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MIXED CROPPING EFFECTS ON GROWTH OF WHEAT (*TRITICUM AESTIVUM* L.) AND CHICKPEA (*CICER ARIETENUM* L.)

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Abstract

A pot experiment was conducted to study the effect of mixed cropping of wheat and chickpea on their growth and nodulation in chickpea. The plants were grown to maturity alone and in a mixture and data on different plant parameters collected after 2, 3, and 4 (maturity) months of seed sowing. When grown in mixture, wheat had an inhibitory effect on root proliferation, total biomass and grain yield of chickpea; the value of different parameters in mixture being one third of that determined when chickpea was grown as a sole crop. This inhibition was also reflected in the number of nodules per plant and was assumed to result at least partially from physiological malfunctioning of roots as reflected by a drastic and significant decrease ($p = 0.05$) in tissue water concentration. The inhibition intensified with time and severity of damage to chickpea roots maximized at maturity as suggested by a sharp decrease in root/shoot ratio. Interestingly, the weight of individual nodules was significantly better when chickpea was grown in mixture. Contrary to chickpea, biomass yield of wheat increased by >100% due to the companion crop. The improvement was observed in all the plant components except for 100-grain weight that showed a significant decrease ($p = 0.05$); harvest index and green-ness of flag leaf was not affected.

Introduction

Intercropping or simultaneous growing of two or more crops on the same piece of land (Ofori & Stern, 1987) has the potential of enhanced ecosystem productivity (Wiley 1979) *vis-à-vis* environment-friendly management of pests (Mitchell *et al*., 2002), nutrients (Jensen, 1996; Houggaard-Nielsen *et al*., 2001), weeds (Midmore, 1993), and produce quality (Anil *et al*., 1998). In a cereal-legume intercropping system, however, an increase in cereal and a decrease in legume intercrop yield is frequently reported (Houggaard-Nielsen & Jensen, 2001; Li *et al*., 2001). These changes are attributed to above- and below-ground interactions (Zhang & Li, 2003). Difference in the pattern and spatial extension of root growth is one of the important factors determining the relative success of the two crops that are grown together. Cereals generally have much greater rooting densities (Anil *et al*., 1998) making them more competitive with respect to uptake of nutrients from the rhizosphere (Houggaard-Nielsen *et al*., 2001). Besides the difference in rooting characteristics, the interference of one crop plant species with another when grown together (or in rotation) is also a common observation (Roth *et al*., 2000). These effects are attributed to allelochemicals especially phenolic compounds that are released from the actively growing as well as decaying plant residues (Kuk *et al*., 2001). However, above-ground productivity is generally taken as a measure of these interactions, while the root component has not been given due consideration.

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Many intercrop studies have dealt with the association of two annual crops (Ofori & Stern, 1987; Jensen, 1996; Houggaard-Nielsen *et al*., 2001). In Pakistan and several other countries, chickpea is frequently intercropped with wheat but hardly any reports are available on mutual effects of the two crop types on root proliferation. In a previous study (Gill *et al*., 2006), it was observed that chickpea (*Cicer arietenum* L.) and wheat (*Triticum aestivum* L.) grown as sole crops had widely different effects on some of the rhizospheric microbial functions particularly those related to the dynamics of N. It was hypothesized that in an intercrop, enhancement in nitrate reductase activity by wheat roots may facilitate nodulation and thus N_2 fixation in chickpea. Likewise, chickpea could support wheat growth through enhancing the availability of NO_3. Presently, the objective was to study the effect of intercropping on i) biomass yield and its distribution in different components of chickpea and wheat, ii) tissue water concentration of root and shoot portions, and iii) nodulation in chickpea.

Material and Methods

Soil used in the study was collected from the top 0-15 cm of an experimental field at the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan. Air-dried and sieved (<2mm) soil had the following characteristics: pH (1:1, soil:water suspension), 7.6; electrical conductivity, 0.8 d Sm^{-1}; organic carbon (C), 0.6%; total nitrogen (N), 0.09%; NH_4^+-N, 4.2 mg kg^{-1} soil; NO_3^--N, 11.9 mg kg^{-1} soil; sand, 30%; silt, 31%; clay, 39%; and water-holding capacity, 30%. Standard methods were followed for all analyses as described elsewhere (Lodhi *et al*., 2007). Organic C was determined using a modified wet oxidation method (Azam & Sajjad, 2005).

Six-kg portions of air-dried and sieved soil were filled in 27 plastic pots closed at the bottom and moistened to 15% (w/w) using a solution of KH_2PO_4 to obtain P and K addition rates of 25 and 31 mg kg^{-1} soil, respectively. Three sets of triplicate pots were sown to: i) wheat (*T. aestivum* L., CV WL-1076 that has been produced by crossing bread wheat with *Aegilops cylindrica* (Farooq *et al*., 1995), ii) chickpea (*C. arietenum* L., CV Punjab-2000), and iii) wheat + chickpea. In each case, 4 seeds were sown pot^{-1} and in case of intercropping 2 seeds of wheat and 2 of chickpea were sown pot^{-1}. Triplicate pots from each set of nine were harvested 8, 10 (boot stage of wheat), and 17 (maturity) weeks after seed sowing. At the first harvest data were collected on i) fresh and dry matter of root and shoot portions of the two plant types and ii) green-ness of wheat leaves using Minolta Green-ness meter. At the second harvest data were collected on i) fresh and dry matter of root and shoot portions of the two plant types and ii) number and weight of nodules. At maturity biomass distribution in root, straw, and grain portions was quantified and harvest index calculated.

Tissue water concentration (TWC; defined as the amount of water held per unit dry weight of root or shoot portions; g g^{-1}) was calculated from the fresh and dry weight of root and shoot portions at first and second harvest. For the determination of root biomass, plants were removed from the pots along with soil and the latter was removed by gentle hand tapping. Moisture content of the soil was determined by drying an aliquot at 65 ^{o}C. Roots plus remnants of soil were weighed (a), rinsed in pre-weighed water and the weight of soil determined (b). Difference of (a) and (b) was taken as fresh weight of roots. This exercise precluded the error that could arise if the roots were weighed following rinsing with water to remove the soil. Care was also taken to establish a similar level of soil moisture (15%, w/w) in all the pots at the time of harvesting the plants.

Standard deviation of means was calculated using MS Office Excel software, while significance of difference between means was determined by using the SAS statistical package (Anon., 1998).

Results

Table 1 presents the data on dry matter distribution in different plant components at harvest-I and harvest-II. The second harvest was taken after 10 weeks when tillering in wheat had attained stability and booting was initiated. At harvest-I that was taken after 8 weeks, wheat biomass was significantly higher ($p=0.05$) when grown as an intercrop; both the root and shoot components gathered 50% more biomass. Shoot portion showed a significantly higher positive effect of chickpea as compared to root portion. As a result, root/shoot ratio was significantly narrow compared to that of wheat grown as sole crop. At harvest-I, biomass of chickpea (4.8 g pot^{-1}) was several times lower than that of wheat (13.4 g pot^{-1}) when the two were grown as sole crop and did not show a significant effect of the companion wheat plants on either of the plant components; root/shoot ratio also remained unaffected. The edge of wheat plants over chickpea in gathering biomass significantly increased at harvest-II when total biomass of the former almost doubled (97% increase) due to the presence of chickpea as compared to sole cropping; root biomass was enhanced more than the shoot biomass (119 and 89%, respectively). Chickpea plants suffered greatly between harvest-I and II and their total biomass was reduced to almost half in the presence of wheat; root biomass being 0.7 and 2.4 g pot^{-1} in the presence and absence of wheat, respectively (Table 1 and Fig. 1), leading to a significant reduction in root/shoot ratio.

Tissue water concentration (TWC) was lower for the shoot as compared to root component in both the crops and at either of the harvests; average of all the 8 figures in a column being 4.4 and 6.2, respectively (Table 1). At harvest-I, TWC was significantly higher in both shoot and root portions of chickpea as compared to wheat when both were grown as sole crop. When grown together, wheat had a significant negative impact on TWC of both root and shoot portions of chickpea, while a small positive change was observed for wheat. At harvest-II, wheat had a more drastic effect on the TWC of chickpea roots that decreased from 9.7 (when grown solely) to 4.6 (when grown with wheat). At this stage, shoot portion of chickpea maintained higher TWC compared to wheat and was not affected by the latter.

Nodulation of chickpea studied at harvest-II was significantly affected by wheat. The number of nodules per pot decreased from 106 when grown solely to 88 in the presence of wheat whereas the weight of nodules increased significantly from 922 to 1545 mg pot^{-1} (Fig. 1). As a result, average weight of a nodule increased from 8.7 mg to 17.5 mg. Not only this, but the nodules formed a major proportion of the below-ground plant component i.e. 39.5% compared to only 3.6% when chickpea was grown in mixture and as a sole crop, respectively.

The benefit of chickpea to wheat increased significantly towards maturation (harvest-III) as the total biomass of the latter increased by 2.4 folds as compared to that of sole cropping; increase in straw, root, and grain components was 2.5, 2.1, and 2.4 folds, respectively (Table 2). However, the harvest index of wheat was not significantly affected by mixed cropping of chickpea. The number of wheat grains was 3 times higher in the presence than the absence of chickpea, while 100-grain weight showed some decrease. In chickpea, on the other hand, the number of grains was 31 and 15 when grown solely and in mixture, respectively. The most negatively affected part of chickpea was the root portion that showed about 9 times reduction due to presence of wheat plants in the vicinity. This immense inhibition/restriction of root proliferation could be the major cause of low performance of chickpea in the presence of wheat. In fact, root biomass of chickpea was lower at harvest-III as compared to that at harvest-II suggesting deterioration and hence lower recovery of intact roots during excavation from the soil.

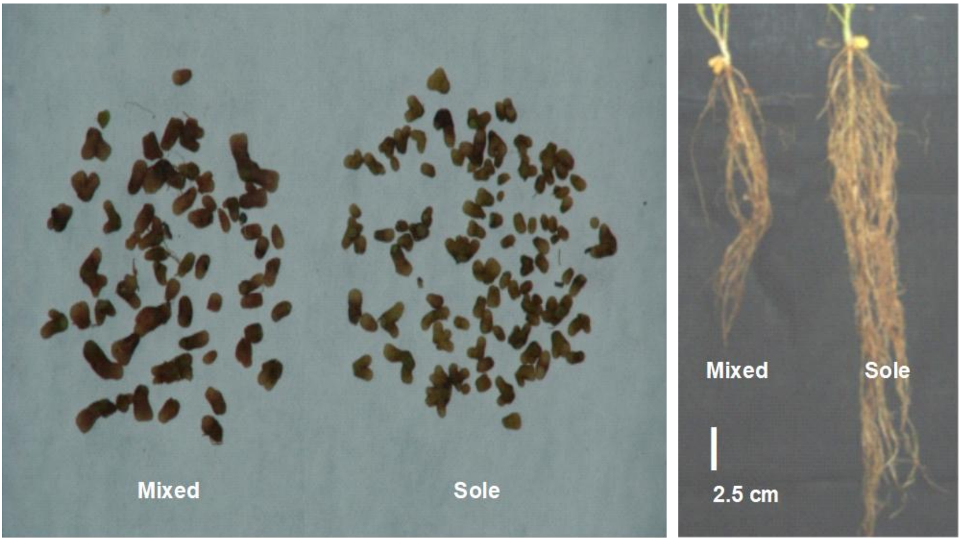

Fig. 1. Comparison of nodules and roots of chickpea grown as sole or mixed with wheat.

Discussion

In most studies dealing with intercropping of a legume with a non-legume, the yield of the former is reported to decrease in comparison to the sole crop, while the latter is benefited in several ways (Houggaard-Nielsen & Jensen, 2001; Li *et al*., 2001). Most of these studies have, however, dealt primarily with plants at the end of some competitive period and not with the dynamics of certain changes in plant growth parameters (Connolly *et al*., 1990; Turkington & Jolliffe, 1996). Weigelt & Jolliffe (2003) suggested that it may be worthwhile to obtain sequential harvests to track the changes in the two crops over a period of time. In the present study, therefore, 3 harvests were taken and over time significant changes in the growth patterns of the two crops were observed. Biomass yield of wheat (including grain yield) increased significantly in the presence of chickpea, the effect increased with the age of the plants and was the maximum at maturity (Table 1). Conversely, the biomass yield (including grain number and grain yield) of chickpea decreased drastically, especially towards maturity (Table 2) when its root growth was almost halted by wheat.

The increase in the yield of cereal is reported to result from inherently more proliferated root system and thus a higher volume of the soil being explored for nutrients *vis-à-vis* selective mobilization of nutrients like P by the legume, while that of the legume is inhibited by a more intense competition from the non-legume that has more extensive root system. It is seldom, however, that mutual effects on root growth are considered an important factor that could affect the ultimate growth/yield of the two companions although relatively extensive root system of the cereal is considered an advantage for more efficient exploration/uptake of nutrients (Anil *et al*., 1998). In the present study also, wheat roots were more prolific than those of chickpea whether the two were grown solely or as a mixture. In the latter case, however, root growth of wheat was more pronounced in the presence than the absence of chickpea. This enhancement could have possibly resulted from the enhanced availability of P in the chickpea rhizosphere and the competitive edge of wheat for P uptake *vis-à-vis* more proliferated root system. The suggestion is based on the reports that besides N-use complementarity (Anil *et al*., 1998; Jensen, 1996; Anderson *et al*., 2004), facilitated P nutrition of a non-legume by a legume is considered as one of the factors responsible for higher yield of the former when intercropped with the latter. A part of the benefit to wheat could have been derived from the release of N from fast degrading root system. Difference in root proliferation in the limited rooting environment of the experimental pots was well reflected in above-ground biomass.

An important observation in the present study was a progressive inhibition with time of root proliferation in chickpea by wheat that resulted in overall yield reductions and ultimately the grain yield. There are several physical (e.g., competition) and chemical mechanisms (e.g., allelopathy) by which certain plants inhibit the growth of neighbouring plants (Bezuidenhout & Laing, 2006). Inhibition of root growth in chickpea in the present study could possibly be due to the alleochemicals released directly from the wheat roots and/or resulting from microbial synthesis induced by root exudates. Such allelopathic effects on roots have been reported (Rizvi *et al*., 1992) and may vary in intensity from subtle to startling (Bezuidenhout & Laing, 2006) depending upon the nature of receiving plant and the physiological/metabolic processes that are influenced. Amongst several processes susceptible to allelopathic influences (Rice, 1984; Putnam & Tang, 1986), decrease in cell water potential could significantly hamper root growth and physiological activity. In the present study, the roots of chickpea plants studied after 8 and 10 weeks of growth showed a significant reduction is tissue water concentration due to the companion crop (Table 1). This observation is also in line with other reports that show reduced tissue water concentration in plants subjected to stresses like salinity and drought (Azam *et al*., 2006). Thus the chickpea plants grown in association with wheat were under some kind of stress; allelopathy being one of the possibilities. Interestingly, the tissue water concentration of wheat was not affected adversely by chickpea.

Although not studied, chickpea roots could have been physically damaged due to the allelochemicals of wheat origin making the cells leaky (greater partitioning of the photoassimilates into the rhizosphere) as well as interrupting the flow of water/nutrients into the roots and disturbing the normal physiological functioning of roots. The possibility of damage to chickpea roots by wheat and consequently higher flow of photosynthates towards roots was also supported by i) significant decrease in TWC of roots and ii) significant increase in the total weight pot^{-1} of nodules. Indeed, root damage is a prelude to nodulation that can also be induced by chemical means, more precisely the pseudonodulation caused by 2,4-D treatment of roots (Cocking *et al*., 1990; Akao *et al*., 1991; Azam 2002). Reduction in root proliferation did result in decreased number of nodules but the average weight of nodules was almost twice in the presence than the absence of wheat. Thus wheat roots would seem to enhance effective nodulation but reduce the competitiveness of chickpea through inhibition of root growth. Indeed, the proportion of biological fixed N in intercropped legume is reported to improve (Jensen, 1996).

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