Mysore J. Agric. Sci., 55 (4) : 1-10 (2021)

Agronomic Research on Intercropping Millets and Pulses - A Review

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ABSTRACT

In recent years, there has been increasing recognition of the importance of millets in India. Millets are rich in many minerals and hence often termed as nutriacereals / nutraceuticals. In general, millets are cultivated mainly as rainfed crops. They are hardy crops that can be grown in very harsh climate, moisture and nutrient deficit soils, which reveals its importance in current climate change scenario. In addition, reducing land resources associated with poor soil fertility status leads to finding a better way for efficient resource utilisation with increased productivity. This situation can be achieved by adoption of efficient intercropping systems. Inclusion of legumes with millets can achieve higher net return, more crop equivalent yield with less cost of cultivation than sole cropping of millets. This review will be useful for the researchers who are involved in research on cropping systems involving millets and pulses.

Keywords : Millets, Pulses, Intercropping, Soil productivity, Yield

MILLETS have been cultivated for around 3,000 years making them an integral part of the culture in the history of India. Millets are not only food grains; they are still intricately interwoven in the socio-cultural fabric for numerous regions. They are known to be low in dietary bulk, high in nutrient content and known for its good profile of amino acids. Millets are highly nutritious and has antioxidant properties which provides balanced nutrition (Mishra *et al*., 2014). Among thirteen species in millets, sorghum (*Sorghum bicolor* L.) and pearl millet (*Pennisetum typhoides* L.) are considered as major, while finger millet (*Eleusine coracana* L.), barnyard millet (*Echinochloa frumentacea* L.), foxtail or Italian millet (*Setaria italica* L.), kodomillet (*Paspalum scrobiculatum* L.), little millet (*Panicumsumatrens* L.) and prosomillet (*Panicum miliaceum* L.) are smaller millets.

Millets are unique among cereals due to their richness in calcium, dietary fibre, polyphenols and protein (Devi *et al*., 2011). They generally contain significant amounts of essential amino acids including sulphur containing amino acids, *viz*., methionine and cysteine (Obilana and Manyasa, 2002). Though the crops pass both the heritage and health benefits, more focus has been given on rice, wheat and maize production after the green revolution. Millets have been neglected (NAAS, 2013; Padulosi *et al*., 2015 and Thakur & Sharma, 2018). Yet during recent years, they are regaining their pride owing to their nutritional value and ecological hardiness (Padulosi, 2011; Saha *et al*., 2016 and Bandyopadhyay *et al*., 2017).

Health Benefits of Millets in Relation to Controlling Life Style Diseases

All the millet foods are having significant health benefits, with their rich content of nutrients like fibre which helps in metabolic disorders like Diabetes, Obesity, Cardiovascular diseases etc. Millets are unique among the cereals because of their richness in calcium, dietary fibre, polyphenols and protein (Devi *et al*., 2011). Small millets are high energy, nutritious food comparable to other cereals and some of them are even better with regard to protein and mineral content. They are particularly low in phytic acid and rich in dietary fibre, iron, calcium and B vitamins. Thus, millets can act as a shield against nutritional deficiency disorders and provide nutritional security.

Millets offer several health benefits to consumers. They have excellent nutritional qualities and are comparable to some commonly consumed cereals like wheat and rice (Ragaee *et al.,* 2006). These crops lack gluten and hence can be consumed by people suffering from celiac disease (Gabrovska *et al.,* 2002).

Obesity is the biggest emerging problem in India and it is associated with several chronic diseases including diabetes and CVD. Recent studies show that intake of high dietary fibre decreases the incidence of obesity (Alfieri *et al*., 1995). Chethan, *et al*. (2007), reported that there is 15.7 per cent insoluble dietary fiber, 1.4 per cent soluble dietary fiber, in finger millet grain. The total dietary fibre (22.0%) of finger millet grain were reported to be relatively higher than that of many other cereal grains (e.g., 12.6, 4.6 and 12.8%, respectively for wheat, rice, maize and sorghum (Shobana & Malleshi, 2007 and Siwela *et al*., 2010).

Millet consumption can also lower glycemic response, which can be helpful for the treatment of type II diabetes (Choi *et al.,* 2005). Magnesium is an important mineral which helps in increasing the efficiency of Insulin and glucose receptors by producing many carbohydrate digesting enzymes, which manages insulin action. (Reddy, 2017). Millets which are known to be rich in phyto-chemicals which contains phytic acid helping in lowering cholesterol and preventing cardiovascular disease by reducing plasma triglycerides (Lee, *et al.,* 2010).

Inclusion of millets in the human diet can lower the risk of duodenal ulcers, anemia and constipation (Nambiar *et al.,* 2011). For patients suffering from allergic diseases such as atopic dermatitis, Japanese barnyard millet grains have been recommended to replace rice and wheat grains. (Watanabe and Mitsuru, 1999). It is showed that phenolics in millets are effective in preventing the cancer initiation and progression *in vitro* (Chandrasekara and Shahidi, 2011). Celiac disease is a genetically susceptible problem triggered by the consumption of gluten. As the millets are gluten free, they help in reducing the celiac disease by reducing the irritation caused by the common cereal grains which contain gluten. (Saleh *et al.,* 2013).

Climate Resilient Nature of Millets

Millets are climate-resilient crops adaptable to wide variety of ecological conditions requiring less water for irrigation with better growth and productivity in low nutrient soils. They also have short life-cycle which assists them from escaping stress as they require 12-14 weeks to complete their life-cycle whereas rice and wheat requires a maximum of 20-24 weeks. However, the prevalence of stress conditions and their consequences are circumvented by several traits such as short stature, small leaf area, thickened cell walls, and the capability to form dense root system (Li and Brutnell, 2011).

The C_4 photosynthetic of the millets is highly advantageous character. In C_4 system, carbon dioxide (CO_2) is concentrated around ribulose - 1, 5 - bisphosphate carboxylase / oxygenase (RuBisCO), which in turn suppresses ribulose 1, 5 - bisphosphate (RuBP) oxygenation and photorespiration (Aubry *et al*., 2011). Thus, C_4 mechanism enhances the concentration of CO_2 in bundle sheath, which suppresses photorespiration (around 80%) depending on the temperature and increases the *in planta* catalytic activity of RuBisCO (Sage *et al*., 2011). Since RuBisCO of C_4 plants works at elevated CO_2 levels, millets have enhanced photosynthetic rates at warm conditions and confers immediate water use efficiency (WUE) and nitrogen use efficiency (NUE) which are 1.5 to 4-fold higher than C_3 photosynthesis (Sage and Zhu, 2011). These attributes of millets make them next-generation crops holding the potential for research to explore the climate-resilient traits.

The increasing population of India is not only throwing challenges as higher food productivity but also it is high time that we must check the threats on nutritional security because of drastically changing climatic conditions environmental pollutions. This is high time that we must incorporate millets in agricultural biodiversification as a promising tool in overcoming the environmental stresses. We are in need of very strong and yet resilient agricultural sector supporting the livelihoods of tribal and rural populations and this can be enhanced by allowing these smart foods in our daily meals. Also, growing of a single crop in a year or cereals as sole crop is not so much remunerative in present scenario. There is an urgent requirement for incorporation of the pulses in millets production system to stabilize the production to feed the increasing population besides restoring the soil nutritional status. Hence some selective work has been reviewed here for understanding the beneficial effect of millets and pulses intercropping system.

Signifiacnce of Millets + Pulses Intercropping System

Agriculture in India faces many constraints like climate change and vagaries in rainfall, but millets are the crops which can tolerate and withstand varied climatic conditions. Even though these crops have higher nutritional and health benefits, the area under millets has been shrinking. This is mainly because of low productivity of millets when compared to other cereal crops and hence situation can be overcome by intercropping of millets.

Also, growing of millets and other crops in their pure stands is risky under rainfed and dryland conditions due to unpredictable rainfall and drought. Under such conditions to achieve guaranteed productivity, diversification of crops is inevitable. Among the crop diversification options, intercropping are considered as the most suitable for sustaining crop productivity (Bantie *et al*., 2014). Small millets are compatible for polyculture as mixed and intercropping, thus offering sustainable usage of available resources, providing food, nutrition and livelihood security to small holders in drylands (Kiwia *et al*., 2019 and Opole, 2019).

Intercropping is advantageous in many ways as it assures greater resource use, reduction of population of harmful biotic agents, higher resource conservation and soil health and more production and sustainability of the system (Maitra *et al*., 2019 and Maitra *et al*., 2020). The main advantage of intercropping are the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Launay *et al*., 2009).

In intercropping system, more than one crop is grown together on the same land and utilizes the soil nutrients (Xue *et al*., 2016; Chavan *et al*., 2017; Yang *et al*., 2018 and Jensen *et al*., 2020), soil moisture (Chen *et al*., 2018 and Singh *et al*., 2020), green house gas flux (Adler *et al*., 2007; Signor & Cerri, 2013 and Collins *et al*., 2017) sunlight (Kermah *et al*., 2017 and Raza *et al*., 2019) and also reduces run off (Zougmore *et al.,* 2000 and Banik *et al*., 2006). Crop diversification is also necessary to get higher yield and return besides maintaining soil health apart from other benefits like sustaining crop productivity (Yogesh *et al.,* 2014; Chai *et al*., 2014; Bantie *et al*., 2014 and Jan *et al*., 2016) and enabling diversity of beneficial soil microorganisms (Li & Wu, 2018 and Maitra & Ray, 2019).

Intercropping of legumes with cereals is a recognized practice for economizing the use of nitrogenous fertilizers and increasing the productivity and profitability per unit area and time. Also, presence of leguminous crops in the mixture benefits the associated non-leguminous crops, as they provide a portion of biologically fixed nitrogen to non-leguminous components (Kurdali *et al*., 2003). Hence, intercropping of pulses with millets will pave way for higher millet productivity besides increasing soil fertility (Gregorich *et al.,* 2001 and Gathumbi *et al.,* 2003).

Growth and Yield Attributes in an Millet - Pulse Intercropping System

One of the main reasons for the use of intercropping around the world is produced more than a pure cropping of same land amount (Caballero and Goicoechea, 1995). Intercropping with cereal and legume is a very common combination and it provides numerous advantages in terms of total productivity of crops (Yogesh *et al*., 2014). The yielding ability of a crop is reflected through its yield attributing characters. The yield attributes of little millet like number of productive tillers per hill and test weight was found to be increased when intercropped with pigeon pea at 6:1 ratio (Sharmili and Manoharan, 2018).

Basavarajappa *et al*. (2010) revealed that under shallow alfisols, higher foxtailmillet equivalent yield (5270 kg/ha) was recorded in foxtail millet and pigeonpea followed by foxtail millet and mesta (3053 kg/ha). Sharmili *et al*. (2019) stated that intercropping little millet with pigeonpea in 6:1 row ratio followed by sequential cropping of horsegram recorded higher grain and straw yield (1602 kg/ha grain yield and 4774 kg/ha straw yield, respectively). Maitra *et al.,* (2000) reported that finger millet produced more yield under intercropping with pigeon pea.

Sivagamy *et al*. (2020) presented that higher grain and straw yields were recorded little millet + pigeonpea followed by sequential crop of blackgram at 8:2 ratio (652 kg/ha grain yield and 1676 kg/ha straw yield, respectively) and it was on par with little millet + pigeonpea followed by horsegram sequence. According to Binod Kumar and Pankaj Kumar (2020) the maximum yield of finger millet (2010 kg/ha) was recorded when intercropped with black gram in 6:2 ratio. Nigade *et al*. (2012) also reported that intercropping of finger millet with blackgram or mothbean in 8:2 or 4:1 row proportion resulted in maximum grain and straw yield. Further, Milenkovic *et al.* (2019) reported that 1:1 ratio of soybean and proso millet in intercrop resulted in high biomass yield in Belgrade, Serbia.

Soil Health and its Effects in Alternate Cropping System

Intercropping of cereals with legumes is an excellent practice for reducing soil erosion and sustaining crop production. Moreover, deep roots of pulses like pigeonpea penetrate more while breaking up hardpans into the soil and utilize moisture and nutrients from deeper down in the soil. On the other hand, shallow roots of crops like millets bind the soil particle at the surface and thereby help to reduce erosion. Further, presence of leguminous crops in the mixture benefits the associated non-leguminous crops, as they provide a portion of biologically fixed nitrogen to non-leguminous components (Kurdali *et al*., 2003). Further, the leguminous crops increase content of nitrogen in soil and help in maintaining soil fertility (Gregorich *et al.,* 2001 and Gathumbi *et al.,* 2003).

In addition, legumes enrich soil by fixing the atmospheric nitrogen converting it from an inorganic form to forms that are available for plants uptake. Biological fixation of atmospheric nitrogen can replace nitrogen fertilization wholly or in part. Biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems when nitrogen fertilizer is limited. In addition, roots of the legume component can decompose and release nitrogen into the soil where it is made available to subsequent crops (Fujita *et al*., 1992).

Singh *et al*. (1998) reported that intercropping of legume, particularly blackgram with maize resulted in efficient utilization of the growth resources besides conservation of the soil health. Velayutham and Somasundaram (2000) indicated that intercropping of pulses with cereals and other non-legume companion crops have certain in-built advantages over pure cropping. Further they have recorded that, pulses leave 20 - 25 kg/ha of nitrogen inthe soil at the time of harvest, which is utilized by the subsequent crop and tremendous leaf fall will form best source of organic matter. Oberson *et al*. (2001) conducted a field experiment at the Carimagua Research Station, Colombia on maize + soybean and rice + cowpea intercropping systems and observed that legume-based cropping systems maintained higher organic and available P levels than non-legumes in rotation. Greater turnover of roots and above ground litter inlegume-based intercropping could provide steady organic inputs resulting in high P cycling and availability.

According to Lithourgidis *et al*. (2011) after the harvest of pulse intercrop, decaying roots and fallen leaves provide nitrogen and other nutrients for the next crop. Also, a report by Rahman *et al*. (2009) stated that residual effect of the pulse crop on the next crop is largest when the remains of the pulse are left on the field and ploughed after harvest.

Tripathi and Kushwaha (2013) reported that nutrient uptake by pearl millet in terms of N, P and K was significantly increased under intercropping system. Kalu Ram and Meena (2015) revealed that the intercropping of pearl millet with mungbean in 1:7 ratio recorded better nutrient uptake compared to sole and other intercropping treatments.

Plant Health and Weed Competitiveness in Millet - Pulse System

Traditionally intercrops have been practiced to smother the weeds which depends mainly on crop behaviour and weed growth. Intercrops may demonstrate weed control advantages over sole crops in two ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than sole crops in resources from weeds or by suppressing weed growth through allelopathy. Alternatively, intercrops may provide yield advantages without suppressing weed growth if intercrops use resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than sole crops (Geno and Geno, 2001).

According to Meena *et al.* (2017) intercropping of finger millet with pulses and oilseeds significantly reduced the weed population in the crop field because of more crop plant per unit area in intercropping systems which suppress the weed growth and also some crop plant act as trap crop or non-host crop which cause suicidal germination of parasite weeds and result in death of the weed plant due to lack of host plant.

The findings of Mutnal and Hosmani (1985) stated that there was a reduction in weed population under maize + cowpea intercropping system. Further, intercropping of cowpea, greengram, groundnut and soybean in sorghum crop would effectively reduce the weed population. Chandran (1987) stated that under sorghum and cowpea intercropping system there was a significant reduction in weed population.

Lawson *et al.* (2006) noticed that in maize-legume intercropping system, the growth of legume crops was found to be suppressed by the presence of weeds. Chandra *et al.* (2013) observed that weed biomass was higher in sole finger milletplots (250 kg/ha) compared to intercropping.

Economics of Millet-Legume Cropping Pattern

Economics of particular intercropping system is supposed to be the most important aspect from the crop production point of view. Intercropping aims at maximum production and net return per unit of space and time. Though the yield of main crop was reduced due to inclusion of component crop in intercropping systems, higher monetary return was recorded by many research workers.

Sharmili and Parasuraman (2018) conducted an experiment in Tiruvannamalai district of Tamil Nadu during *kharif* season to study the impact of intercropping little millet with pigeonpea and lablab bean on growth and productivity of crops. The study revealed that higher grain and straw yields were recorded in little millet + pigeonpea followed by sequential crop of horsegram at 6:1 ratio (1602 kg/ha grain yield and 4774.1 kg/ha straw yield, respectively) and it was on par with littlemillet + pigeonpea followed by sequential crop of mothbean at 6:1 ratio (1584.1 kg/ha grain yield and 4655.5 kg/ ha straw yield, respectively).

Murali *et al.* (2014) reported that intercropping of finger millet + pigeonpea (transplanted) gave maximum net returns Rs.26,218/ha with benefit: cost ratio of 2.49. Jakhar *et al.* (2015) revealed from his studies that strip cropping of finger millet + groundnut in 6:4 ratio resulted in maximum net returns and benefit: cost ratio. Also, in other studies conducted in finger millet by Ramamoorthy *et al.* (2003), net returns of Rs.23,277 /ha and benefit: cost ratio (5.90) were recorded under strip cropping of finger millet + pigeon pea as compared to sole crop of finger millet.

Girase *et al.* (2007) reported higher net monetary returns (Rs.14,617 /ha) and benefit-cost ratio (2.98) in the pearl millet + moth bean intercropping system. Sonawane *et al.* (2007) from their study, reported that the net returns and benefit cost ratio (Rs.17,021/ha and 2.31, respectively) were higher over the sole crop of pearl millet. Anchal Dass and Sudhishri (2010) recorded the highest net returns (Rs.9,665/ ha) and benefit cost: ratio (1.00) obtained with finger millet + pigeonpea (6:2).

The literature on economics of intercropping system clearly indicated that millet and pulse based intercropping system accounted for higher economic returns than sole cropping of millets.

Future Prospects / Road Map of Future Millet – Pulse Intercropping System in Agriculture

Although the history of millets and intercropping is age old, only very little attention is given towards intercropping small millets from researchers, farmers, and policy makers for sustaining crop productivity and nutritional security. Participatory research on farmers' field involving small and marginal farmers, extension workers and other related stakeholders is very much needed to create awareness on the role of pulse-based millet intercropping in which pulse crop has great role in fixing atmospheric nitrogen besides sustaining the productivity and improving soil quality and economic profitability with additional benefit of nutritional security with diversified cropping.

The potential of intercropping is well known for multifaceted benefits like greater resource use, reduction of population of harmful biotic agents, higher resource conservation and soil health and agricultural sustainability. These benefits are prominently pronounced in drylands. On the other hand, small millets are important ecologically hardycrops of drylands which can provide food and nutritional security to small holders. On the basis of available literature studied it could be said that intercropping small millets in drylands is one of the suitable options for ecologically sound agriculture.

References

Adler, P. R., Del Grosso, S. J. and Parton, W. J., 2007, Life cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. *Ecological Applications,* **17** : 675 - 91.

Alfieri, M. A. H., Pomerleau, J., Grace, D. M. and Anderson, L., 1995, Fiber intake of normal weight, moderately obese and severely obese subjects. *Obesity Research,* **3** (6) : 541 - 547.

Anchal Dass and Sudhishri, S., 2010, Intercropping finger millet (*Eleusine coracana*) with pulses for enhanced productivity, resource conservation and soil fertility in uplands of Southern Orissa. *Indian Journal of Agronomy,* **55** : 89 - 94.

Aubry, S., Brown, N. J. and Hibberd, J. M., 2011, The role of proteins in C3 plants prior to their recruitment into the C4 pathway. *Journal of Experimental Botany*, **62** : 3049 - 3059.

Bandyopadhyay, T., Mehanathan, M. and Prasad, M., 2017, millets for next generation climate smart agriculture. *Frontiers Plant Science*, **8**.

Banik, P., Midya, A., Sarkar, B. K. and Ghosh, S. S., 2006, Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. *European Journal of Agronomy,* **24** : 325 - 332.

Bantie, Y., Fetien, A. and Tadesse, D., 2014, Competition indices of intercropped lupine (local) and small cereals in additive series in West Gojjam, North Western Ethiopia. *American Journal of Plant Science*, **5** : 1296 - 05.

Basavarajappa, R., Prabhakar, A. and Halikatti, S., 2010, Foxtail millet (*Setaria italica* L.) based inter cropping systems under shallow alfisols. *Karnataka Journal of Agricultural Sciences,* **16** (4).

Binod Kumar and Pankaj Kumar Ray, 2020, Performance of intercropping of legumes with finger millet (*Eleusine coracana*) for enhancing productivity, sustainability and economics in Koshi region of Bihar. *Journal of Pharmacognosy and Phytochemistry,* **9** (3) : 1568 - 1571.

Caballero, R. and Goicoechea, E. L., 1995, Forage yield quality of common vetch and oat sown varying seeding ratios and seeding rates of vetch. *Field Crops Research,* **41** : 135 - 140.

Chai, Q., Qin, A., Gan, Y. and Yu, A., 2014, Higher yield and lower carbon emission by intercropping maize with rape, pea and wheat in arid irrigation areas. *Agronomy for Sustainable Development*, **34** : 535 - 543.

CHANDRAN, S., 1987, Response of sorghum to nitrogen with and without weed control under sole and intercropping systems. *M.Sc., (Ag.) Thesis,* IARI, New Delhi, India.

CHANDRA, A., KANDARI, L. S., VIKRAM, S. N., MAIKHURI, R. K. AND RAO, K. S., 2013, Role of intercropping on production and land use efficiency in the central Himalaya, India. *International Journal of Environmental Science and Technology,* **8** : 105 - 113.

CHANDRASEKARA, A. AND SHAHIDI, F., 2011, Antiproliferative potential and DNA scission inhibitory activity of phenolics from whole millet grains. *Journal of Functional Foods,* **3** : 159 - 170.

CHAVAN, I. B., JAGTAP, D. N. AND MAHADKAR, U. V., 2017, Weed control efficiency and yield of finger millet [*Eleusine coracana* (L.) Gaertn.] influenced due to different establishment techniques, levels and time of application of nitrogen. *Farm Manage*, **2** : 108 - 113.

CHEN, G., KONG, X., GAN, Y., ZHANG, R., FENG, F., YU, A., ZHAO, C., WAN, S. AND CHAI, Q., 2018, Enhancing the systems productivity and water use efficiency through coordinated soil water sharing and compensation in strip intercropping. *Scientific Reports,* **8** : Article No. 10494. doi: 10.1038/ s41598-018-28612-6.

CHETHAN, S AND MALLESHI, N. G., 2007, Finger millet polyphenols: optimization of extraction and the effect of pH on their stability. *Food Chemistry,* **105** : 862 - 870.

CHOI, Y. Y., OSADA, K., ITO, Y., NAGASAWA, T., CHOI, M. R. AND NISHIZAWA, N., 2005, Effects of dietary protein of Korean foxtail millet on plasma adiponectin, HDL- cholesterol, andinsulin levels in genetically type 2 diabetic mice. *Bioscience, Biotechnology and Biochemistry*, **69** : 31 - 37.

COLLINS, H. P., FAY, P. A., KIMURA, E., FRANSEN, S. AND HIMES, A., 2017, Intercropping with switchgrass improves net greenhouse balance in hybrid poplar plantations on a sand soil. *Soil Science Society of America Journal*, **81** : 781 - 95.

DEVI, P. B., VIJAYABHARATHI, R., SATHYABAMA, S., MALLESHI, N. G. AND PRIYADARISINI, V. B., 2011, Health benefits of finger millet (*Eleusine coracana* L.) polyphenols and dietary fiber : A review - *Journal of food science and technology*, DOI: 10.1007/s13197-011-0584-9.

FUJITA, K., OFOSU-BUDU, K. G. AND OGATA, S., 1992, Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant and Soil*, **141** : 155 - 176.

GABROVSKA, D., FIEDLEROVA, V., HOLASOVA, M., MASKOVA, E., SMRCINOV, H., RYSOVA, J. AND HUTAR, M., 2002, The nutritional evaluation of underutilized cereals and buckwheat. *Food and nutrition bulletin*, **23** : 246 - 249.

GATHUMBI, S. M., CADISCH, G., BURESH, R. J. AND GILLER, K. E., 2003, Subsoil nitrogen capture in mixed legume stands as assessed by deep nitrogen placement. *Soil Science Society of America Journal*, **67** : 573 - 582.

GREGORICH, E. G., DRURY, C. F. AND BALDOCK, J. A., 2001, Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Canadian Journal of Soil Sciences*, **81** : 21 - 31.

GENO, L. AND GENO, B., 2001, Polyculture production: principle, benefits and risk of multiple cropping. A report for the Rural Industry Research and Development Corporation (RIRDC), Publication, No. 01134.

GIRASE, P. P., SONAWANE, P. D. AND WADILE, S. C., 2007, Effect of pearl millet (*Pennisetum glaucum*) based intercropping system on yield and economics of pearl millet on shallow soils under rainfed conditions. *International Journal of Agricultural Sciences*, **3** : 192 - 193.

JAN, R., SAXENA, A., JAN, R., KHANDAY, M. AND JAN, R., 2016, Intercropping indices and yield attributes of maize and black cowpea under various planting pattern. *The Bioscan*, **11** : 1 - 5.

JENSEN, E. S., CARLSSON, G. AND HAUGGAARD-NILESEN, H., 2020, Intercropping grain legumes and cereals improves use of soil N resources and reduces the requirement of synthetic fertilizer N : a global scale analysis. *Agronomy for Sustainable Development*, **40**.

Kalu Ram and Meena, R. S., 2015, Evaluation of pearl millet and mungbean intercropping systems in arid region of Rajasthan. *Bangladesh Journal of Botany*, **43** : 367 - 370.

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D. K., Abaidoo, R. C. and Giller, K. E., 2017, Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea of northern Ghana. *Field Crops Research,* **213** : 38 - 50.

Kiwia, A., Kimani, D., Harawa, R., Jama, B. and Sileshi, G., 2019, Sustainable intensification with cereal-legume intercropping in Eastern and Southern Africa. *Sustainability*, **11** : 1 - 18.

Kurdali, F., Janat, M. and Khalifa, K., 2003, Growth and nitrogen fixation and uptake in Dhaincha / Sorghum intercropping system under saline and non-saline conditions. *Community of Soil Sciences and Plant Analysis*, **34** : 2471 - 2494.

Lawson, Y. D. I., Dzomeku, I. K., Asempa, R. and Benson, S., 2006, Weed control in maize using Mucuna and Canavalia as intercrops in the Northern Guinea Savanna zone of Ghana. *Journal of Agronomy*, **5** : 621 - 625.

Launay, M., Brisson, N., Satger, S., Hauggaard-Nielsen H., Corre - Hellou, G., Kasynova, E., Ruske, R., Jensen, E. S. and Gooding, M. J., 2009, Exploring options for managing strategies for pea-barley intercropping using a modelling approach. *European Journal of Agronomy*, **31** : 85 - 98.

Lee, S. H., Chung, I. M., Cha, Y. S. and Parka, Y., 2010, Millet consumption decreased serum concentration of triglyceride and C - reactive protein but not oxidative status in hyper lipidemic rats. *Nutrition Research*, **30** : 29 - 296.

Li, P. and Brutnell, T. P., 2011. *Setariaviridis* and *Setariaitalica*, model genetic systems for the panicoid grasses. *Journal of Experimental Botany,* **62** : 3031 - 3037.

Li, S. and Wu, F., 2018, Diversity and co-occurrence patterns of soil bacterial and fungal communities in seven intercropping systems. *Frontiers in Microbiology*, **9** : 15 - 21.

Lithourgidis, A. S., Vasilakoglou, I. B., Dhima, K. V., Dordas, C. A., and Yiakoulaki, M. D., 2011, Annual intercrops: an alternative pathway for sustainable agriculture. Review article. *Amity Journal of Computational Sciences*, **5** : 396 - 410.

Maitra, S. and Ray, D. P., 2019, Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems : A review. *International Journal of Bioresource Science*, **6** : 11 - 19.

Maitra, S., Palai J. B., Manasa, P. and Prasanna Kumar D., 2019, Potential of Intercropping System in Sustaining Crop Productivity. *International Journal of Agriculture Environment and Biotechnology*, **12** : 39 - 45.

Maitra, S., Shankar, T. and Banerjee, P., 2020, Potential and advantages of maize-legume intercropping system. Intech. Open, London, U. K. DOI:10.5772/intech. open. 91722.

Meena, D. S., Gautam, C., Patidar, O. P., Singh, R., Meena, H. M., Vishwajith and Prakash, G., 2017, Management of finger millet based cropping systems for sustainable production. *International Journal of Current Microbiology and Applied Sciences*, **3** : 676 - 686.

Milenkovic, M., Simic, M., Brankov, M., Milojkovic - Opsenica, D., Kresovic, B. and Dragicevic, V., 2019, Intercropping of soybean and prosomillet for biomass production. *Journal on Processing and Energy in Agriculture,* **23** : 38 - 40.

Mishra, V., Yadav, N., Pandey, S. and Puranik, V., 2014, Bioactive components and nutritional evaluation of underutilized cereals. *Annals of Phytomedicine*, **3** : 46 - 49.

Murali, K. T., Sheshadri and Byregowda, M., 2014, Effect of pigeonpea transplanting on growth, yield and economics in sole and finger millet intercropping system under late sown condition. *Journal of Food Legume*, **27** : 28 - 31.

MUTNAL, S. AND HOSMANI, M., 1985, Weed smothering ability of legumes in maize (*Zea mays* L.) based on intercropping systems. *In* : Annual Conference of Indian Society of Weed Science.

NAAS, 2013, Role of millets in nutritional security of India, National Academy of Agricultural Sciences, New Delhi. Policy paper 66. Pp : 16.

NAMBIAR, V. S., DHADUK, J., SAREEN, N., SHAHU, T. AND DESAI, R., 2011, Potential functional implications of pearl millet (*Pennisetum glaucum*) in health and disease. *Journal of Applied Pharmaceutical Science*, **1** : 62.

NIGADE, R. D., KARAD, S. R AND MORE, S. M., 2012, Agronomic manipulations for enhancing productivity of finger millet based on intercropping system. *Advance Research Journal of Crop Improvement*, **3** (1) : 8 - 10.

OBILANA, A. B. AND MANYASA, E., 2002, Millets. *In*: P. S. Belton and J. R. N. Taylor (Eds.). Pseudo cereals and less common cereals: Grain properties and utilization potential. Springer-Verlag : New York. Pp: 177 - 217.

OBSERSON, A. FRIESEN, D. K., RAO I. M, BUHLER, S. AND FROSSARD. E., 2001, Phosphorus transformation in an oxisol under contrasting land - use systems : The role of the soil microbial biomass. *Plant and Soil*, **237** : 197 - 210.

OPOLE, R. A., 2019, Opportunities for enhancing production, utilization and marketing of finger millet in Africa. *African Journal of Food, Agriculture, Nutrition and Development*, **19** : 13863 - 13882.

PADULOSI, S., 2011, Unlocking the potential of minor millets. *Appropriate technology*, **38** : 21 - 23.

PADULOSI, S., MAL, B., KING, O. I. AND GOTOR, E., 2015, Minor millets as a central element of sustainability enhanced incomes, empowerment and nutrition in rural India. *Sustainability*, **7** : 8904 - 8933.

RAGAEE, S., ABDEL-AAL, E. S. M. AND NOAMAN, M., 2006, Antioxidant activity and nutrient composition of selected cereals for food use. *Food chemistry*, **98** : 32 - 38.

RAHMAN, M. M., AMANO, T. AND SHIRAIWA, T., 2009, Nitrogen use efficiency and recovery from N fertilizer under rice-based cropping systems. *Australian Journal of Crop Science*, **3** : 336 - 351.

RAMAMOORTHY, K., CHRISTOPHER LAURDURAJ, A., RADHAMANI, S., SANKARAN, N. AND THIYAGHORASAN, T. M., 2003, Effect of intercropping of field bean on productivity of finger millet under rainfed condition. *Crop Research*, **26** : 515 - 518.

RAZA, M. A., FENG, L. Y., VAN DER WREF, W., IQBAL, N., KHAN, I., HASSAN, M. J., ANSAR, M., CHEN, Y. K., XI, Z. J., SHI, J. Y., AHMED, M., YANG, F. AND YANG,W., 2019, Optimum leaf defoliation: a new approach for increasing nutrient uptake and land equivalent ratio of maize soybean relay intercropping system. *Field Crops Research,* **244.**

REDDY, O. S. K., 2017, Smart millet and human health**,** *Green Universe Environmental Services Society.*

SAGE, R. F., CHRISTIN, P. A. AND EDWARDS, E. A., 2011, The lineagesof C4 photosynthesis on planet Earth. *Journal of Experimental Botany,* **62** : 3155 - 3169.

SAGE, R. F. AND ZHU, X. G., 2011, Exploiting the engine of C4 photosynthesis. *Journal of Experimental Botany,* **62** : 2989 - 3000.

SAHA, D., GOWDA, M. V. C., ARYA, L., VERMA, M. AND BANSAL, K. C., 2016, Genetic and genomic resources of small millets.*Critical* Reviews in *Plant Sciences,* **35** : 56-79.

SALEH, A. S. M., ZHANG, Q., CHEN, J. ANDSHEN., 2013, Millet frains: Nutritional quality, processing and potential health benefits. Comprehensive reviews in Food Science and Food Safety, **12** : 281 - 295.

SHARMILI, K. AND MANOHARAN, S., 2018, Studies on intercropping in rainfed little millet (*Panicum sumatrense*). *International Journal of Current Microbiology and Applied Sciences*, **7** (2) : 323 - 327.

SHARMILI, K. AND PARASURAMAN, P., 2018, Effect of little millet-based pulses intercropping in rainfed conditions. *International Journal of Chemical Studies*, **6** : 1073 - 1075.

SHARMILI, K., PARASURAMAN, P. AND SIVAGAMY, K., 2019, Studies on intercropping in rainfed littlemillet (*Panicum sumatrense*). *International Journal of Current Microbiology and Applied Sciences*, **8** (3) : 299 - 304.

SHOBANA, S. AND MALLESHI, N. G., 2007, Preparation and functional properties of decorticated finger millet (*Eleusine coracana*). *Journal* of *Food Engineering,* **79** : 529 - 538.

SIGNOR, D. AND CERRI, C. P. E., 2013, Nitrous oxide emission in agricultural soils: A review. *Pesquisa Agropecuária Tropical,* **43** : 322 - 338.

SINGH, D., MATHIMARAN, N., BOLLER, T. AND KAHMEN, A., 2020, Deep-rooted pigeon pea promotes the water relations and survival of shallow rooted finger millet during drought-despite strong competitive interactions at ambient water availability. PLoS ONE 1**5**: Article No. 0228993. doi.org/10.1371/journal.pone. 0228993.

SINGH, M. K., THAKUR, R., VERMA. U. N., PAL, S. K. AND PASUPALAK, S., 1998, Productivity and nutrient management of maize + blackgram intercropping as affected by fertilizer and plant density management of blackgram. *Indian Journal of Agronomy*, **43** : 495 - 500.

SIVAGAMY, K., ANANTHI, K., KANNAN, P., VIJAYAKUMAR, M., SHARMILI, K., RAJESH, M., NIRMALAKUMARI, A. AND PARASURAMAN, P., 2020, Studies on agro techniques to improve the productivity and profitability of Samai + redgram intercropping system under rainfed conditions. *International Journal of Current Microbiology and Applied Sciences*, **9** (6) : 4126 - 4130.

SIWELA, M., TAYLOR, J. R. N., DE MILLIANO, W. A. J. AND DUODU, K. G., 2010, Influence of phenolics in finger millet on grain and malt fungal load, and malt quality. *Food Chemistry*, **121** : 443 - 449.

SONAWANE, P. D., RODGE, R. G. AND ATTARDE, D. R., 2007, Effect of fertilizer, biofertilizer, intercropping system on pearl millet under rainfed conditions. *Journal of Maharashtra Agricultural University*, **32** : 176 - 178.

THAKUR, S. S. AND SHARMA, H. O., 2018, Trend and growth of small millets production in Madhya Pradesh as compared to India. *International Journal of Agricultural Science*, **10** : 4983 - 4986.

TRIPATHI, A. K. AND KUSHWAHA, H. S., 2013, Performance of pearl millet (*Pennisetum glaucum*) intercropped with pigeonpea (*Cajanus cajan*) under varying fertility levels in the rainfed environment of Bundelkh and region. *Annals Agricultural Research New Series*, **34** : 36 - 43.

VELAYUTHAM, A. AND SOMASUNDARAM, E, 2000, Change of management of pulses intercropping system. *In*: Recent advances in pulse crop production technology. CAS training held at Centre for advanced studies in agronomy. 13 Sept - 30 Oct. Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

WATANABE AND MITSURU., 1999, Antioxidative phenolic compounds from Japanese barnyard millet (*Echinochloa utilis*) grains. *Journal of Agricultural and Food Chemistry*, **47** : 4500 - 4505.

XUE, Y., XIA, H., CHRISTIE, P., ZHANG, Z., LI, L. AND TANG, C., 2016, Crop acquisition of phosphorus, iron and zinc from soil in cereal / legume intercropping systems : A critical review. *Annals of Botany*, **117** : 363 - 377.

YANG, C., FAN, Z. AND CHAI, Q., 2018, Agronomic and economic benefits of pea/ maize intercropping systems in relation to N fertilizer and maize density. *Agronomy,* **8** : Article No. 52. 10.3390/ agronomy8040052.

YOGESH, S., HALIKATTI, S. I., HIREMATH, S. M., POTDAR, M. P., HARLAPUR, S. I. AND VENKATESH, H., 2014, Light use efficiency, productivity and profitability of maize and soybean intercropping as influenced by planting geometry and row proportion. *Karnataka Journal of Agricultural Science*, **27** : 1 - 4.

ZOUGMORE, R., KAMBOU, F. N., OUATTARA, K. AND GUILLOBEZ, S., 2000, Sorghum-cowpea intercropping: An effective technique against runoff and soil erosion in the Sahel (Saria, Burkina Faso). *Arid Land Research* and *Management*, **14** : 329 - 342.

(*Received :* August 2021 *Accepted :* October 2021)