EFFECT OF DIFFERENT LEVELS OF SOIL WATER STRESS ON ROOT DEVELOPMENT OF BEAN AND POPLAR IN A SIMULATED AGROFORESTRY

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ABSTRACT

The growth and distribution of root systems of an annual crop (French dwarf bean) and a young tree species (poplar) in large soil columns at three different soil water supply regimes were studied in a simulated agroforestry under a greenhouse condition at the University of Edinburgh, UK. The root biomass production of bean plants was found unaffected under the limited soil water supply whether grown in a monoculture or in mixed stands in contrast to that of poplar plants. The root system of bean explored only top 36 cm of soil column whereas poplar root system explored beyond the depth of 36 cm . These differential responses of an annual crop and a young tree species may be used as a basis for selecting complementary agroforestry components in a dry area.

সারসংক্ষেপ

যুক্তরাজ্যের এডিনবার্গ বিশ্ববিদ্যালয়ের গ্রীনহাউজ পরিবেশে একটি একবর্ষজীবী শস্যের (ফ্র্যান্স বামন সীম) সাথে একটি বৃক্ষ প্রজাতি চারা গাছ (পপলার) তিনটি ভিন্ন পানি সরবরাহ প্রক্রিয়াযুক্ত মাটির বড় কলামের মধ্যে এগ্রো-ফরেষ্ট্রি পদ্ধতি অবলম্বনে প্রজাতি দুইটির মূলের বর্ধন ও বিস্তার নিরীক্ষা করা হয়। মাটিতে অপর্যাপ্ত পানি সরবরাহে সীমের মূল উৎপাদন ব্যাহত না হইলেও পপলারের মূল উৎপাদনের তারতম্য দেখা যায়। প্রজাতিদ্বয় একক অথবা যৌথভাবে রোপণেও একই ফলাফল দৃষ্ট হয়। সীমের মূলের পানি-আহরণ ক্ষমতা যেখানে মাটির কলামের উপরস্থ ৩৬ সেঃ মিঃ পর্যন্ত বিস্তৃত থাকে সেখানে পপলার-মূলের আহরণ ক্ষমতা ৩৬ সেঃ মিঃ হইতে আরো গভীরে বিস্তৃতি লাভ করে। মাটিতে পানির পরিমাণের বিভিন্নতায় একবর্ষজীবী শস্য ও বৃক্ষ-প্রজাতির চারা গাছের এই তারতম্য শুষ্ক অঞ্চলে সহমর্মী এগ্রো-ফরেষ্ট্রি প্রজাতি নির্বাচনে ব্যবহার করা যাইতে পারে।

INTRODUCTION

The increase in productivity and sustainability from a particular unit of land is the prime objective of agroforestry, which involves an intimate association of different plant components, particularly trees and annual crops. In this association, the interaction between the component species in the exploration of environmental resources such as light, nutrient and water, is inevitable. Among these environmental resources, limitation of soil water is the most important plant stress variables in many parts of the world, because of the uncertainty and periodic variation of precipitation.

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There is evidence of both competition (Thomas 1984, Muthana 1985, Campbell 1989) and complementarity (Mathavan 1985 Corack *et. al.,* 1987) between the component species in mixed cropping in relation to soil water supply. The growth and distribution behaviour of the root systems in an environment with a restricted supply of soil water is related to the competition and complementarity of other components.

The competition for soil moisture between trees and crop components in an agroforestry association raises the important issue of rooting depth, particularly during the establishment of tree seedlings. The root length density rather than rooting depth and root dry matter production is considered to be a better guide for determining the degree of exploitation of the soil. However, an increase in root growth is manifested as an increase in both root dry weight and root length (Sharp and Davies, 1979). Thus, the competition for the below-ground moisture is related to the development of the root systems of component species (Thomas, 1984). Although annuals are shallow rooted and trees are deep rooted, soil drying induces deep penetration of root systems of annuals (Sharp and Davies, 1985) resulting in a possible competition for moisture at a region of sub-soil layer. However, during soil drying, root system development not only varies between trees and annual crops but also within trees (Osonubi and Davies, 1981) and annual crops (Molyneux and Davies, 1983). Moreover, the condition of soil drying may also change the development pattern of root system even within the same species (Sharp and Davies 1979; 1985). Thus, in a water shortage area root system development of the component species in an agroforestry association may be modified relative to the root system development in a monoculture because of possible changes in the soil drying process. Kummerow (1980) emphasized the importance of fine roots (< 1 mm diameter) in soil moisture extraction since the fine roots comprise a substantial fraction of the root biomass. Jonsson *et al.* (1988) observed a gradual reduction in fine roots with depth in tree-maize associations. Thus, in agroforestry shallow soil layers may dry faster resulting in dehydration of shallow roots long before the roots in the deeper soil layers and this could lead to regulate the shoot behabiour.

Considering the facts, the present study was conducted to investigate the root growth and its distribution of an agricultural annual and a young tree in defferent soil profiles, growing in monoculture and in mixed stands under three different soil water supply regimes in greenhouse. Although the greenhouse differs from the field, responses to water shortage may be similar (Thomas and Norris, 1981).

MATERIALS AND METHODS

Plant materials : The pre-rooted cuttings (about 8 weeks of age) of poplar *Populus trichocarpa* x *P. deltoides* cv. Raspalje) were transplanted into black tubes (15 cm diameter and 75 cm depth), prepared from drain pipe, which were filled to 72 cm with compost of a mixture of 50% loam soil, 25% sand and 25% peat. The pH of the compost was recorded as 6.6 ± 0.06. The seeds of French dwarf bean (*Phaseolus vulgaris* cv. Argus) were sown directly into the tubes. All tubes were kept in a greenhouse of the University of Edinburgh, UK and watered every alternate day until the cuttings of poplar and the seedlings of bean were established. Poplar cuttings with new leaves and bean seedlings with nearly fully expanded first trifoliate leaf were considered as established plant stocks. In monoculture the number of plants in each pot was kept to one, either poplar or bean, whereas in mixed stands there were one poplar and one bean in each pot. The design of the experiment was a completely randomized block with five blocks and nine treatments as follows: three cropping systems (bean grown in monoculture; poplar grown in monoculture; bean and poplar grown in mixed stands) each with three water supply regimes (watered every alternate day, i. e. watered control = WC; watered at weekly intervals ; i. e. rewatered = RW; unwatered from day 1 = UW). The treatments were started from the date of establishment of the plant stock. The experiment was continued for three consecutive drying cycles of treatment UW with six days of regular watering (every alternate day) in between each cycle. The first drying cycle was for 12 days and the two subsequent cycles of 14 days each. The first drying cycle took place before flowering of the bean plants.

Soil water content : The water content of four different layers (0-18; 18-36; 36-54; 54-72 cm) of the soil columns was monitored on day 11th of the both first and second drying cycles. The soil samples were collected in two replicates, using a 13 mm diameter metallic corer. The fresh and oven dry weights of the samples were recorded and the water content of the soil was calculated.

Harvesting of root system : At the end of the third drying cycle, because of abnormal appearance like yellowing and drying of stem and leaf of a few plants in one block, the root systems of other four replicates of each treatment were harvested. During harvesting, the entire soil column of two replicates of each treatment was divided into four sections of 18 cm. The roots in each section were collected separately, with the poplar and bean roots also being separated in the mixed culture treatment. In the remaining two replicates of each treatment the entire root system of bean and poplar was separated from the soil, whether grown in monoculture or in mixed stands, before being divided into four sections of 18 cm length. These two methods of harvesting roots were used to identify the root systems of the two species and to compare estimates of the amount of roots of each species, particularly in mixed culture, in each section by these two methods, so as to harvest the roots with minimum error. The fine roots of each species (excluding coarse roots of *ca* 3 mm diameter or above for bean and *ca* 4 mm or above for poplar) in each section were also separated. The roots were oven dried at 80°C for seven days and then the dry weights were recorded.

RESULTS

Soil water content : In the first drying cycle, a significant reduction in soil water was restricted to the top 36 cm when bean and poplar were grown in monoculture, but in the mixed stands the reduction extended below 36 cm depth of soil column in treatment UW (Figure 1 left). In the second drying cycle, when bean was grown in monoculture the reduction in soil water content was also restricted to the top 36 cm, whereas in the monoculture of poplar and in the mixed stands, reduction could be seen at 54 cm and 72 cm, respectively (Figure 1 right). Irrespective of the cropping system, there was a larger reduction in soil water content in the upper 36 cm than throughout the whole soil column (0-72) in both drying cycles (Figure-1). The water supply treatments were successful in imposing different degrees of water stress on the plants, although differences between treatments RW and UW were small in the second drying cycle. Comparing the cropping systems, there were larger reductions of soil water in the mixed stands of bean and poplar than in the monocultures.

Root biomass : There was no significant effect of soil water supply on root biomass production when bean was grown either in monoculture or in mixed stands with poplar. However, in the watered control treatment WC, bean root biomass was significantly more reduced in the mixed stands than in the monoculture (Figure 2 left). By contrast in poplar root biomass production was significantly reduced by limited soil water supply when grown either in monoculture or in mixed stands (Figure 2 right). In the limited water supply treatments UW and RW, root biomass production of beans in mixed stands was almost the same as in monoculture while poplar root biomass production was significantly lower in mixed stands than in monoculture (Figure 2).

Feeding root distribution : The root system of bean plants in treatment UW extended below 60 cm, compared with a maximum of 50 cm in treatments RW and WC. A similar rooting pattern was observed whether beans were grown in monoculture or in mixed stands, although in monoculture, the root system was slightly more extensive than in mixed stands at all depths in the soil column (Figure 2 left). Similarly, *ca* 45% of bean root weight in treatment UW occurred in the top 18 cm of the soil column compared with *ca* 60% in the watered control WC (data not shown). When

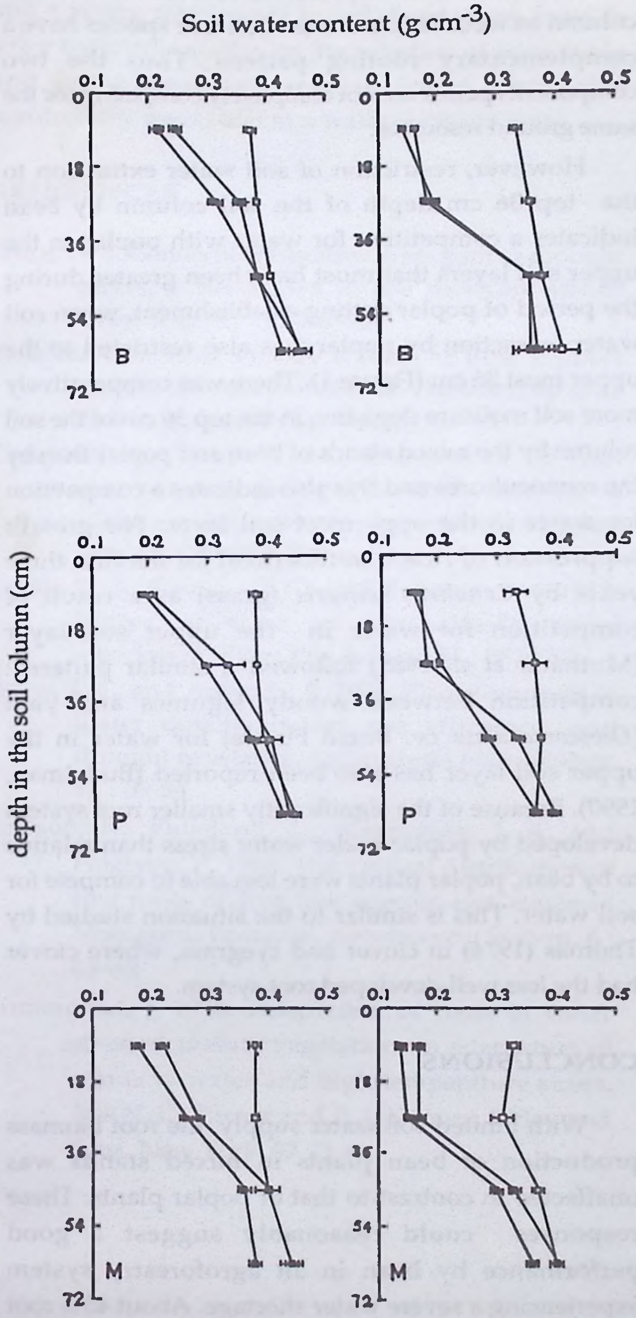

Figure 1 : Water content at various depths in the soil column, for bean and poplar, grown in monoculture (B & P, respectively) and in mixed stands (M) on the 11th day of the first (left) and the second (right) drying cycles under three different soil water supply regimes. (□) watered control WC; (□) re-watered RW and (■) unwatered UW.

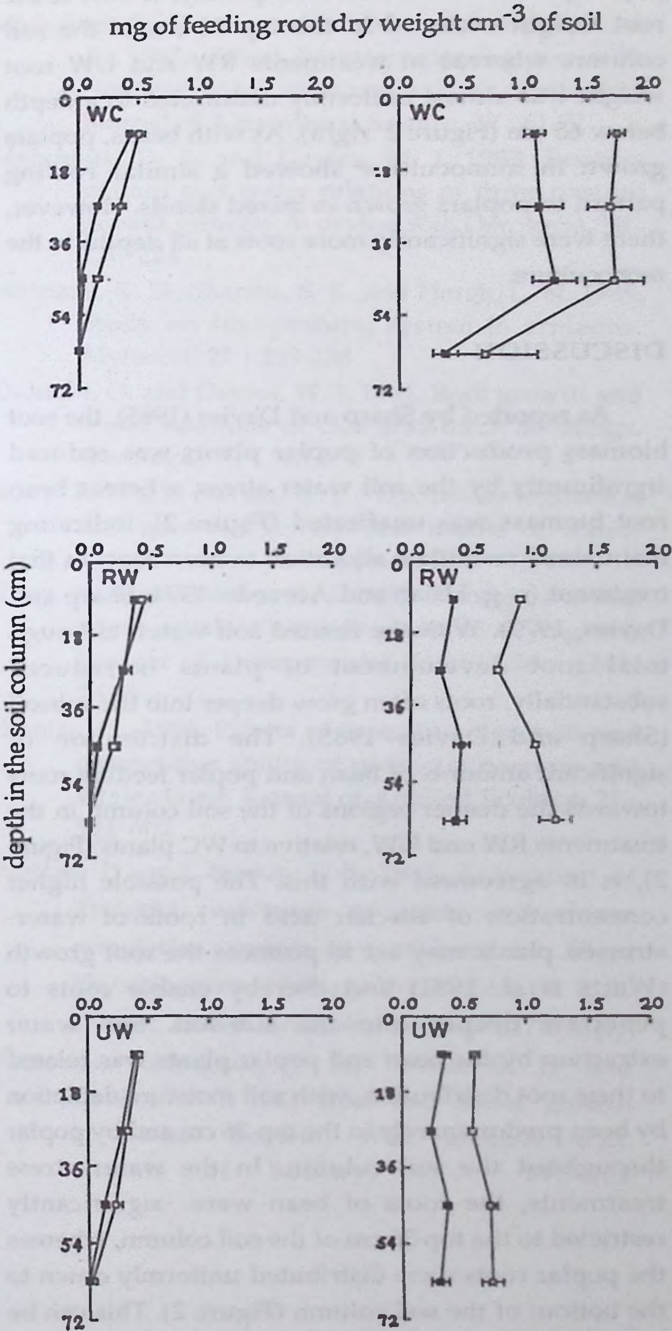

Figure 2 : Dry weight distribution of bean (left) and poplar (right) feeding roots, grown in monoculture (□) and in mixed stands (■), down the soil column at the end of three consecutive drying cycles under three different soil water supply regimes, (WC) watered control; (RW) re-watered and (UW) unwatered.

poplar plants were watered frequently, *ca* 90% of the root weight occurred in the top 50 cm of the soil column, whereas in treatments RW and UW root weight was almost uniformly distributed to a depth below 65 cm (Figure 2 right). As with beans, poplars grown in monoculture showed a similar rooting pattern to poplars grown in mixed stands. However, there were significantly more roots at all depths in the monoculture.

DISCUSSION

As reported by Sharp and Davies (1985), the root biomass production of poplar plants was reduced significantly by the soil water stress, whereas bean root biomass was unaffected (Figure 2), indicating maintained assimilate allocation to bean roots in that treatment (e. g. Hsiao and Acevedo 1974; Sharp and Davies, 1979). With the limited soil water, although total root development of plants is reduced substantially, roots often grow deeper into the subsoil (Sharp and Davies 1985). The distribution of significant amounts of bean and poplar feeding roots towards the deeper regions of the soil column in the treatments RW and UW, relative to WC plants (Figure 2), is in agreement with this. The possible higher concentration of abscisic acid in roots of water-stressed plants may act to promote the root growth (Watts *et al.* 1981) and thereby enable roots to penetrate deeper into the sub-soil. Soil water extraction by the bean and poplar plants was related to their root distribution, with soil moisture depletion by bean predominantly in the top 36 cm and by poplar throughout the soil column. In the water stress treatments, the roots of bean were significantly restricted to the top 36 cm of the soil column, whereas the poplar roots were distributed uniformly down to the bottom of the soil column (Figure 2). This can be attributed to the genetically determined shallow and deep rooting characteristics of annual crops (Blum, 1974) and trees (Osonubi and Davies 1981), respectively. Thus, the root system of bean was only able to explore the top soil layer, whereas poplar roots were able to explore further down the soil column as well. This indicates that tree species have a complementary rooting pattern. Thus the two component species are not completely competing for the same ground resources.

However, restriction of soil water extraction to the top 36 cm depth of the soil column by bean indicates a competition for water with poplar in the upper soil layers that must have been greater during the period of poplar cutting establishment, when soil water extraction by poplar was also restricted to the upper most 36 cm (Figure 1). There was comparatively more soil moisture depletion in the top 36 cm of the soil column by the mixed stands of bean and poplar than by the monocultures and this also indicates a competition for water in the uppermost soil layer. The growth suppression of *Acacia tortiles* (tree) for the first three years by *Cenchrus ciliaris* (grass) as a result of competition for water in the upper soil layer (Muthana *et al.* 1985) followed a similar pattern : competition between woody legumes and yam (*Dioscorea alata* cv. Brazo Fuerte) for water in the upper soil layer has also been reported (Budelman, 1990). Because of the significantly smaller root system developed by poplar under water stress than relative to by bean, poplar plants were less able to compete for soil water. This is similar to the situation studied by Thomas (1974) in clover and ryegrass, where clover had the less well-developed root system.

CONCLUSIONS

With limited soil water supply, the root biomass production of bean plants in mixed stands was unaffected in contrast to that of poplar plants. These responses could reasonably suggest a good performance by bean in an agroforestry system experiencing a severe water shortage. About 45% root weight of bean was distributed in the top 18 cm of soil column in the treatment UW whereas, in poplar, root systems were distributed through out the soil column almost uniformly. The results suggest that the differential root development responses of annual crop and a young tree species to soil drying may provide some basic information on the selection of compatible and complementary species for a successful agroforestry plantation in a water shortage area.

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