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Rajveer Singh Yadav
 Livestock/Farm Assistant,
 Rani Lakshmi Bai Central
 Agricultural University,
 Jhansi, Uttar Pradesh, India

HS Kushwaha
 Professor, Department of
 Natural Resource
 Management, Faculty of
 Agriculture Mahatma Gandhi
 Chitrakoot Gramodaya
 Vishwavidyalaya, Chitrakoot,
 Satna, Madhya Pradesh, India

Sharvan Kumar Singh
 Department of Natural
 Resource Management,
 Mahatma Gandhi Chitrakoot
 Gramodaya Vishwavidyalaya,
 Chitrakoot, Satna, Madhya
 Pradesh, India

Corresponding Author:
Rajveer Singh Yadav
 Livestock/Farm Assistant,
 Rani Lakshmi Bai Central
 Agricultural University,
 Jhansi, Uttar Pradesh, India

A review on maize and pigeon pea based intercropping outperforms monocultures under drought

Rajveer Singh Yadav, HS Kushwaha and Sharvan Kumar Singh

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Abstract

Developing resilient agroecosystems that can assist smallholder farmers in adapting to climate change, especially drought, is an urgent necessity. Diversifying maize-based cropping systems in North India by the intercropping of grain and tree legumes may increase yield and increase resistance to unfavorable weather. By forcing drought in monocultures and additive intercrops along a crop variety gradient, such as sole maize, sole pigeonpea, maize-pigeonpea intercropping, and without fertilizer treatment, we examined whether intercropping boosts drought resilience and crop and whole-system yields. Furthermore, it was shown that the intercropping method based on pigeon peas was more advantageous for soil health and compensation. However, in the current context, developing high intensity cropping systems through the use of intercropping is one of the key tactics to boost agricultural output. In terms of revenue, soil health, and other environmental aspects, intercropping systems have been shown to have more benefits than solitary cropping. Additionally, the combination of intercropping grain and legumes primarily yields benefits in terms of increased productivity, better use of available resources, and improved soil health. Widely spaced, maize is a crop that is chosen as a cereal component to better accept legumes in the gaps between rows of maize. The advantages of the maize-legume intercropping system and crop production enhancement are the main topics of this essay.

Keywords: Intercropping, maize, pigeon pea, resource use efficiency, soil health

Introduction

India, which processes and produces the most pulses globally (17.35 MT), imports 4.58 MT on average each year to meet its ever rising 22 MT consumption needs. The Vision paper of the Indian Institute of Pulses Research states that India's population is estimated to reach 1.68 billion by 2030 and that 32 million tons of pulses will be needed, with an expected 4.2% annual growth rate. The second most significant kharif grain legume in India, after chickpea, is pigeon pea (*Cajanus cajan* (L.) Millsp.), which is primarily grown in rainfed environments. With a total production of 3.17 MT and an average productivity of 813 kg/ha, it covers an area of roughly 3.90 m ha. Due to its adaptability to both pure and mixed/intercropping systems, as well as its aptitude for dryland conditions, pigeon peas are a popular pulse crop among Indian farmers. Pigeon pea production on sub-marginal lands is not the only factor contributing to its low yield; constant use of chemical fertilizers, insufficient and uneven fertilization, and reduced productivity all lower soil health and ultimately have an adverse effect on the environment.

There is little actual evidence in low-input smallholder cropping systems to support the claim that these changes in soil and plant processes, as well as the composition of plant mixtures, transfer into increased production stability during droughts. According to one study, when the drought gets worse, sorghum-groundnut intercropping with a replacement design—that is, the same planting density in both monoculture and intercropping—becomes increasingly better than monocultures (Natarajan and Willey, 1986) ^[16]. It is unknown, meanwhile, how additive intercropping—that is, planting more intercropping than monoculture—will react to drought. According to a study conducted in Malawi, the amount of maize yield lost in no-till additive maize-cowpea intercropping systems owing to drought was either equal to or higher than that of solitary maize. (Steward *et al.*, 2019) ^[27]. An assessment of the drought response of additive designs is required given their significance for boosting smallholder food production. Fully additive designs (planting density in intercropping is the sum of densities of monocultures) are almost always superior to monocultures in terms of their productivity

whereas replacement designs are superior to monocultures only about half the time (Yu *et al.*, 2015) ^[30]. While leguminous tree additive intercropping with maize might increase yield under unfavorable conditions (Sileshi *et al.*, 2011) ^[23], higher planting densities and increased competition for water in additive intercropping may also raise yield loss risk (Lobell *et al.*, 2014) ^[9]. The relative benefit of intercropping can be further altered by the co-limitations smallholder systems frequently face, such as low soil fertility combined with drought (Sileshi *et al.*, 2011; Rusinamhodzi *et al.*, 2012) ^[23, 20]. The majority of the data available on intercropping and drought to date focuses only on yield performance, primarily on maize. Assessing how current research goes from maize yield to total system calorie or protein production from all crops (Snapp *et al.*, 2010; Smith *et al.*, 2016) ^[26, 25] is necessary to determine whether intercropping might increase smallholder subsistence farming systems' resilience to drought.

Several factors must be taken into account both before and throughout the cultivation process for an intercropping system to be successful (Seran and Brintha, 2010) ^[22]. For instance, the density of crop light interception, crop species, and nutrient requirements determine the possibility for nitrogen provision in a cereal-legume intercropping system. Nevertheless, other crucial components of an intercropping system include crop selection, water management, and fertilizer use (Maitra *et al.*, 2019) ^[10]. The effectiveness of the component crops' resource consumption determines the yield of an intercropping system in the main. This depends on time and space dimensions in addition to the system's distinct primary and component crops. It is well known and observed that the benefits of intercropping a tall main crop, such as maize, with a short stature legume component, such as greengram, blackgram, cowpea, groundnut, and so forth, accrue from both an improved use of underground resources and an improved use of the atmosphere above ground. Thus, the total productivity of a cropping system based on maize depends in part on how efficiently the crop uses its resources, in part on how well it helps legumes, and vice versa. Thus, the primary crop's productivity as well as its compatibility with other components determine the intercropping productivity of legumes overall. Although it has become widely acknowledged in recent years that intercropping systems can provide higher yields than solitary cropping, determining the exact degree of yield advantages can present challenges. Nonetheless, this kind of evaluation is necessary to ascertain whether a particular intercropping combination is, in fact, superior than solitary cropping and whether, within that combination, one cropping system is superior to the other. There are several techniques to guarantee that the benefits of intercropping are fairly evaluated; the most popular ones involve figuring out the base-crop equivalent yield, the land equivalent ratio (LER), and the area time equivalent ratio (ATER). In a highly populated nation like India, cropping needs to be identified both spatially and temporally in order to keep up with the growing population and the production of food grains. Despite being a long-standing technique, intercropping has gained popularity worldwide due to its potential for increased yields when chosen crops are cultivated using scientific methods (Willey, 1979) ^[28]. Scientifically managing compatible genotypes and crops to reduce intricate interspecific, intervartietal, and interplant interactions is known as intercropping. In order to do this, it

may be possible to reduce competition between component crops by choosing crops with complementary rooting patterns, growth habits, and maturity groups. Additionally, agronomic practices such as adjusting plant geometry, planting time, and population levels can be made in a way that optimizes the use of production resources and increases productivity per unit area and time.

Effect of Drought Differs Between Crops

In two cropping systems—sole maize and maize-pigeonpea—drought considerably reduced maize production under fertilized conditions, but it had no discernible negative effect on pigeonpea yield. Drought did not affect maize yields in any cropping system when nutrients were limited, which is a common occurrence in low-input smallholder cropping systems. In spite of the fact that the drought imposition period lasted for two-thirds of the pigeonpea growing season as opposed to just half of the maize growing season, the pigeonpea exhibited a superior drought response, which is consistent with the plant's early-season taproot development and sluggish initial shoot growth (Snapp *et al.*, 2010) ^[26].

Intercropping Maize and Pigeonpea Is Always Better Than Monocultures

The only intercropping system that continuously outperformed corresponding monocultures was additive maize-pigeonpea intercropping, which required less land area to produce the same amount of food, especially during droughts, regardless of whether fertilizer was added (mean Land Equivalent Ratio >1). One of the two intercrops that produced grain, protein, and calories as high as solitary maize throughout the complete system was maize-pigeonpea. This result held true at all water levels with and without fertilizer. The data from meta-analyses demonstrates that intercropping C4 cereals with C3 legumes, especially additive intercropping, improves land use efficiency for crop production in comparison to solitary planting. This is consistent with the high productivity of maize-pigeonpea intercropping (Yu *et al.*, 2015) ^[30]. While one study found that the LER of C4 cereal/C3 legume replacement intercropping systems increased with drought (Natarajan and Willey, 1986) ^[16], the findings of the meta-analysis that LER did not vary with irrigation level or aridity (Martin-Guay *et al.*, 2018) ^[12] are consistent with the finding that maize-pigeonpea LER does not significantly increase under drought compared to ambient rainfall. More efficient use of available water, nutrients, and light; competition for soil water and nutrients below thresholds for negative impacts on whole-system yield; and/or facilitation of maize by legumes through decomposition of legume residue and maize uptake of mineralized nitrogen could all be contributing factors to superior maize-pigeonpea performance across growing conditions.

The fact that maize-pigeonpea intercropping performs better during droughts than monocultures may also be related to the fact that pigeonpea is a less drought-sensitive crop in the mixture and/or to long-term changes in soil qualities brought about by intercropping. Similar to the stabilizing effect of crop diversification that has been observed at larger spatial scales, trends toward greater drought resistance and LER under drought for maize-pigeonpea compared to sole maize could indicate a portfolio effect whereby pigeonpea responds less negatively than maize to drought (Birthal and

Hazrana, 2019; Renard and Tilman, 2019) [19, 18]. Longer-term research have demonstrated the effects of maize-legume intercropping on soil hydrology and fertility, which may also be the reason for the preference of this intercropping technique over monocultures during droughts. It has been demonstrated that smallholder intercropping systems, like the ones examined here, influence soil and plant mechanisms by mediating facilitative interactions and plant uptake of nutrients and water. Grain and tree legume intercropping, especially when done close to trees and especially in sandy soils, improves soil carbon and water infiltration with detectable increases in soil moisture during peak rainfall events (Chirwa *et al.*, 2007; Rusinamhodzi *et al.*, 2012; Muchane *et al.*, 2020) [1, 20, 14]. Although assessing water fluxes via soil and plants as well as plant water status during droughts should offer more comprehensive insight into drivers of better food production in varied systems in water-limited circumstances, we did not detect a substantial benefit to intercropping for soil moisture per se (Nyadzi *et al.*, 2003) [17]. Sekiya and Yano (2004) [21] have found improved leaf water potential in intercrops and hydraulic lift by pigeonpea to maize; however, their contribution to crop production enhancement beyond aiding plant survival during drought is uncertain and probably negligible.

The Productivity Outcomes of Gliricidia Intercrops Vary

The significance of empirically taking into account various resource constraints that may interact in the field when evaluating the resilience of diverse agricultural systems. The response of low fertility, high aridity marginal smallholder systems to water and nutrient limits may not be reflected in linear increases in LER found along broad global fertility and aridity resource gradients (Yu *et al.*, 2015; Martin-Guay *et al.*, 2018) [30, 12]. The lack of consistent benefits in terms of land-use efficiency between gliricidia intercropping systems and monocultures may be because of resource competition between gliricidia and annual crops (Jackson *et al.*, 2000; Chirwa *et al.*, 2007; Makumba *et al.*, 2009; Muthuri *et al.*, 2009) [6, 1, 11, 15] that were not measured here, such as for light under more productive conditions (i.e., with fertilizer, without drought). A more thorough assessment of intercropping would have been possible if indices like the competitive ratio and aggressivity (McGilchrist, 1965) [13] had been used to evaluate each crop's ability to compete. However, this study was limited by the absence of a gliricidia control or gliricidia productivity measurement. Since maize and pigeonpea grain yields are the primary factors influencing smallholder farmers' adoption of intercropping, this study exclusively considers these yields and leaves out other gliricidia products. When factored into LER calculations, the additional product of gliricidia fuelwood output (Kimaro *et al.*, 2007) [7] would increase the likelihood that gliricidia intercropping systems are more beneficial than monocultures. The benefits of producing wood on farms can also be measured indirectly, such as how it affects food security.

Additive intercropping has no negative effects on resistance to drought

This study provides proof that, although having a higher plant density, additively intercropping maize with pigeonpea and/or gliricidia does not reduce drought resilience (i.e., avoids raising the risk of yield loss). Intercropping

preserved or improved maize drought resilience at the individual crop level, but had no effect on pigeonpea drought resistance. In a similar vein, when compared to the conventional solitary maize system, all intercropping methods preserved or improved the drought resistance of whole-system grain, protein, and calorie yields. Given that we did not discover higher yield losses from intercropping than from solitary cropping, this data provides only shaky support for the notion that intercropping, especially in the tropics, promotes crop yield stability. The lack of a significant relationship between the amount of water input and intercropping versus monocropping (Steward *et al.*, 2019) [27]. At least for the planting densities typical of the study area and within the ranges of rainfall and soil moisture in our study, the lack of downside risk associated with additive intercropping for drought resistance suggests that water use patterns between species were sufficiently complementary or that increased competition for soil moisture was insufficient to make intercrops more susceptible to drought. In intensive cropping systems with increased planting densities, the effects of additive intercropping on the overall system production during a drought may be adverse.

A Novel Rainout Shelter with Tall Slats and Minimal Crop Microenvironment Artifacts

A new design for rainout shelters for drought experiments that combines the taller (≥ 2 m) fully covered rainout shelters previously used in maize (Steward *et al.*, 2019) [27] and wheat (Degani *et al.*, 2019) [3] with the slatted design used in lower stature systems such as grassland, deserts (Yahdjian and Sala, 2002; Gherardi and Sala, 2013) [29, 4], and wheat (Kundel *et al.*, 2018) [8]. Without causing crop microenvironment artifacts like greater air temperature, relative humidity, or vapor pressure deficit, our rainout shelter design effectively lowered soil moisture. The average noon difference between photosynthetically active radiation (PAR) with and without rainout shelters was 16%, which was less than the largest midday difference previously documented in field studies with rainout shelters (25%) (Yahdjian and Sala, 2002) [29]. During the data collecting dates (maize anthesis through harvest), on a cloudy day representative of light circumstances, the average light transmission via rainout shelters was 850 vs. 1,012 $\mu\text{mol m}^{-2} \text{s}^{-1}$ in the absence of rainout shelters. Based on maize photosynthetic light response curves, this discrepancy translates to a 13% loss in maize photosynthesis. In theory, as photosynthetic light response curves reach a light-saturated rate under sunny conditions, the gap in photosynthesis caused by light interception by rainout shelters would get smaller. However, as maize is a C4 plant, the canopy light response may be less saturating than for gliricidia and pigeonpea. Rainout shelters did not appear to have a detrimental influence on either pigeonpea or maize yields in various cropping system-fertilization treatment combinations, suggesting that light was not a factor limiting output. The drawbacks of above-canopy rainout shelters, including the possibility of yield consequences unless they are compensated for with additional rainout shelters devoid of rainwater interception and the potential for confounding rainfall and light interception (Kundel *et al.*, 2018) [8]. Nevertheless, the effects of rainout shelters on light are either unreported (Degani *et al.*, 2019; Steward *et al.*, 2019) [3, 27] or published

as manufacturer standards for roofing materials (Kundel *et al.*, 2018) [8] but not empirically tested. Furthermore, even though our research was done during a single season, we point out the usefulness of rainout shelter experiments for carefully regulating rainfall, which efficiently isolates the effects of drought in terms of precipitation total while maintaining constant rainfall timing, other meteorological factors, and sources of variation. Our water treatments cover appropriate ambient rainfall and drought rainfall levels for this location because we did our study during a season with rainfall that was marginally above average.

Rainout shelter designs featuring slatted roofs minimize negative effects on the crop microclimate by permitting greater air flow and some direct radiation, while also enabling varied amounts of incoming rainfall to be intercepted based on slat spacing. These characteristics make them suitable for drought simulations that last longer than a month (Yahdjian and Sala, 2002; Kundel *et al.*, 2018) [29, 8]. But according to Yahdjian and Sala (2002) [29] and Kundel *et al.* (2018) [8], roof slats are frequently composed of translucent acrylic bands, which can be somewhat costly. Additional research employs less expensive, but less resilient, greenhouse plastic fully covered rainout shelter roofs, affecting both crop microenvironment and air temperature (Degani *et al.*, 2019; Steward *et al.*, 2019) [3, 27]. Transparent corrugated polycarbonate roofing is more durable than greenhouse plastic and more cost-effective than acrylic. In areas where corrugated polycarbonate roofing material is more readily accessible and reasonably priced, this roofing material makes it possible to use slatted roof rainout shelter designs.

Significance for Socio-Economics and Drought Adaptation

When evaluating the superior performance of maize-pigeonpea intercropping over monocultures, it is important to take into account the wider socioeconomic environment. While whole-system grain, calorie, and protein yields from sole maize and maize-pigeonpea intercropping were comparable, maize-pigeonpea outperformed the other systems in terms of protein output. Based on grain and calorie yields, maize monoculture and maize-pigeonpea intercropping may be equally important for resolving food insecurity; however, maize-pigeonpea intercropping produces a variety of nutrients (such as protein) and may be more appropriate for managing malnutrition. Notwithstanding the possible advantages and increased pigeonpea adoption and consumption. The labor and financial costs and benefits of intercropping also have an impact on its utilization. Intercropping increases labor demand, but yield also increases to a similar extent, as seen by the highly varied and generally around one change in crop output per unit labor input (Dahlin and Rusinamhodzi, 2019) [20]. According to Hammerstein *et al.* (2017) [5], intercropping often boosts gross earnings, although there can be a lot of variation based on other management techniques. These variations highlight how crucial it is to match systems to specific community requirements as well as dangers (Sinclair and Coe, 2019) [24].

Conclusions

It is well known that intercropping systems of grain and legumes can maintain soil health by enhancing physical, chemical, and biological soil characteristics while also

increasing production and profitability. As a result, there aren't many studies on how additive maize-legume intercropping affects smallholder maize systems with limited resources' yield sensitivity to drought. The effects of intercropping will probably differ depending on the temperature, edaphic conditions, and the length and severity of drought stress. We offer concrete proof that, in light of climate change, intercropping may be used to diversify maize-based cropping systems and increase productivity in low-input smallholder systems under both drought and non-drought circumstances.

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