Review | Egyptian Journal of Agricultural Research | Agronomy

Encourage farmers to adopt sustainable water and nutrient management in arid agroecosystems: problems, solutions and future studies

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Received:19.03.2021; **Accepted**: 27.05.2021; **Published:** 27.05.2021 10.21608/ejar.2021.68612.1096

ABSTRACT
Crop production is seriously threatened by drought. Greater availability of nitrogen and phosphorus through intercropping with grain legumes and inoculationwith Phosphate Solubilizing Bactaeria (PSB) can alleviate the negative effect of water stress on some crops. However, row crop-grain legume intercropping and using PSB bacteria is not welcomed or widely accepted by smallholder farmers in arid regions. The problem is that N-fixation by grain legumes cannot completely satisfy nitrogen demand of intercropped non-legume row crop especially in low phosphorus soils of these regions under restricted irrigation. The efficiency of PSB bacteria also is very low in the alkaline soil of this region. It suggests that some amount of nitrogen fertilizer should be used in this intercropping system. Nitrogen consumption also improves the efficiency of PSB bacteria. So, consumption of some mineral nitrogen, and incubation with PSB bacteria meet entirely the need for phosphorus fertilizer. Significant water saving by restricting irrigation without significant yield loss in row crop and grain legumes can be regarded as an advantage of this method. So, farmers can cultivate more land with the same amount of water. In such a situation, even small foliage of the grain legumes, as green manure, can convince the farmers to use the row crop -grain legumes intercropping system even under restricted irrigation conditions. Futures studies must focus on a better understanding of competition and facilitation of two crops for water and nutrients. They also must pay attention to nitrogen × PSB bacteria, and Phosphorus × rhizobacteria synergic interactions on yield and resources use efficiency of both crops. These studies may help to better water and plant nutrition management in a way that it is environmentally safe and economical for farmers.
Keywords: Arid Regions, Agro-ecology, Fertilizer, Irrigation, Organic Farming

Organic farming benefits the environment builds healthy soil, supports water conservation and reduces field costs (Andrade *et al.,* 2012; Wang *et al.,* 2020). However, small-scale organic farming did not expectedly spread in arid regions (Min *et al.,* 2017; Stepien *et al.,* 2021). The main challenges of the organic farming systems in these regions include difficulties with soil nutrients and water management (Latati *et al.,* 2017), and consequently a reduction in crop yield and farmers' incomes. Intercropping is an interesting technology in organic farming to provide nitrogen for the system, and the mixture of a nitrogen-fixing legume and non-legume crops is the most common intercrop combination (Latati *et al.,* 2017; Dowling *et al.,* 2021). However, grain legumes are poor N-fixation crops in alkaline, Low-P and dry soils of arid regions (Jemo, *et al.,* 2010; Lazali and Drevon, 2021). Although the use of PSB bacteria is considered as a solution to increase soil phosphorus, their efficiency is very low due to water restriction and low soil nitrogen (Ding *et al.,* 2014; Hussian *et al.,* 2021). These organic methods will not be welcomed by farmers without an appropriate solution to the problems expressed. The purpose of this review article is to describe the problem better, provide possible solutions and focus on future researches.

DESCRIPTION OF PROBLEMS

Crop production is seriously threatened by drought, especially in a climate change scenario and it may drastically affect world food security (Matiu *et al.,* 2017). A variety of agronomic techniques such as intercropping (Andrade *et al.,* 2012), organic matter (*Jami et al.,* 2019), biochar (Paneque *et al.,* 2016; Mannan *et al.,* 2021), mulching (Zhao *et al.,* 2016) and bio-fertilizers (Jalilian *et al.,* 2012; Hosseinzadeh *et al.,* 2021) w ith different results are used for row crops to alleviate water stress. The nitrogen and phosphorous uptake are hampered under moisture deficit stress (Dijkstra, *et al.,* 2015), so greater availability of nitrogen through intercropping with grain legumes (Andrade *et al.,* 2012), and phosphorus through incubation with PSB bacteria (Jalilian *et al.,* 2012), can alleviate the negative effect of water stress on some crops.

The use of grain legumes grown in intercropping with sunflower, corn, cotton or other non-grain legumes row crops are recommended to farmers as an organic method for introducing nitrogen into low-input cropping systems in arid regions (Latati *et al.,* 2017). However, it is not welcomed or widely accepted by smallholder farmers because it takes time for these intercropping systems to achieve significant net economic profit (Min *et al.,* 2017). There are some other limitations with this intercropping system: phosphorus precipitates with calcium and magnesium ions in alkaline soils of these areas, and therefore, it is not mostly absorbable for root and nodules (Shen *and Li,* 2011). Grain legumes are poor nitrogen fixers in these soils because rhizobium bacteria cannot access to phosphorus (Jemo *et al.,* 2010). Consequently, almost all these small amounts of fixed nitrogen directly enter the grain legume and there are only little leaks into the soil for a neighbouring non-grain legumes crop in intercropping (Corre-Hellou *et al.,* 2006). Therefore, this method is only efficient when using the grain legumes as green manure in rotation (Plaza-Bonilla *et al.,* 2016). However, because of the economic losses caused by the low grain yield of grain legumes in these low-phosphorus soils (Latati *et al.,* 2017), the smallholder farmers are reluctant to use the grain legumes as green manure and still prefer to use them for forage (Douxchamps *et al.,* 2013).

Limitation of absorbable P in these alkaline soils (Shen *et al.,* 2011), N deficiency due to inadequate N fixation by grain legumes in low P soil (Jemo, *et al.,* 2010), and water shortage in these semi-arid climates result in decreased grain yield of both crops due to intense intra-specific competition for these two nutrients and water (Latati *et al.,* 2017; Corre-Hellou et al., 2006; Andrade *et al.,* 2012). Yield loss of grain legumes is higher than row crop because the roots of the tall row crops such as sunflower, corn and cotton occupy soil both near the surface and in deep layers, whereas the roots of grain legumes are distributed in the upper soil layers (Albino-Garduno *et al.,* 2015), thus sunflower, corn or cotton competitive ability for soil nitrogen, phosphorus and water is higher than that of grain legumes in intercropping system (Latati *et al.,* 2017; Andrade *et al.,* 2012). For this reason, it is not affordable for the smallholder farmers to harvest grain legume, but they rather use them as forage in crop-livestock systems (Douxchamps *et al.,* 2014). Besides, nitrogen cannot return to the soil for the next crop in a rotation system through the decomposition of residues if all herbage is removed (Plaza-Bonilla *et al.,* 2016). Description of problems is shown in **Figure 1**.

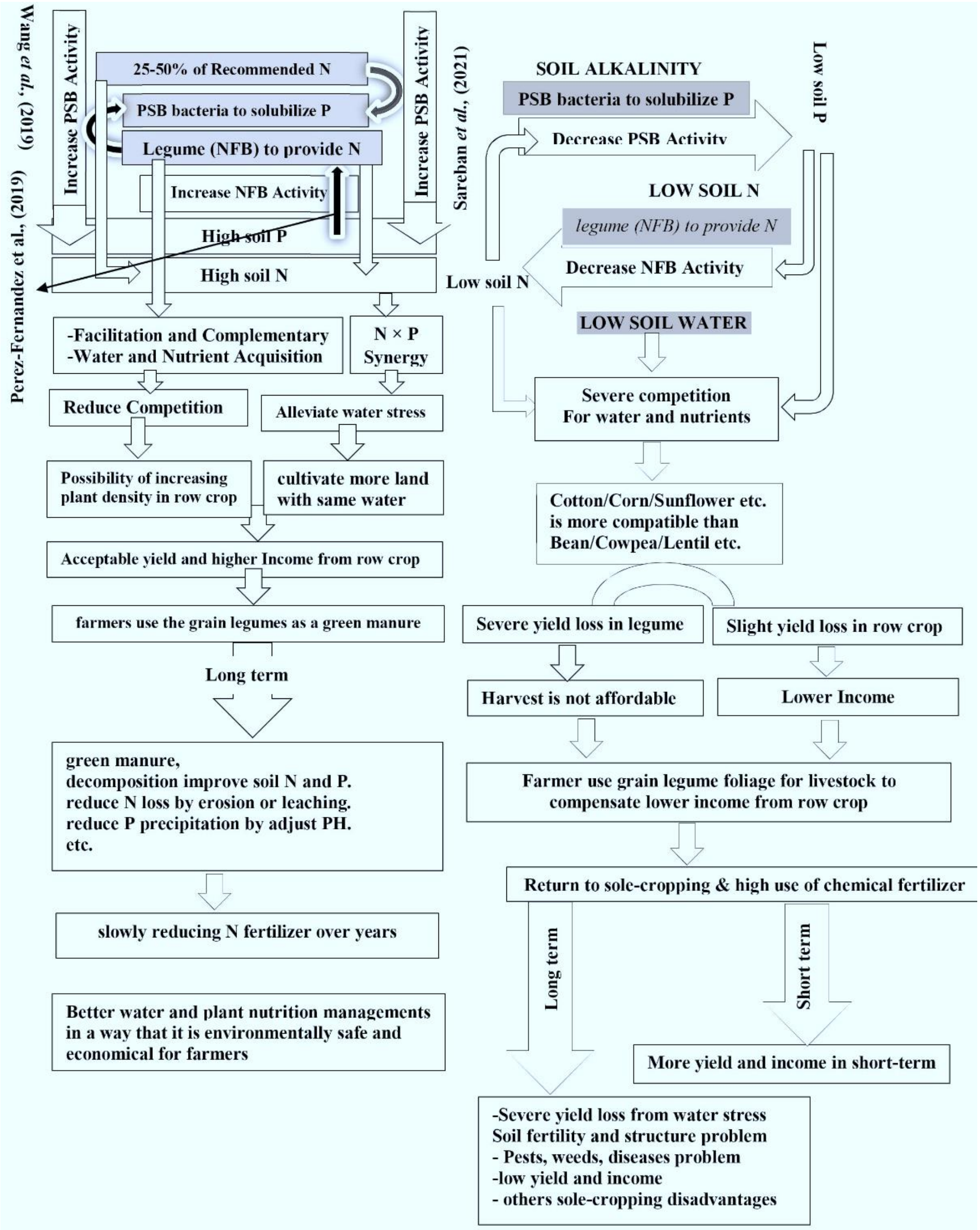

Figure 1. Description of Problems (right) and possible solutions (left) to sustainable water and nutrient management in arid agroecosystems.

POSSIBLE SOLUTIONS

The spatial distribution of roots indicates the root interaction of nutrients and water in intercropping system (Albino-Garduno *et al.,* 2015). nutrients have a relatively more uniform distribution in the soil layers, rather than water, which is more available in lower layers of the soil where sunflower, corn or cotton roots can access (Estrada *et al.,* 2015). So, the competition between these two crops appears to be mainly for nutrients especially nitrogen and phosphorus rather than water. Accordingly, the consumption of some nitrogen and incubation with PSB under both moderate and restricted irrigation may be considered as a solution for increasing nitrogen fixation by grain legumes, decreasing competition for nitrogen and phosphorus between sunflower, corn or cotton with grain legumes, and yield loss in both of these crops, and alleviating water stress in this row crop-grain legumes intercropping system.

Moreover, significant water saving by restricting irrigation without significant yield loss in row crop and grain legumes can be regarded as another advantage of this method, so that farmers can cultivate more land with the same amount of water. In such a situation, even a small foliage of the grain legumes, as green manure can convince the farmers to use the row crop -grain legumes intercropping system even under restricted irrigation conditions. Grain legumes cultivation for its grain or forage plays a negligible role in providing non-grain legumes row crops such as sunflower, corn or cotton with nitrogen in this system (Douxchamps *et al.,* 2014), but when it is used as green manure for long-term, it has very beneficial effects for the non-grain legumes row crops through increased organic matter, water retention in the soil, and nutrient availability (Plaza-Bonilla *et al.,* 2016). These will gradually reduce nitrogen fertilizer and the amount of irrigation in this system over several years (Plaza-Bonilla *et al.,* 2016; Douxchamps *et al.,* 2014). Efficient acquisition of nutrients and water is another advantage of using the intercropping system. Supplying some of the nitrogen required by the intercropping system is not the only benefit of grain legumes. Grain legumes cultivation increases the availability of phosphorus and water for the system:

Grain legumes could increase secretion H ion in the soil via N-fixation, this soil acidification improves the dissolution of phosphorous in low P soil. Li et al., (2016) reported that biomass and P uptake of the wheat in wheat-grain legumes intercropping were 1.3-1.9 and 1.9-2.3 times of mono-cropped wheat, respectively. Intercropping Promotes the Ability of Legume and Cereal to Facilitate Phosphorus and Nitrogen Acquisition through Root-Induced Processes (Latati *et al.,* 2016). Intercropping enhance the spatial distribution of soil-water across roots, improves the coordination of soil-water sharing and provides the compensatory effect of available soil water, improvement of soil water content facilitates absorption of nitrogen, phosphorus and other nutrients from the soil.

Reducing competition is not the only advantage of using nitrogen in this system. nitrogen consumption improves the efficiency of PSB bacteria. Ding et al. (2014) reported that nitrogen increased inorganic phosphorus uptake in soils with low phosphorus by improving the PSB performance. It has been reported that increased resistance of photosynthesis to water stress at higher nitrogen conditions (Singh *et al.,* 2016) in PSB incubated plants (Shintu and Jayaram, 2015) resulted from improved relative water content (RWC). Nitrogen × phosphorus interaction increases phosphorus uptake and consumption. Shen and Li (2011) also reported that water stress impaired PS II function in wheat, and this effect was significantly ameliorated by NP fertilizer but not N alone.

Eventually, phosphorus-related mechanisms such as better root system growth and synergy process induced by the N×P interaction result in increased relative water content (RWC) of the leaves and reduced chlorophyll fluorescence (Singh *et al.,* 2016;), thereby preventing a significant decrease in the yield of row-crop and grain legumes under restricted irrigation, and leading to increased WUE and improved nitrogen and phosphorus absorption and their use efficiencies. Possible solutions is shown in Figure 1.

FUTURE STUDIES

Future studies aim to find an efficient and accruable solution to alleviate water stress and decrease grain yield loss of row crops and grain legumes under restricted irrigation in a row crops-grain legumes intercropping system by water and plant nutrition management in a way that is environmentally safe and economical for farmers. They also must investigate the synergic nitrogen× PSB bacteria or nitrogen × phosphorus interactions effect on yield and water and nutrient use efficiencies in the sole and intercropped row crops under both moderate and restricted irrigation. Research must also seek to find out how the grain legumes are mainly useful for this system: directly through N-Fixation, or indirectly by providing more soluble phosphorus and water in the soil for crops and finally, it deals with the competition and facilitation between row crops and grain legumes underdifferent water and nutrient management. Phosphate solubilizing microorganisms (PSMs) and nitrogen fixation bacteria (NFBs) from rhizosphere soil of different crop plants and their inteactiuon must be evaluated to better benefit the plant-microbe interactions in organic agriculture. Future research must find solutions to troubleshooting the Practical Challenges of Intercropping, and breeding varieties and cultivars that are better suited for growing as part of a mixed crop.

CONCLUSION

Row crop-grain legume intercropping and using PSB bacteria is not welcomed or widely accepted by smallholder farmers in arid regions. The efficiency of PSB bacteria also is very low in alkaline soil of this region. N-fixation by grain legumes cannot satisfy nitrogen demand of row crop in low phosphorus soils of these regions under especially restricted irrigation.It can be concluded that intercropping with grain legumes, consumption of some nitrogen, and incubation with PSB bacteria increase PUE and completely meet the need for phosphorus fertilizer, alleviate water stress by P-related mechanisms and increase WUE. However, it seems that N-fixation by grain legumes cannot completely satisfy the nitrogen demand of sunflower, corn or cotton especially under restricted irrigation, and some nitrogen fertilizer should be used in this intercropping system to decrease crops competition for nitrogen, and benefit from the N× PSB or N×P interactions to alleviate water stress. Significant water saving by restricting irrigation without significant yield loss in row crop and grain legumes can let farmers to cultivate more land with the same amount of water. In such a situation, even a small foliage of the grain legumes, as green manure can convince the farmers to use the row crop -grain legumes intercropping system even under restricted irrigation conditions. Future studies must focus on organic methods in irrigation and plant nutrition, in a way that is environmentally safe and economical for farmers.

Funding: Not applicable.
Conflict of Interest: The authors declare no conflict of interest

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تشجيع المزارعين على الإدارة المستدامة للمياه والمغذيات في النظم الإيكولوجية الزراعية القاحلة: مراجعة مصغرة للمشاكل والحلول والدراسات المستقبلية

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الملخص العربى

يتعرض إنتاج المحاصيل لتهديد خطير بسبب الجفاف. زيادة توافر النيتروجين والفوسفور من خلال الزراعة البينية مع البقوليات والحضانة مع بكتيريا PSB يمكن أن يخفف التأثير السلبي للإجهاد المائي على بعض المحاصيل. ومع ذلك ، فإن الزراعة البينية للبقوليات والمحاصيل الصفية واستخدام بكتيريا PSB غير مرحب بها أو مقبولة على نطاق واسع من قبل المزارعين أصحاب الحيازات الصغيرة في المناطق القاحلة. تكمن المشكلة في أن تثبيت النيتروجين بواسطة البقوليات الحبيبية لا يمكن أن يلبي بشكل مكمل طلب النيتروجين لمحصول الصف خاصة في التربة منخفضة الفوسفور في هذه المناطق تحت الري المقيد. كفاءة بكتيريا PSB منخفضة جدًا في التربة القلوية في هذه المنطقة. يقترح أنه يجب استخدام بعض كمية الأسمدة النيتروجينية في نظام الزراعة البينية هذا. يحسن استهلاك النيتروجين أيضًا من كفاءة بكتيريا PSB. لذلك ، فإن استهلاك بعض النيتروجين ، والحضانة مع بكتيريا PSB يلبي تمامًا الحاجة إلى سماد الفوسفور. يمكن اعتبار توفير المياه بشكل كبير عن طريق تقييد الري دون خسارة كبيرة في الغلة في محصول الصف وبقوليات الحبوب كميزة لهذه الطريقة. لذلك ، يمكن للمزارعين زراعة المزيد من الأراضي بنفس كمية المياه. في مثل هذه الحالة ، حتى أوراق الشجر الصغيرة من بقوليات الحبوب ، مثل السماد الأخضر ، يمكن أن تقنع المزارعين باستخدام نظام زراعة المحاصيل الصفية والبقوليات حتى في ظل ظروف الري المقيدة. يجب أن تركز الدراسات المستقبلية على فهم أفضل للمنافسة وتسهيل محصولين للمياه والمغذيات. يجب عليهم أيضًا الانتباه إلى بكتيريا النيتروجين PSB × ، والتفاعلات التآزرية بين الفوسفور × البكتريا الجذرية على محصول ومصادر تستخدم كفاءة كلا المحصولين. قد تساعد هذه الدراسات في تحسين إدارات المياه وتغذية النبات بطريقة تكون آمنة بيئيًا واقتصادية للمزارعين.

الكلمات المفتاحية: المناطق الجافة ، الزراعة الإيكولوجية ، الأسمدة ، الري ، الزراعة العضوية