeonpea (Fig. 3). Application of 25 kg N/ha to pigeonpea under two hand weeded plots resulted in maximum yield and nutrient uptake by pigeonpea and this treatment was similar to application of 25 kg N/ha to pigeonpea with pendimethalin + one hand weeding at 45 DAS. Further, there was minimum removal of NPK by weeds (Fig. 6) in this treatment which was ultimately utilized by the crop and promoted its growth and yield. All weed management practices along with no nitrogen application in pigeonpea gave higher pigeonpea grain yield and nutrient uptake over the weedy check along with application of 25 kg N/ha in pigeonpea. This might be due pigeonpea growing better even without nitrogen addition where weeds were controlled. In case of weedy check, weeds were dominant competitor to applied nitrogen over crop.

Interaction effect of nitrogen levels in pigeonpea and weed management practices was significant in respect to pigeonpea grain equivalent yield, rice grain yield and rice grain nutrient uptake (Fig. 4). Application of 25 kg N/ha to pigeonpea following two sequential hand weedings gave maximum pigeonpea grain equivalent yield, rice grain yield and rice grain nutrient uptake and minimum yield and nutrient uptake resulting from no nitrogen application under weedy condition. These results agree with findings of Soundara and Mahapatra (1978) and Sharma (1997). The significant increase in pigeonpea grain equivalent yield, rice grain yield and rice grain N, P and K uptake with N application were observed only in weed controlled plots (Fig. 4). This might be due to rice compete strongly with pigeonpea for nitrogen in absence of weeds when first at its log phase and second at its lag phase of growth.

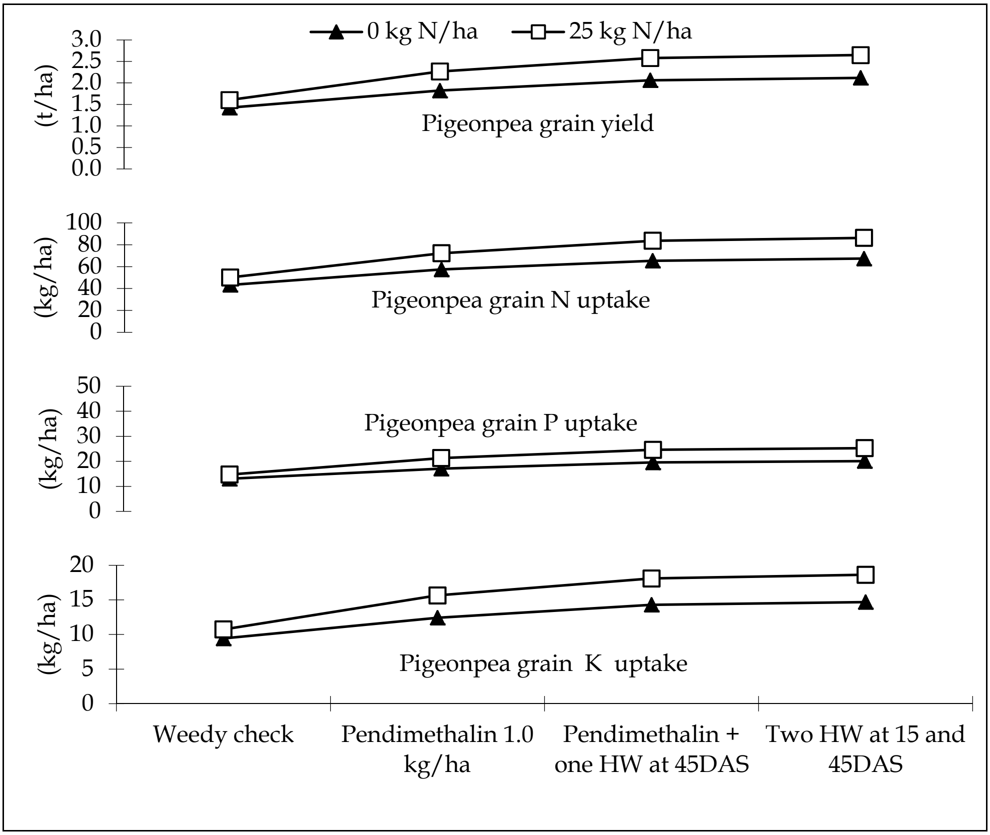

Fig. 3. Interaction effect of nitrogen levels in pigeonpea and weed management practices on pigeopea grain yield and pigeopea grain nutrient uptake under pigeon pea + rice intercropping system (mean of two years).

Interaction effect of nitrogen levels in rice and weed management practices was significant in respect to grain yield and grain nutrient uptake by rice (Fig. 5). Application of 100 kg

N/ha to rice under two hand weeded plots resulted in maximum grain yield and grain nutrient uptake by rice which was similar to the application of 75 kg N/ha under two sequential hand weeded plots and superior than rest of the other treatment combination (Fig. 5). All weed management practices in combination with 50 kg N/ha applied in rice produced higher grain yield and NPK uptake by rice over weedy check in combination with 100 kg N applied in rice. This might be due to crop plants utilizing nitrogen more efficiently even at lower level of nitrogen (50 kg/ha) in absence of weeds than higher level of nitrogen (100 kg/ha) in presence of weeds because most of which was utilized by weeds. Similar results were also reported by Sharma (1997).

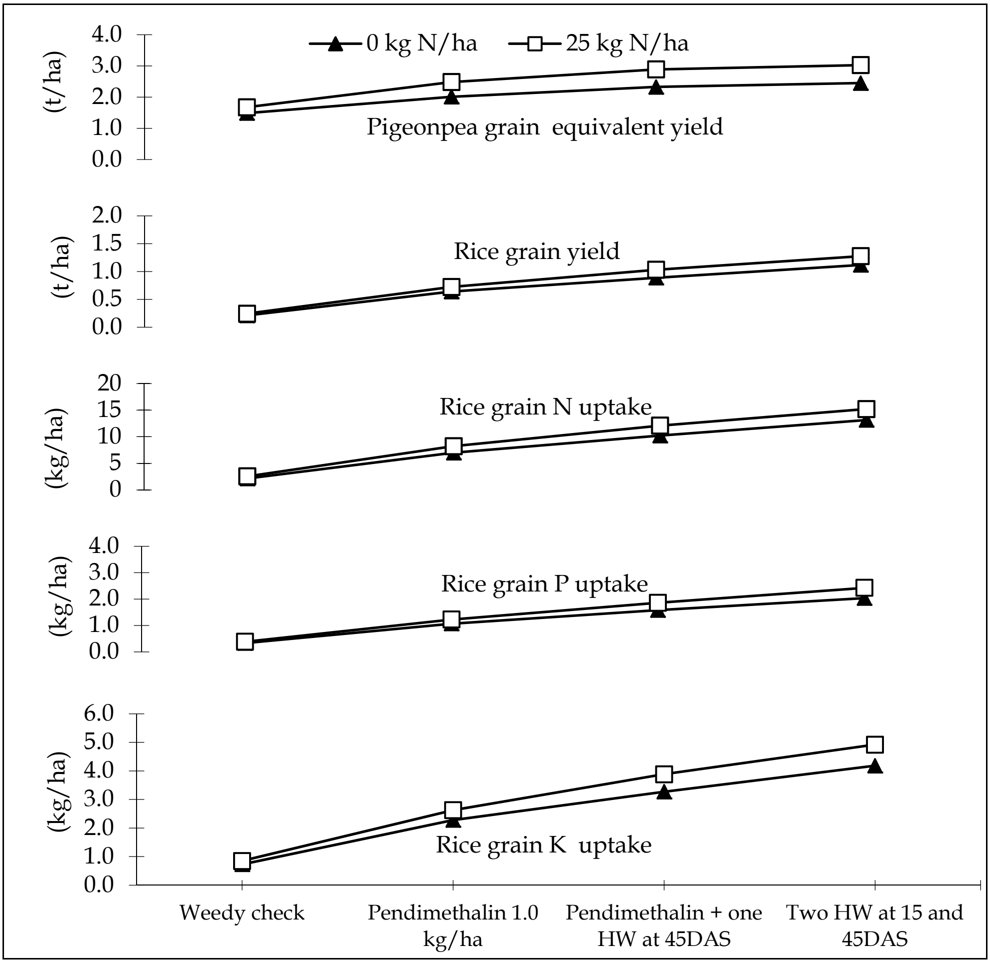

Fig. 4. Interaction effect of nitrogen levels in pigeonpea and weed management practices on pigeonpea grain equivalent yield, rice grain yield and rice grain nutrient uptake under pigeon pea + rice intercropping system (mean of two years).

Interaction effect of nitrogen levels in pigeonpea and weed management practices was significant in respect to weed dry weight and weed nutrient uptake (Fig. 6). The weed dry weight and weed nutrient uptake were recorded lower with or without application of 25 kg N/ha to pigeonpea under weed controlled plots than with or without application of 25 kg N/ha to pigeonpea under weedy check. Whereas, application of 25 kg N/ha to pigeonpea increased the weed dry weight and weed nutrient uptake only under weedy check. This due to one would exert severe competition on another under their dominance.

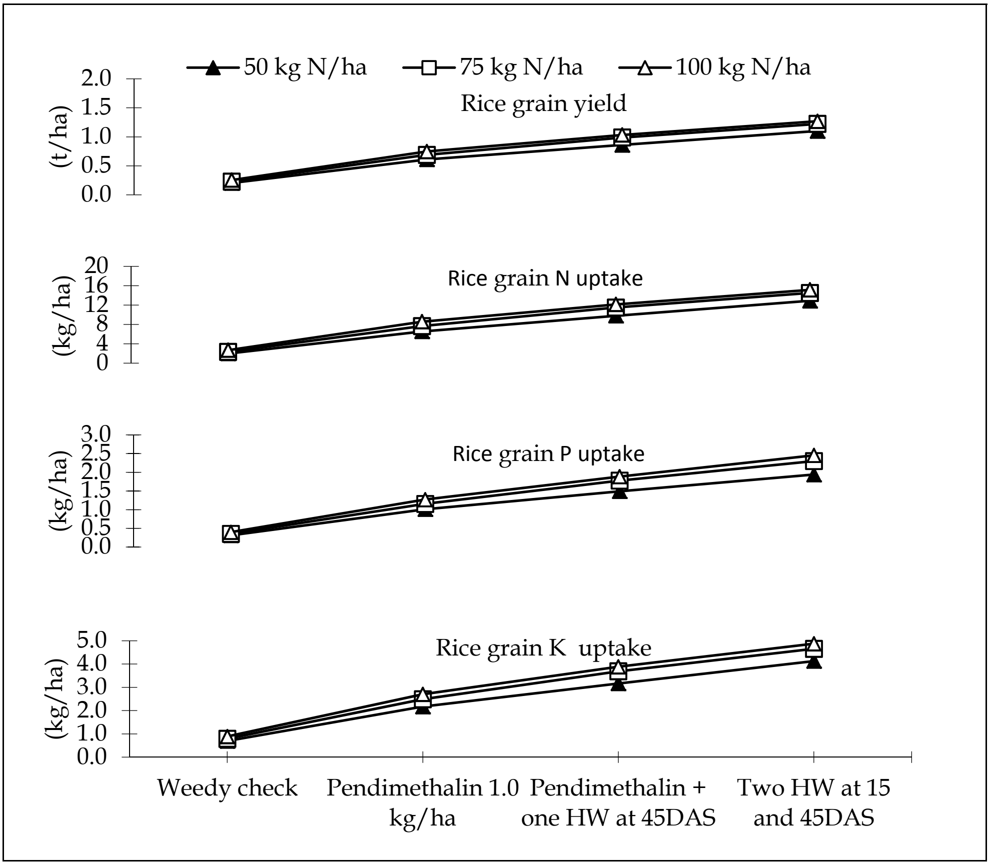

Fig. 5. Interaction effect of nitrogen levels in rice and weed management practices on rice grain yield and rice grain nutrient uptake under pigeon pea + rice intercropping system (mean of two years).

Interaction effect of nitrogen levels in rice and weed management practices was significant in respect to weed dry weight and weed nutrient uptake (Fig. 7). All weed management practices recorded lower nutrient removal by weeds irrespective of nitrogen levels applied in rice over weedy check which had maximum nutrient removal by weeds. This might be due to lower weed density and their dry weight in weed free condition ultimately resulting in lower NPK removal by weeds. Varying nitrogen levels applied in rice either along with two hand weeding at 15 and 45 DAS or pendimethalin + one hand weeding at 45 DAS did not cause any significant variation in NPK removal by weeds. Maximum weed dry weight and weed nutrient uptake were recorded with application of 100 kg N/ha to rice under the weedy check (Fig. 7). This might be due to weeds utilizing more inputs than crop plant under severe competition.

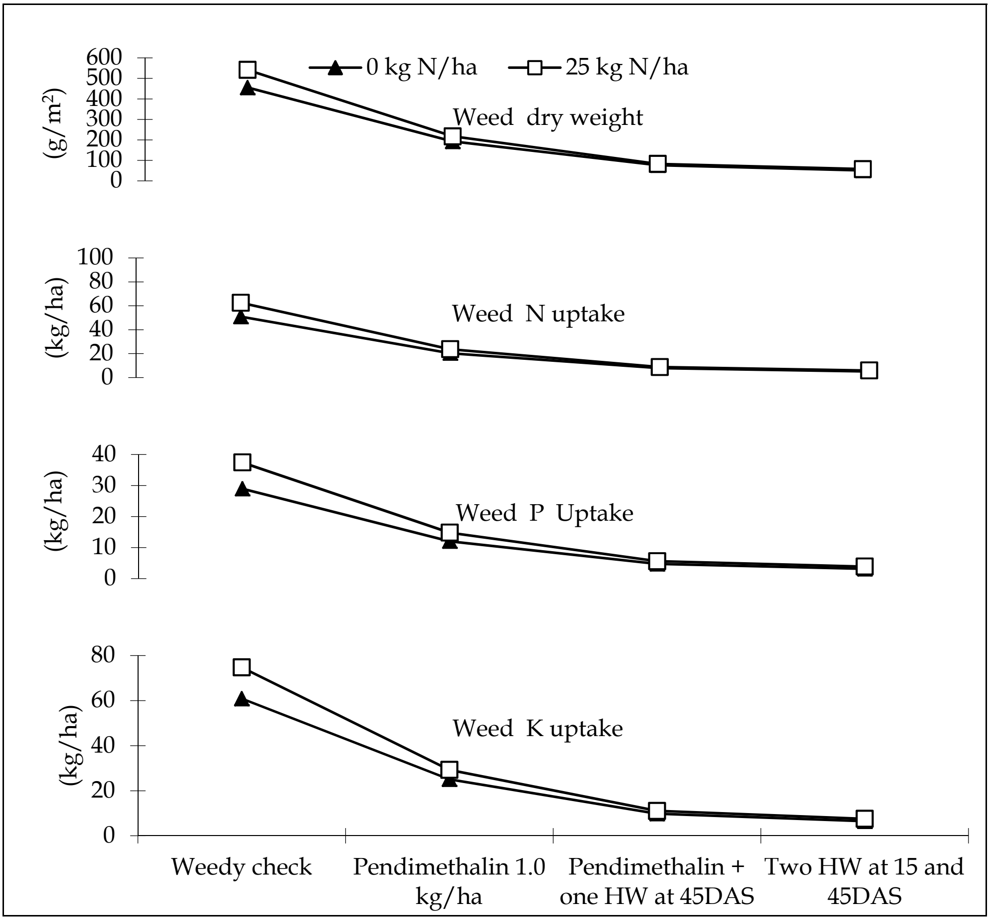

Fig. 6. Interaction effect of nitrogen levels in pigeonpea and weed management practices on weed dry weight and weed nutrient uptake under pigeon pea + rice intercropping system (mean of two years).

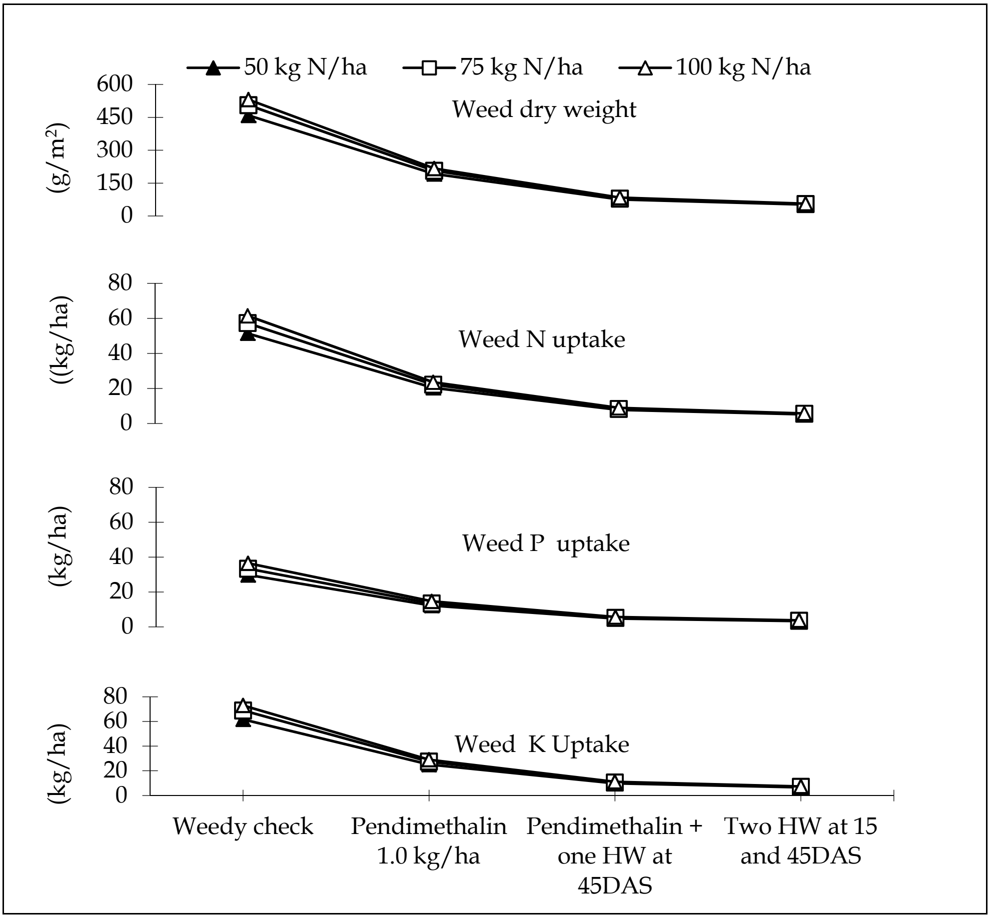

Fig. 7. Interaction effect of nitrogen levels in pigeonpea and weed management practices on weed nutrient uptake under pigeon pea + rice intercropping system (mean of two years)

4. Conclusion

Pigeonpea and rice could be fertilized with 25 kg N/ha and 75 kg N/ha, respectively, in an intercropping system integrated with two sequential hand weeding at 15 and 45 DAS for higher growth, yield and nutrient uptake by the crops. The next most effective treatment was application of 25 kg N/ha to pigeonpea and 75 kg N/ha to rice in the intercropping system integrated with a pre emergence application of pendimethalin at the rate of 1.0 kg/ha followed by one hand weeding at 45 DAS.

5. Future research

Studies are required to investigate the effect of rice cultivars, nitrogen levels under weeded and weedy condition in a pigeonpea+ rice intercropping system.

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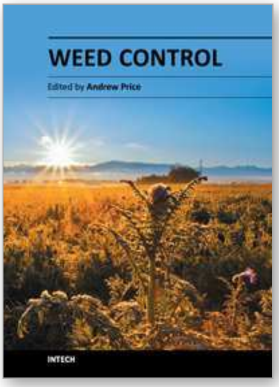

Weed Control

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Crop loss due to weeds has challenged agricultural managers since man began to develop the first farming systems. In the past century, however, much progress has been made to reduce weed interference in crop settings through effective yet mostly non-sustainable weed control strategies. With the commercial introduction of herbicides during the mid-1900's, advancements in chemical weed control tactics have provided efficient suppression of a broad range of weed species for most agricultural practices. Currently, with the necessity to design effective sustainable weed management systems, research has been pushing new frontiers on investigating integrated weed management options including chemical, mechanical as well as cultural practices. Author contributions to Weed Science present significant topics of research that examine a number of options that can be utilized to develop successful and sustainable weed management systems for many areas of crop production