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Plant functional diversity improves short-term yields in a low-input intercropping system

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ABSTRACT

In natural ecosystems, plant communities composed of functionally diverse species produce more biomass overall than less diverse communities. This increased biomass production is thought to occur due to complementary use of resources such as nutrients and water, and facilitation during sub-optimal environmental conditions. Using the same concept in a crop setting may lead to increased yield (overyielding) in diverse cropping systems when compared to monocultures. Different combinations of peanut, watermelon, okra, cowpea, and pepper planted alone or in various intercropping combinations were investigated over two growing seasons in a low-input system in the peak of summer heat in Texas. Each species was selected to perform a specific function within the system. Results from land equivalent ratio (LER) indicate that the within-row combination with peanut, watermelon and okra (W_{pwo}) and peanut, watermelon, okra and cowpea (W_{pwoc}) consistently overyielded in 2011 and 2012. LER values were 1.17 each for W_{pwo} and W_{pwoc} in 2011 and 1.17 and 1.20 in 2012, respectively. In 2011, watermelon was the dominant crop and was up-regulated in all intercropping combinations while all other component crops were down-regulated. Watermelon per plant production was significantly higher in the combination containing all species (W_{all}) when compared to its monoculture, 5.50 and 2.09 $\mathrm{kg_{fruit}\,plant^{-1}}$, respectively. In 2012, okra was the dominant crop and was up-regulated in all intercropping combinations while watermelon, cowpea, and pepper were down-regulated. Okra per plant production was significantly higher in W_{pwoc} and W_{all} than in monoculture, 2.28, 2.46, and 1.13 $\mathrm{kg_{fruit}\,plant^{-1}}$, respectively. These findings suggest that three and four species intercropping combinations, whereby each crop is selected to perform a specific function within the system, may provide small-scale sustainably-minded producers a model system that can be utilized in suboptimal conditions and allow them to reduce inputs while increasing overall yields.

1. Introduction

In natural ecosystems, increased plant species diversity has been shown to increase net primary productivity (Tilman et al., 1996). Two possible explanations have been proposed to explain this; the sampling effect hypothesis and the complementarity effect hypothesis. Multispecies systems may include highly productive species that dominate the community (Hector, 1998), leading to what is known as the “sampling effect”. The likelihood of including species that contribute disproportionately to overall community productivity increases as the number of species in the community increases (Loreau, 1998; Gastine et al., 2003). Therefore, an increase in total community productivity may be due to one or few dominant species rather than the biological interactions underlying the complementary effect hypothesis.

In multispecies systems, complementarity and facilitation can offset the negative effects of competition (Hooper et al., 2005). Complementarity results from niche partitioning and a reduction of interspecies competition (Vandermeer, 1989), while facilitation occurs when neighboring plants have a beneficial effect on each other (Chu et al., 2008). Facilitation can occur during times of suboptimal environmental conditions when one species alleviates those conditions or provides a resource for neighboring species (Hooper et al., 2005). Complementarity occurs when species use different resources or use the same resource but separate its utilization in time or space. This can result in more efficient use of resources by the community as more of the total available resources

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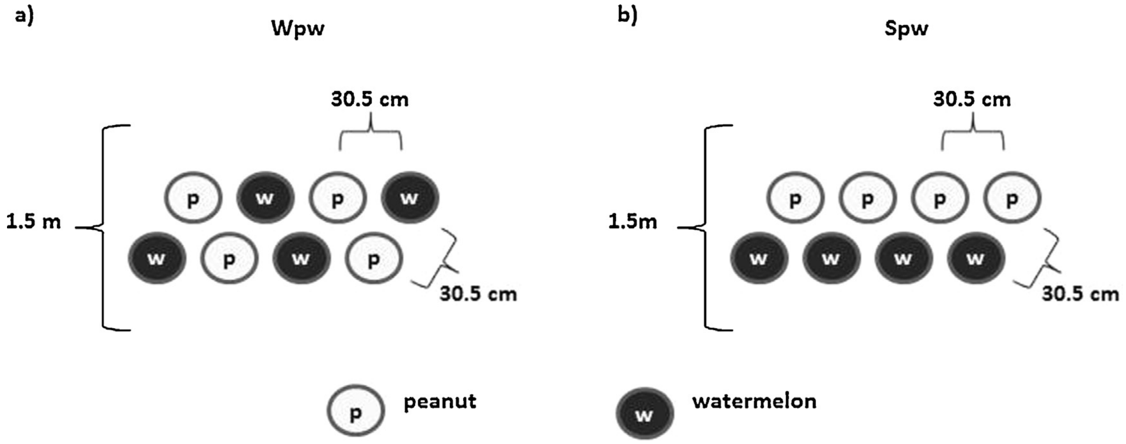

Fig. 1. Planting layout and spacing for the (a) within-row intercropping system of peanut–watermelon (W_{pw}) and the (b) strip intercropping system of peanut–watermelon (S_{pw}). The subsequent within-row intercropping combinations would follow the same spacing and layout as W_{pw}.

are being used (Harper, 1977; Vandermeer, 1989). Competition in plants ultimately occurs between individuals (Weiner, 1990) and classic competition theory asserts that intraspecies competition is often more intense than interspecies competition due to greater niche overlap (Bengtsson et al., 1994). Overyielding, a phenomenon where plant production in mixture exceeds that of production in monoculture, has been attributed to complementarity in resource use and minimal niche overlap between species (Vandermeer, 1990). Complementarity, along with facilitation, has been cited as a reason why species are able to coexist in diverse natural communities and it is thought that even partial complementarity may increase system productivity (Hooper, 1998).

Some researchers have emphasized the importance of functional differences between species and the relationship between species in space and time rather than the effect of species richness *per se* on improving ecosystem functioning (Landis et al., 2000). Species from different functional groups differ significantly in their use and acquisition of resources (Reich et al., 2004). The loss or gain of functional types within a plant community can change the flow of energy and resource supply, thereby changing the productivity of the community and functioning of the ecosystem (Reich et al., 2012).

Small farmers in tropical forest areas have long utilized intercropping systems and have incorporated a variety of crops with different growth forms, which creates a complex multi-layered habitat that closely mimics nature (Denevan, 1995). In agroforestry systems of the tropics, it has been observed that deep-rooted trees bring nutrients up from deeper soil layers, thereby increasing nutrient use efficiency and reducing leachate (van Noordwijk et al., 1996). The “three sisters” intercropping system of squash, bean, and corn practiced by Native Americans located in North America is another well documented example of a multi-layered agroecosystem (Mohler and Stoner, 2009). In these types of systems, each crop occupies a functional group niche and contributes differently to the overall ecosystem (Vitousek and Hooper, 1993). In the case of the “three sisters”, squash suppresses weed growth (smother crop), bean as the nitrogen-fixer, and corn as structural support (Mohler and Stoner, 2009).

According to Altieri (1999), Latin American farmers grow 70–90% of their beans in a mixed system with maize, potatoes, and other crops. However, despite the success of intercropping in developing countries and the rising popularity of intercropping in developed ones (Kahn, 2010), multi-layer architecturally complex intercropping systems have not been studied extensively in the United States. Many studies have evaluated the role of biodiversity in agroecosystems. Most have not incorporated the concept of functional diversity, but only the number of species present. What is known is that functionally diverse plant communities can lead to increased total community productivity. What is unknown, however, is if this will translate into an increase in yield and total food production per area and per plant. The objectives of this study were to determine if a multifunctional intercropping system can lead to overyielding in crop production and to examine the effects on fruit quality. We hypothesized that a functionally diverse cropping system will lead to overyielding and an increase in total fruit production in an organic system consisting of peanut (*Arachis hypogaea* L.), watermelon (*Citrullus lanatus* Thunb.), okra (*Abelmoschus esculentus* Moench.), cowpea (*Vigna unguiculata* L.), and hot pepper (*Capsicum annuum* L.). We also hypothesized that fruit quality will be reduced only in sub-dominant crops.

2. Materials and methods

2.1. Study area

Low input managed plots were established at Texas A&M University’s Horticulture Farm (30°37′N, −96°22′W) during the 2011 and 2012 growing seasons. Average monthly air temperatures for this area from May to October when the study was conducted ranged from 28 to 39 °C for the maximum and 15–26 °C for the minimum in 2011 and 27–37 °C and 15–25 °C in 2012 (NOAA/NCDC).[1] Total precipitation for the 2011 growing season (August 1 through October 31) was significantly less than for the 2012 growing season (June 21 through October 31), 98 and 185 mm, respectively (NOAA/NCDC; Fig. A1).[1] Additionally, there were more frequent precipitation events in 2012, particularly at the time of planting. Supplemental irrigation was applied several times during each growing season (Fig. A1), making total water input for 2011 244 mm and 2012 483 mm.

2.2. Experimental design

The study design was a randomized complete block with three replicates, five intercropping treatments, and five controls. The controls consisted of monocultures of the five component species;

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[1] NOAA National Climatic Data Center. http://doi.org/10.7289/V5D21VHZ (Nov 20, 2014).