

Intercropping Induce Changes in Above and Below Ground Plant Compartments in Mixed Cropping System

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ABSTRACT

Crops growing in a mixture is an ancient agricultural practice and usually been used for improving yield and growth of the crops and to fulfill the world fast growing population food demand. The two crops growing on same soil zone may be in direct competition to utilize the available resources because planting plants on same land using the same resources for normal growth. In intercropping system there may be facilitative and competitive interaction among the plants in both above and below ground plants compartments. The intension of intercropping is to utilize the use of physical, temporal and spatial resources both above and below ground plant compartments by maximizing the complementary interaction and minimizing the competitive ones. The changes and complex interaction both in upper and underground plant parts in inter-cropping system those adopted by local farmers in China are not yet fully understood. Information's from such studies are likely to provide knowledge about the complex interactions among two crops growing in a mixture. This study was therefore assessed to perceive how plants in mixture change the above below ground compartments and how they interact.

Introduction

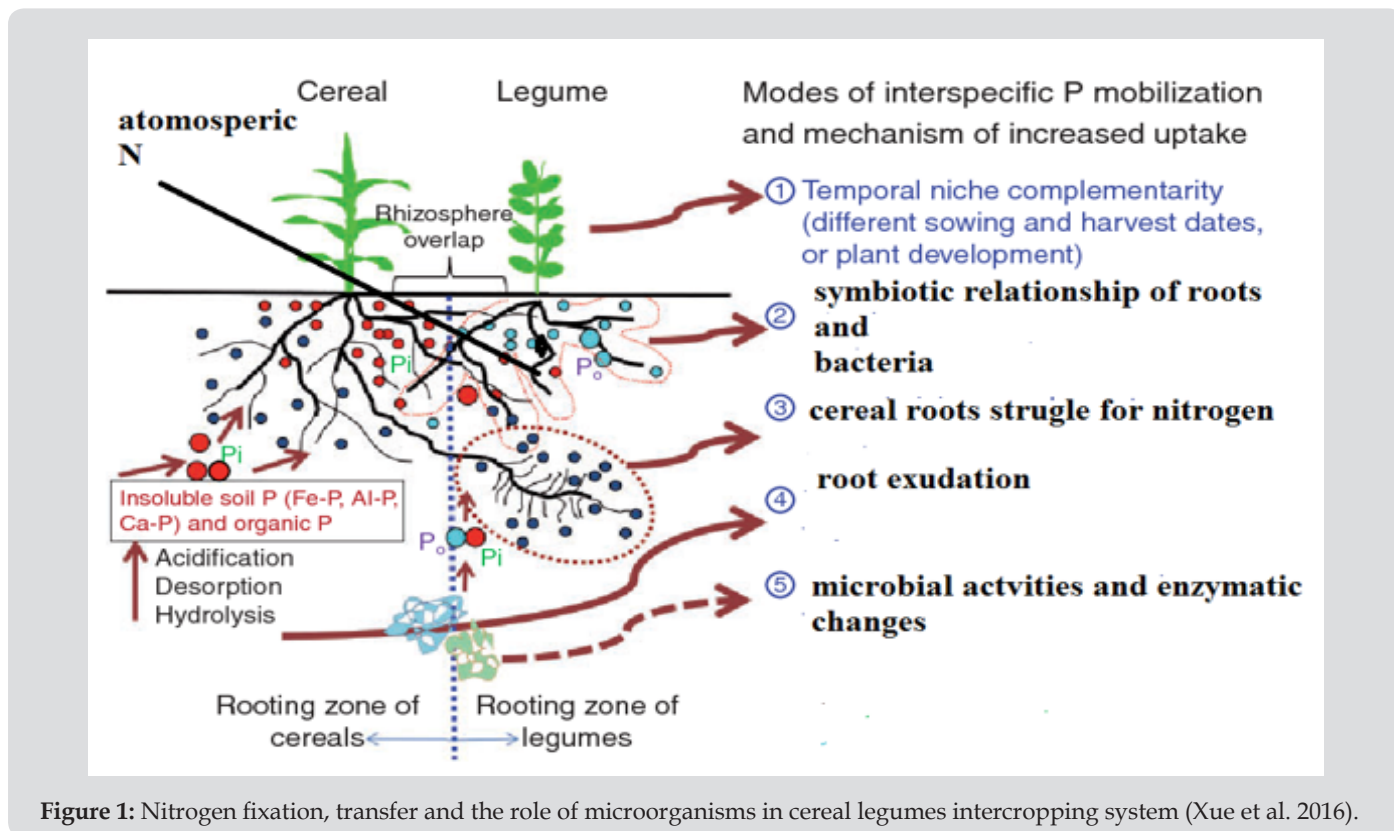
Intercropping is an old cropping system which dates back to ancient civilization and practice globally to achieve more yields and to satisfy the world food demand [1-6]. Mix cropping system not only enhance crop production and returns but can help safe the plants from complete failure as compare to mono-cropping [2]. The purpose of intercropping is to efficiently utilize the available plant growth resources like water [3], nutrients [4], and sun light and to minimize the competition and control weeds, disease and pest incidences [5]. The facilitations occurs both above and below ground plant compartments when plants using the same soil zone [7,8]. Cereal-legumes intercropping is common cropping system in which cereal get growth and yield advantages from legumes by sharing nutrients and some other unknown resources [1,9]. It

is well known that plants growing in mixture interact with each both positively and negatively in the above and below ground plant compartments. The above plants facilitative integrations are well investigated, however what's going inside in the below ground plants-soil and plant-plant in mix cropping system are still not clear [9-11]. Rhizospheric plant roots, soil and microbial interactions are beneficial to plant ecosystem. Rhizosphere root exudations process play a vital role in plant nutrition [12,13].

To date, the below ground interactions in intercropping and its effect on plant growth acquired a little attention [9-11]. To achieve greater yield, improve rhizospheric microbial conditions, soil quality betterment, resources utilization, soil nutrients recycling, proper management practices require in mixed cultures [14]. Though

cereals and legumes grown singly are highly investigated but few researches are available on the complex mixed cropping system specially on the below ground plant compartments (rhizosphere interactions), hence more studies are required to explore the fact about rhizospheric soil in intercropping [9]. The intention of growing plants in a mixture is to efficiently utilize facilitative (positive interactions) resources and curtail competitions both in the

above and underground plant compartments [15-22]. Insufficient literatures are available on the below ground mechanism involved in mixed cropping system those practiced by traditional farmers [9,11] because of its complexity in mixed cropping system rhizosphere. This study is therefore designed to collect information for understanding above and below ground interaction in crop mixtures (Figure 1).



Plant to Plant Interaction in Intercropping

Plants interact with each other in mixed cropping system for improving their growth and yield. However, little knowledge is available on plants interactions growing in mixture, particularly in cereal/legumes mixture [23]. For instance, the interspecific interactions both facilitative and competitive contribute to high yielding [23]. However, the below-ground root interactions are highly responsible for yield betterment [23]. In mixed cropping system, crops will be in direct competitions while capturing the same resources. Whereas, the differences can only occur in phenological characteristics which results in improving limited plant growth resources among plant species [15-20,22] and maximize plant productivity when compared to single culture [15,16,24-32]. Hence, legumes/cereal mixture interactions (facilitative & competitive) are complicated to examine [33-36] in utilization and modification of natural resources. Further research is required to address the interactions (above & below ground) in traditional cropping mixture.

Rhizospheric interaction in intercropping

In intercropping system both plant species use the same soil zone for root resources which is directly associated with growth performance [16,37-39]. Under such situations, root nutrient competitions frequently happen. Previously documented that the below ground activities in maize/cowpea mixture occur at a soil depth of 30-45cm and at more depth shows decreased densities [40]. As a result, significantly higher yield was recorded in maize crop than cowpea [26]. Apart from that side effect on plant yield, plant and soil were positively affected by mixed cropping root system, for example, increased the availability of carbon through C transformation [41,42], phenolics discharge, root exudates (phytosiderophores and carboxylic acids) in plant parts [12,13].

These elements are responsible for plant mineral nutrition. Additionally, several researches on low phosphorous soil have shown that plant roots (pigeon pea) use phytic, malonic and oxalic acid to solubilize iron, calcium, and Al-bound P [43]. Once phosphorous and iron are mobilized, they are readily available for plant

acquisition and available for microorganisms in an intercropping. Similarly buckwheat roots discharge oxalate as an Al-oxalate in Al toxic soil which change Aluminum to plants and microorganisms available form in mixed cropping [44]. Under such circumstances crop productiveness can be increased when grown in a mixture. Similar activities in underground plant parts are occur in all intercropping system use by all farmers. Although there has been

relatively little research on below ground activities in crop mixture so more studies are need to be established. So far the competition among plants for utilizing light and water resources has been studied earlier but research on nutrients competition in cropping mixture are rare [8-11]. Thus, more experiments are suggested to investigate more about the nutrient competitions between plants in cereal/legumes mixture (Figure 2).

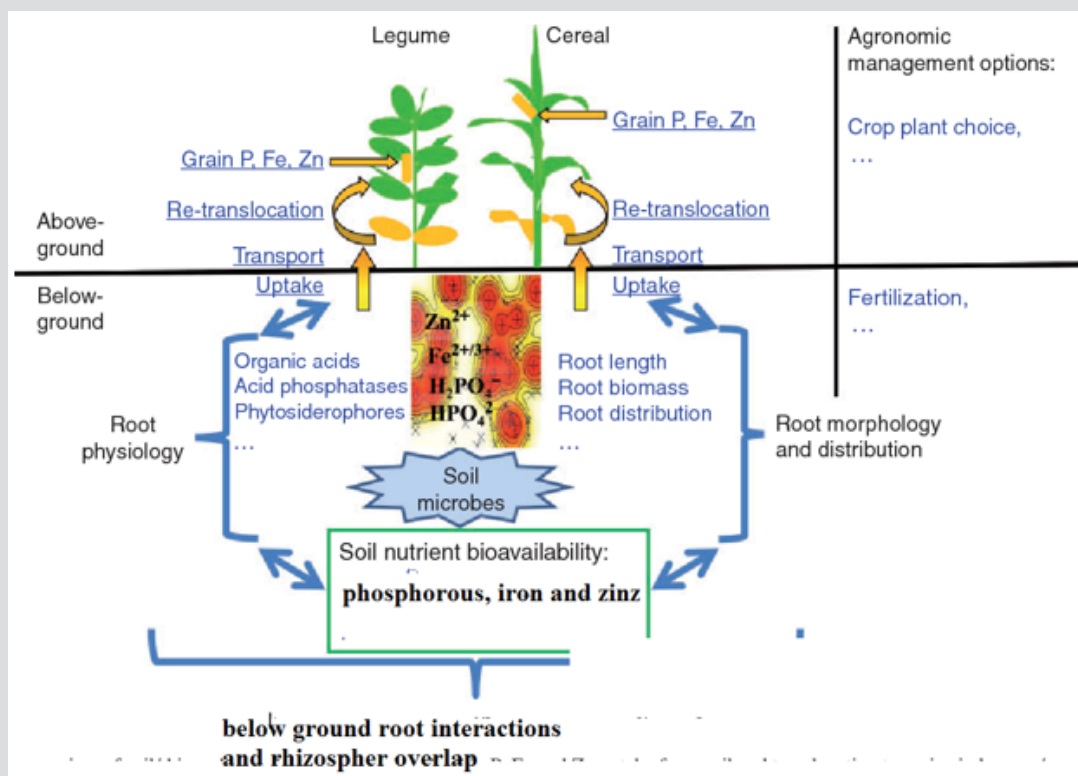


Figure 2: The fig shows the below ground interspecific root interaction, rhizospheric changes, nutrients transport, uptake and facilitation in intercropping system (Xue et al. 2016).

Rhizospheric pH Changes in Intercropping System

Several plants have the capability to change their rhizospheric soil pH [12,45-49] and convert P, K, Ca, and Mg to available form, [7,50]. For example many reactions occur in the rhizosphere of leguminous crop which can definitely affect the plants nutrients uptake and acquisition [51-53]. As previously, [54] documented that as the rhizospheric soil pH changes the plant nutrients availability was increased up to 45-120% P, 108-161% K, 120-148% Ca, 127-225% Mg and 117-250% B in cropping mixture (tea/*Cyclopia genistoids*) in South Africa. Hence, in balancing internal processing pluses may absorb more base cations and release H⁺ to rhizospheric soil that results in soil acidification [12,51-53,55]. Various leguminous crop like alfalfa, cowpea, lupine and chickpea can lower their rhizospheric soil pH because of releasing some considerable amount of organic anions [56-62] and enhance the organic P availability to plants and soil microorganisms. Similarly white lupine (*lupinus albus*) in sole cropping can lower their rhizospheric soil pH due to the release of organic anions and proton which recovered considerable amount of P from soil and

increased its availability to next crop (wheat) [63,64]. Likewise, peagon pea when intercropped with sorghum increased P uptake by exuding piscidic acid anions that chelated Fe³⁺ and subsequently released P from FePO₄ [43]. In field trial, maize P concentration can be improved by intercropped with faba bean [8,65-67]. In contrast, chickpeas has the potential to mobilize organic P proved to be superior to that of corn due to greater exudation of protons and organic acids by chickpea compared to maize [62]. Hence, plants in a mixture those cereals do not have strong rhizosphere acidification and can dependent directly on legumes root exudates for nutrients solubilization. It is however not clear that what changes the rhizosphere pH in mix culture those involving legumes and cereal and their effect on different soil chemical and biological reactions.

N₂ fixation, N Uptake and N Transfer in Cereal/Legumes Intercropping

Nitrogen is key element required for plants normal growth and productivity. More research are available on the biological

N fixation in grain legumes [35,68-70] because of legumes are able to acquire almost 75 % of their nitrogen requirement from atmosphere [71,72]. Nevertheless, less study on the biological nitrogen fixation in cereal/legumes mixture are available [70,73]. More specifically, the cropping mixture typically exhibits nutrients advantage [74,75]. Nitrogen uptake in mix cropping system enhances the nutrients status of associated crops. This N facilitation in intercropping system may be due to that, leguminous crops obtain N through biological nitrogen fixation which then available or transfer to associated cereal crop by direct root contact or exudation and mycorrhizal association and thus improve the N_2 fixation ability of legumes [76]. It is well known that intercropping cereal with legumes under low fertilization improve the N nutrient in cereal and thus overyield [50].

Previously documented that different cropping system like wheat/soybean, maize/faba bean, barley/pea and sorghum/soybean significantly increased the N acquisition compare to sole cropping system [77-79]. The atmospheric N taken up by faba bean was increased 8% to 33% (early flowering stage), 54%–61% (full flowering stage), 18%–50% (grain-filling stage), and up to 72% (full maturity stage) than monocropped faba bean [80]. The ^{15}N labeling techniques are using for direct transfer of N from legumes to neighboring non-legume plant in intercropping system, legumes are the dominant crop for fixing atmospheric nitrogen which is beneficial to the system [20,81], increase the N uptake in cereal and thus yield. It is evident previously that nitrogen fixed by legumes can be significantly transferred to their associated non-legumes crop grown in a mixture [68,69,73,82,83]. Thereby increased the soil N content [36,84,85]. In mixed culture, planting legumes at long distance from non-legumes may lead to decreasing N transfer. In past researcher declared that N competition in legumes/cereal mixed culture may further be increase through nitrogen fixing activity by leguminous crops [79,86]. Cereal plants efficiently utilize soil N which results more N fixation in legumes. It is therefore an important study to expose the effect of planting mixtures on biological nitrogen fixation and nutrition.

Soil Microbial Biomass in Intercropping

Microbial biomass in plants mixture is influence by various physio-chemical and biological characteristics those involve in an intercropping system. In general, soil microbial C is highly affected by different agricultural practices [87-89]. For example, the farm-land and grass land found to be higher in soil microbial C than uncultivated lands [87,90]. Intercropping in comparison with single cropping is expected more suitable cropping pattern for increasing soil microbial biomass. The intercropping of durum wheat with legumes like chickpea, lentil increased the soil microbial biomass [91]. Studies on the legumes has shown that these plants are capable to increase soil microbial C than cereal [92], tend to reduce carbon to nitrogen ratio in legumes compare to cereals. The microbial biomass activities can further be increase by adding any energy sources to soil. Higher microbial biomass activities can be

expected in soil by natural manuring than commercial fertilization [93,94]. Soil microbial biomass activity and organic matter are responsible factors for improving soil nutrients status, fertility and productiveness and can be enhanced by additional organic sources incorporated to the soil [93,94]. Under sufficient application of P, the soil microbial biomass can be boost in a result plant growth and soil organic matter can also be improve [93]. The biological soil activity in legumes/cereal mixture results in improving soil organic substrates utilizing by soil micro flora need more research attention. Although soil-microbes relationship has been considerable investigated but few literature are available on such studies those practice in humid regions [95]. In this prospective, useful information can acquire by measuring these activities in a relation to soil health in diverse cropping system.

Phosphatase Activity, P Acquisition and P Uptake in Intercropping

Intercropping can improve the P uptake under P deficient soil [43,63,96]. Soil contains phosphorous mostly in organic which cannot directly taken up by the plant [97]. Plants can acquire the phosphorus after hydrolyzed by below ground microbes and phosphatase activities release by plant roots. Different biochemical processes and release of carboxylates, protons and enzymes from the roots of P-mobilizing plants can mobilize the organic and immobilize P and benefit the non-P mobilizing crops in mix cropping culture [98]. In P-impoverished soil, some species form dauciform roots or cluster roots [98]. It reviewed earlier that Dauciform roots or cluster roots exude carboxylates and mobilize soluble P in soil increased P acquisition and supply P to neighbor plant in inter-crop [99]. Numerous studies have shown P use efficiency in inter-rhizosphere those of cereal and legumes. The P-mobilizing crop promisingly improved the phosphorous acquisition of cereal when inter cropped together [44,96]. Chickpea P facilitation for its associated intercrop plant are more prominent because of its high release rhizospheric acid phosphatases which convert organic P to inorganic [34]. Faba bean can facilitate its neighboring plants with P by mobilizing P through release of protons, malate and citrate into the rhizosphere. The efficient utilization of phosphorous in intercropping sytem helps reducing the in-P fertilization in agro-ecosytem [96].

The root exudation in mixed cropping system improve the Phosphoric acid, citrate, protons and acid phosphatase activities which helping in P mobilization and thus P acquisition by neighboring plant (cereals) [43,63,96,100]. The inter-rhizospher processes possibly facilitate the P to associated cereal in intercropping system [101]. Previously demonstrated that P concentrations both in above shoot and below roots and plants P utake were increased when maize were intercropped with faba bean [34,98]. Crops can survive under low phosphate availability because of different enzymatic and morphological abilities conversion of phosphatases which tend to increase in P starvation condition [102-109] but low P availability adversely affect the N_2 fixation in legumes.

Phosphatase enzyme is a key factor involving in soil fertility and performs different functions [110-112]. This enzyme is more likely to increase in low P soils [59,113-116], a comparative research on the acid phosphatase activity in white lupin root growing in high and low phosphorus soils show that acid phosphatase activity both in root extracts and root exudates in low P soil were significantly higher. Under different stress level these phosphatase enzyme are able to release phosphate from cells [104,117]. The increasing rate of P transportation in P-deficient plant is because to remobilize and optimize P uptake [118-130]. These enzymatic and completion of P starvation are considered to be managed by common P stress-related and specific signaling system.

The secreted plant acid phosphate amount is genetically controlled; differ at plant to plant [124] and various cropping techniques [126-127]. Different experimental results showed that legumes plants discharge more enzymes compare to grain crop as for instance [128] in their experiment observed that the enzyme secretion by legumes was 72% higher than that of cereals. The amount of enzyme secrete by chickpea root was higher than maize plant [62]. In biological manage system phosphate activity expected to be higher because of high carbon present in the system. As these activity of was found to be correlated with OM in different studies [129, 130]. Hence mix cropping practices is expected to induce P-stress in the rhizosphere, in a result different enzymes excretion may be occur. Till now a little research on the impact of mix cropping system on phosphatase activity in the rhizosphere are available. It is crucial to understand the rhizosphere enzyme activities, nutrients acquisitions by such activities and their effect on the plants growth and yield in mix cropping system.

Conclusion

The interspecific interactions among crops in intercropping system provide facilitative interaction both in upper and underground plant ecosystems which contribute promote crop productivity and nutrients acquisitions. More ever the below ground interactions in mixed cropping system play better role than above interactions. For better crop productivity and growth improvement future research should focus on the below ground plants roots, soil and microbial interactions those involve in mix cropping system. Studies on the micronutrients acquisition in intercropping system are less available so such research are encourage to investigate the micronutrients acquisition, transformation and uptake in both above and below ground plant parts and the role rhizpheric microbial community.

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