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Review Article

SEED PRIMING-LOW COST TECHNOLOGY TO ENHANCE THE GROWTH AND YIELD OF CEREALS UNDER DROUGHT CONDITION

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Abstract: In many parts of the world water scarcity is becoming an increasingly important issue. Climate change predictions of increase in temperature, atmospheric CO_2 level and erratic rainfall mean that water will become even scarcer and scarcer. Since agriculture is the major water user, efficient use of water in agriculture is needed for conservation of this limited resource and to get higher productivity. Enhanced drought tolerance and increased water use- efficiency can be achieved by different strategies such as change of crops capable of producing acceptable yields under deficit irrigation or rainfed situations or developing genetically modified crops which can withstand drought condition or by strategies involving agronomic practices like different seed-priming methods such as hydro-priming, halo-priming, osmo-priming or use of microbial inoculants *etc.* particularly at on farm level.

Keywords: *Drought, Seed priming, Microbial inoculants, Growth, Yield*

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Introduction

Poor crop stand is one of the major abiotic constraints encountered by resource-poor farmers in marginal areas in India [1]. The main reasons for this include, use of low-quality seed, inadequate seedbed preparation, untimely sowing, poor sowing technique, inadequate soil moisture, adverse soil properties (*e.g.*, crusting) and high temperatures. Efficient and effective amelioration of these physical constraints is often beyond the control of resource-poor farmers in rainfed farming systems. A simple, low-cost, low-risk intervention; on-farm seed priming can, if refined and developed using farmer-participatory approaches, make a positive impact on farmers livelihoods by increasing the rate of crop emergence, thus increasing rates of crop development, reducing crop duration and raising yields [2]. Sorghum seedlings that germinated and emerged faster grew more vigorously and that rate of emergence could be increased by soaking the seeds overnight in water before sowing [3]. Similarly, there is ample literature indicating the beneficial use of on-farm seed priming in sorghum [4] and in maize [5].

Effect of seed priming on field performance of maize and sorghum

Soaking seeds in water (hydro-priming) before planting is not a new practice. Over the last 40 years, priming seeds with various substances has become a common seed treatment to induce drought tolerance in many field crops. In maize hydro-priming had pronounced effect on emergence of seedlings, its rate and early seedling growth of maize crop and it improved the field stand and plant growth, both at vegetative and at maturity stage in maize [6]. It was noted significantly faster emergence, taller and heavier seedlings and more leaves per plant (14 DAS) from maize seeds primed for longer than 8 h in India [7] and in Zimbabwe [8]. However, the number of root axes per plant was not increased relative to the non-primed treatment, until seeds had been primed for at least 14 h to 20h. Plant height and shoot dry weight of maize were increased by priming (without drying) [9]. The hydro-primed maize seed produced consistently and significantly longer shoots after 5 days than the untreated control [10]. In contrast, many scientists have reported that, the beneficial effect of hydro-priming persisted only till early vegetative growth of maize and failed to improve the plant height [11], shoot dry weight and leaf area of maize plants that had emerged on the same day [12]. Priming had no effect on number of root axes and leaf number of maize crops [13]. Work in Zimbabwe suggests inconsistent response of maize in a study where there was no significant effect of priming on final stand nor on relative growth rate and, although priming significantly reduced time to maturity from 113 to 100 days, there were few meaningful effects on other components of yield (test weight) [14] and no seed yield increases were noticed [15]. Additionally, priming is also known to induce drought tolerance in maize by reducing the ASI. Hydro-priming reduced the period to anthesis and silking of maize by about a day each. However, there was little effect of priming of maize plants emerging on the same day on time taken to flowering (days to pollen shedding and silking) [16]. In addition to its beneficial effect on growth of crop plants, priming is also known to increase the yield by its significant effect during drought on yield parameters of crops under study. The grain yield of maize was increased significantly by 16 percent as a result of increases in the number of grains per panicle and grain size [17]. Priming for 16-18 h resulted significant increases in grain yield ranging from 17 percent to 76 percent in 11 out of the 14 trials. The results of these studies indicated no case was the result of priming worse than not priming. There was little effect of priming of maize plants emerging on the same day on yield, cob length and grains per cob [18]. In researcher managed field trials, total dry matter (11.84Mgha^{-1}), stover yield (7.46Mgha^{-1}), cob yield (4.42Mgha^{-1}) and grain yield (3.39 Mg ha^{-1}) of maize were all significantly increased by priming with water. The same pattern was apparent for other components of yield (cob weight-79.7 g/cob, grain weight-60.9 g/cob, cob number-53414/ha, 1000-grain weight-227.3 g, grain number (240.6/cob), although differences between primed and not primed treatments were not consistently significant.

For the two principal economic products of the maize crop, priming with water alone increased grain yield by 14 percent and stover yield by 17 percent relative to using non-primed seed [19]. In addition to hydro-priming, osmo-priming of seeds (soaking seeds in osmoticals – Calcium chloride) also known to induce drought tolerance in crop plants. Since calcium is most important element in plant during stress or drought condition, has ability to change stomatal movement. Drought resistance in plants can be induced by pre-sowing soaking of seeds with 0.25 percent solution of $CaCl_2$ for 20 h and drying back to original moisture content [20]. In sorghum (Sorghum bicolor), plants raised from seeds treated with 100 mg per litre of solution of $CaCl_2$ had increased plant height, chlorophyll content and yield compared to plants raised from untreated seeds [21]. Seed treatment with agro- chemicals (0.25%, $CaCl_2$ 100 ppm) increased the plant height, LAI, LAD and dry matter accumulation at different growth stages in finger millet [22]. Hardening of seeds with 1 percent $CaCl_2$ for six hours increases grain yield in finger millet [23]. Among the different pre-sowing seed hardening treatments in wheat, seed soaked in 2.5 percent $CaCl_2$ produced significantly higher plant height (98.8 cm), effective tillers per plant (3.16), effective tillers per m (85.3), ear head length (7.90 cm), spikelets per ear head (18.09), grains per ear head (32.8), test weight (38.4 g), grain yield per plant (3.16 g), grain yield per ha (64,014 kg), biomass yield (16,465 kg ha^{-1}) and harvest index (38.58%) over control treatment [24]. In direct seeded fine rice, osmo-hardening ($CaCl_2$) significantly recorded higher number of tillers (684.7 m-2), number of panicles bearing tillers (545.7 m^{-2}), 1000-kernel weight (17.00 g), straw yield (10.13 t ha^{-1}), kernel yield (2.96 t ha^{-1}) compared to hydro-priming and control treatments. However, plant height, number of branches per panicle, number of kernels per panicle and harvest index were non-significant between hydro-priming and osmo-hardening treatment [25].

On-farm seed priming

The phrase 'on-farm seed priming', coined by Harris *et al*. (1999). Although not a new technique, on-farm seed priming has spread through participatory research.

In India and Zimbabwe Harris used participatory rural appraisal techniques to identify poor crop establishment as a major constraint on rainfed crop production by farmers. Almost 1250 on farm trials, considering the safe limits, were implemented by farmers in India for maize and upland rice between 1995 and 1998 and 91 trials for maize and sorghum in Zimbabwe in 1997-98. In each trial, farmers were asked to soak seeds overnight, surface dry it and sow in the normal way in a plot next to a plot with dry seed. In these study areas the farmers in each village evaluated the trials during farm walks and group discussions. Direct benefits in all crops included: faster emergence, better, more uniform stands, less need to re-sow, more vigorous plants, better drought tolerance, earlier flowering, earlier harvest and higher grain yield. In recent years, priming has been tested in over 1000 trials in India, Pakistan, Nepal, Bangladesh and Zimbabwe on a range of crops, including maize (*Zea mays*), and sorghum (*Sorghum bicolor* (L.) Moench) [26]. Fifty-three farmers tested maize-seed priming in the kharif season in 1996 in tribal areas of Rajasthan, Gujarat and Madhya Pradesh; India [27]. In the study area almost, all farmers thought that crops grown from primed seeds grew more vigorously, flowered and matured earlier and produced bigger cobs and higher yield than the crops grown from non-primed seeds. From 35 trials conducted, it was concluded that a mean increase in cob weight of 6 percent in maize. The farmers in the study area of seed priming reported that crops grown from primed seeds grew more vigorously, tolerated dry spells better, flowered earlier (typically 7-10 days) and matured earlier (8-10 days). In the similar way in two similar series of on-farm trials of seed priming in maize, mean yield increases of 6 percent (non-primed yield 4.4 Mg ha^{-1} and 33 percent (non-primed yield 3.1 Mg ha^{-1}) were recorded [28]. In farmer managed trials across different sites, priming led to a significant increase in maize grain yields by 105 kg ha^{-1} and 182 kg ha^{-1} higher than those from un-primed maize, a 14 percent increase during 1999-2000 and 2000-01, respectively [29]. The maize plants grown from primed seeds were consistently larger and also flowered and matured earlier than maize crop grown from non-primed seed. In addition, in six farmer implemented trials, total biomass (10.81 t ha^{-1}), straw yield (7.49 t ha^{-1}), cob yield (3.32 t ha^{-1}), grain yield (2.74 t ha^{-1}) of maize were significantly increased by priming with water (hydro-priming) as compared to non-primed treatment. In Zimbabwe forty farmers used primed sorghum seeds during the 1997 and 1998 season and most of the farmers agreed that priming accelerated emergence and plants flowered and matured earlier relative to that of sorghum grown from non-primed seeds [30]. On-farm seed priming in most reported literature focused on hydro-priming, but there are also reports on seed-priming using other media like osmoticals, microbial inoculants etc. There is now increasing evidence that the beneficial microbial populations can also enhance plant resistance to adverse water stress. Microbial inoculants prepared from *rhizobium, Azotobacter, Azospirillum* and phosphate solubilizing microorganisms are known to increase the yield of crops [31]. In addition to this, vesicular arbuscular mycorrhizae (VAM) and Plant Growth Promoting Rhizobacteria (PGPR) also play an important role in protecting the crops from adverse environmental stress such as drought and are known to have potential use in agriculture [32].

Effect of microbial inoculants on field performance of maize and sorghum

Growth and yield parameters

Microbial inoculants prepared from *Azospirillum*, *Azotobacter*, *Trichoderma viride* and Phosphate-solubilizing microorganisms are known to exert beneficial effects on plant growth [33]. In addition, the extra metrical fungal hyphae of VAM absorb large amounts of water and nutrients for the host root [34]. Apart from this, there are abundant microorganisms thriving in the rhizosphere soil [35] and are generally referred to as Plant Growth Promoting Rhizobacteria (PGPR) and have an impact on plant growth and development by facilitating the uptake of nutrients from the environment [36]. Inoculation of maize crop with an active strain of *Azospirillum brasilense*, a N_2 fixing bacteria, has a beneficial effect on maize vigour leading to increased chlorophyll content in plants and increased the shoot dry matter production [37] and thus its effect on growth promotion of maize seedling was found to be significant [38]. The maximum plant height of maize 102 cm was achieved with the treatment of *Glomus intraradices* [39]. Shoot dry weight of sorghum increased significantly above non-inoculated control by 27 percent 2 weeks after emergence [40]. In addition, *Azospirillum* inoculation will improve the physiological status of maize plant by ameliorating the harmful effects of water short fall during the flowering period which will help in increase in grain production [41]. Arbuscular mycorrhizal (AM) inoculated plants recorded higher shoot length (137.78 ± 7.80 to 138.13 ± 13.43 cm) and leaf number (12.00 ± 0.00 to 15.00 ± 0.00) as compared to uninoculated treatment at 75 DAS [42]. When sorghum and maize plants were inoculated with *Glomus fasciculatum* there was increase in shoot length (44.2 and 63.4 cm – maize, 50.6 and 72.3 cm – sorghum) at 30 and 60 DAS, respectively [43]. When maize plants were inoculated with VAM (*Glomus fasciculatum*) there was increase in shoot length of 65.0 and 92.1 cm at 30 and 60 DAS, respectively. *Pseudomonas fluorescens* PS1A12, *P. agglomerans* strain 050309, strain 370320 and strain 020315 significantly increased shoot dry matter of maize from 21 to 27 percent in Uzbekistan [44]. Apart from its effect on shoot growth, microbial inoculants significantly affect the root growth of crops understudy. Number of adventitious roots, the total adventitious root dry weight and root length increased significantly above non-inoculated controls by 24, 37 and 41 percent respectively, 2 weeks after emergence of sorghum plant and higher root dry weight of 0.26 g was recorded in maize upon inoculation with *Azospirillum* KBC_1 compared to control (0.21g) [45]. *Azospirillum* strain Sp6 IAA++ was found to enhance root length density especially in the arable layer (0-40 cm), in which it was significantly higher (32%) than the non-inoculated control (2.55 vs. 1.93 cm cm^{-3}) in sorghum [46]. Inoculation with rhizosphere microorganisms increased total root length (17%) and root length per unit root dry weight (35%) [47]. AM inoculated plants recorded higher root length (22.62 ± 0.86 cm) and root dry weight (2.09 ± 0.29 to 6.37 ± 1.17 g) as compared to uninoculated treatment at 75 DAS (Gupta *et al*., 2006). When maize plants were inoculated with VAM (*Glomus fasciculatum*) there was increase in root length 74.0 and 44.2 cm and root weight -18.6 and 18.9 g at 30 and 60 DAS, respectively. When sorghum and maize plants were inoculated with *Glomus fasciculatum* there was increase in root length (13.2 and 14.6 cm maize, 16.3 and 18.2 cm -sorghum) and root weight (5.1 and5.4 g- maize, 5.2 and 6.3 g -sorghum) at 30 and 60 DAS, respectively. Upon inoculation of maize with *A. lipoferum* CRT1, root biomass recorded were 1.14±0.25, 1.39±0.45, 1.48±0.07, 2.10±0.54, 2.93±0.88, 3.25±1.08 and

5.47±0.43 g and root length recorded were 52±24.7, 165±60.4, 406±69.4, 407±82.3, 659±68.5, 798±113.1 and 738±63.9 cm at 7, 10, 15, 20, 26, 30 and 35 DAS, respectively in France [48]. It was found that, world wide data accumulated over 20 years of inoculation experiments with *A. brasilense* concluded that this bacterium is capable of increasing the yield of agriculturally important crops in different soil and climatic condition [49]. Upon inoculation of maize seeds with *A. brasilense*, significant increase in maize productivity by 17 percent were noticed, while maize cob length increased from 13.6 to 14.4 cm [50]. Seed inoculation with either *Azotobacter* or *Azospirillum* produces higher grain, stover yield and yield parameters in maize compared to control [51]. In India it was reported that seed inoculation with *Azotobacter* strain No. 1 or *Azospirillum* significantly increased grain and fodder yield of sorghum [52]. In contrast, there was no increase in grain yield of maize (11,029 and 12,061 kg ha^{-1}) and 1000-grain dry weight (217.59 and 224.94 g) when inoculated with *A. brasilense* SP 245 and *A. irakense* respectively compared to control (11,395 kg ha^{-1} and 221.80 g of grain yield and 1000-grain dry weight respectively) [53]. Upon inoculation of sorghum with *A. brasilense* strains such as SP245lacZ, SP6gusA and SP6IAA++ gus A, the grain yield obtained were 7.58, 7.43 and 7.54 Mg ha^{-1}, respectively compared to control (6.90 Mg ha^{-1}) in Italy [54]. Percent root colonization of Vesicular Arbuscular Mycorrhizal (VAM) fungi Vesicular Arbuscular Mycorrhizal colonization is known to have a beneficial effect on plant growth. Many workers have linked this effect with the ability of VAM to affect the water relations in plants. The proportional response of maize to inoculation with VAM (*Glomus fasciculatum*) increased with increasing drought stress. The percent root colonization of VAM found to be higher in sorghum plants upon inoculation with *Arbuscular Mycorrhizal* (AM) fungi (37%) compared to control (15%) [55]. Similarly, when maize plants inoculated with AM fungi showed mycorrhization in their roots (5.67 to 84 %) whereas uninoculated plants had no mycorrhization (0%) [56]. The VAM percentage infection levels were 29.2 and 52.2 percent and 68.0 and 60.8 percent in maize and; 19.0 and 58.2 in sorghum at 30 and 60 DAS, respectively. The amount of extra radical hyphae found in non-mycorrhizal soils was only 8 percent (0.10 ± 0.003 m g^{-1}) of the amount found in mycorrhizal soil (1.30 ± 0.041 m g^{-1}). The mycorrhizal inoculum significantly increased the extent of AMF colonization of the root system (50 to 78%) compared to the uninoculated control treatments (10%) in China [57]. Given the obligate biotrophism of AM fungi it is logical that root colonization of AM fungi can be improved by the presence of certain microorganisms such as *Azospirillum, rhizobium, acetobacter, pseudomonas etc*. VAM infection levels in sorghum were significantly higher in plots where VAM was inoculated (42.5 and 47.4 in treatments NP + Ab/R + Bm + VAM – 50% N & P + *A. brasilensel Rhizobium* + *Bacillus megaterium* var. Phosphaticum+ VAM and 10 FYM + Ab/R + Bm + VAM, respectively) compared to those uninoculated with VAM (21%) [58]. Root colonization (%) of VAM fungi was 80.8 and 85.1 during 1999 and 2000 in the treatment which receives combined inoculation of *A. brasilense, Bacillus megaterium* var. Phosphaticum (PSM) and Arbuscular mycorrhizal fungi (*Glomus fasciculatum*) and it was 84.4 and 87.5-1999 and 2000, respectively in the treatment which receives combined inoculation of microorganisms along with 5 Mg of FYM compared to control (20.8 and 21.3% during 1999 and 2000, respectively) [59].

Enzyme activity

Enzyme activities in the soils have been suggested as potential indicator of soil quality. Dehydrogenase, urease and phosphatase are recognized as important soil enzymes. The measurement of activities of these enzymes has often been used as an index of microbial activity. Application of *A. brasilense* to maize plants at an inoculum concentration of 107 colony forming units (CFU) per plant increased the specific activity of the enzyme's alcohol dehydrogenase, acid phosphatases, glutamine synthetase, isocitrate dehydrogenase, malate dehydrogenase, pyruvate kinase and shikimate dehydrogenase in root extracts in Belgium. Increased activity of dehydrogenase was noticed in root cell when inoculated with *Azospirillum* compared to uninoculated control plant. Application of mixed inoculum (*A. brasilense*+ *Bacillus megaterium* var. Phosphaticum (PSM) + Arbuscular mycorrhizal fungi (AMF)) increased the dehydrogenase activity by 79 percent [60]. Upon inoculation with phosphobacteria, in maize and sorghum the phosphatase activity recorded was 24.57 and 32.38 micromoles g^{-1} h^{-1} respectively in Tamil Nadu (India)[61].

Conclusion

Seed priming is one of the low-cost technologies for combating the drought. It helps in significant increase in yield in cereals. Under soil moisture stress seed priming methods helped in maintaining higher plant water status thus helps to get higher yield.

Application of Review: In the recent years due to aberrant weather condition the yield levels of rainfed crops are decreasing and farmers are unable to manage the drought situation. In this context, this paper helps the farming community to adopt simple low-cost technology *i.e*., seed priming to combat drought.

Review Category: On-farm seed priming, microbial inoculants

Abbreviations: CO_2: Carbon Di-oxide, DAS: Days After Sowing, h: Hour, %: percent, Mg: Mega gram, ha: hectare, $CaCl_2$: Calcium Chloride, AMF: Arbuscular mycorrhizal fungi , CFU: colony forming units, FYM: Farm Yard Manure, N: Nitrogen, P: Phosphorous, ppm: Parts Per Million, LAI: Leaf Area Index, LAD: Leaf Area Duration, cm^3: cubic centimetre, kg-kilogram, m^2: Square meter, t: ton, VAM: Vesicular Arbuscular Mycorrhizal fungi , PGPR: Plant Growth Promoting Rhizobacteria, AM: Arbuscular Mycorrhizal Fungi, NAA: Naphthaleneacetic Acid, KNO_3: Potassium Nitrate

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References

[1] Harris D., Joshi A., Khan P.A., Gothkar P. and Sodhi P.S. (1999) *Experimental Agriculture*, 35, 15-29.
[2] Harris D., Pathan A.K., Gothkar P., Joshi A., Chivasa W. and Nyamudeza P. (2001a) *Agriculture System*,69 (1-2),151-164.
[3] Harris D. (1992) *In: Proceedings of the First Annual Scientific Conference of the SADCC/ODA land and water management programme Private BAG 00108, Gaborone, Botswana, October* 8-10, 1990, pp. 257-262.
[4] Chivasa W., Harris D., Chiduza C. and Nyamudeza P. (1998) *Journal of Applied Sciences Southern Africa*, 4 (2), 109–125.
[5] Murungu F.S., Chiduza C., Nyamudeza P., Clark L.J. and Whalley W.R. (2004a) *Experimental Agriculture*, 40, 23-36.

[6] Nagar R.P., Dadlani M. and Sharma S.P. (1998) *Seed Research*, 26 (1), 1-5.

[7] Harris D., Joshi A., Khan P.A., Gothkar P. and Sodhi P.S. (1999) *Experimental Agriculture*, 35, 15-29.

[8] Chivasa W., Harris D., Chiduza C., Mashingaidze A.B. and Nyamudeza P. (2000) *Tanzanian Journal of Agricultural Sciences*, 3 (2), 103-112.

[9] Al-Soqueer A.A. (2004) *Ph.D. Thesis, University of Nottingham, U.K*.

[10] Matthews S. and Hosseini M.K. (2007) *Seed Science and Technology*,35, 200-212.

[11] Basu S., Sharma S.P. and Daldani M. (2005) *Seed Research*, 33 (1), 24-27.

[12] Harris D., Rashid A., Hollington P.A., Jasi L. and Riches C. (2002) *In: Sustainable maize production systems for Nepal NARC and CIMMYT, Kathmandu*, 180-185.

[13] Murungu F.S., Chiduza C., Nyamudeza P., Clark L.J., Whalley W.R. and Finch-Savage W.E. (2004b) *Field Crops Research*, 89, 49-57.

[14] Basu S., Sharma S.P. and Daldani M. (2005) *Seed Research*, 33 (1), 24-27.

[15] Murungu F.S., Chiduza C., Nyamudeza P., Clark L.J. and Whalley W.R. (2004a) *Experimental Agriculture*, 40, 23-36.

[16] Nagar R.P., Dadlani M. and Sharma S.P. (1998) *Seed Research*, 26 (1), 1-5.

[17] Al-Soqueer A.A. (2004) *Ph.D. Thesis, University of Nottingham, U.K.*

[18] Murungu F.S., Chiduza C., Nyamudeza P., Clark L.J. and Whalley W.R. (2004a) *Experimental Agriculture*, 40, 23-36.

[19] Harris D., Rashid A., Miraj G., Arif M. and Shah H. (2007) *Field Crops Research*, 102,119-127.

[20] Pandey S.N. and Sinha B.K. (1999) *In: Pl. Physiology, Vikas Publishing Pvt. Ltd., New Delhi,* pp. 100-119.

[21] Kadiri M. and Hussaini M.A. (1999) *Global Journal of Pure and Applied Sciences*, 5,179-183.

[22] Maitra S., Ghosh D.C., Sounda G., Jana P.K. and Roy D.K. (1998) *Indian Agriculturist*, 42, 37-42.

[23] Kalarani M.K., Sivakumar R., Vanangamudi M. and Sujatha K.B. (2001) *Madras Agriculture Journal*, 88 (7-9),509-511.

[24] Ugale R.V. and Mungse H.B. (2001) *Journal of Maharashtra Agriculture University*, 26 (1), 103-104.

[25] Farooq M., Basra S.M.A., Tabassum R. and Afzal I. (2006b) *Plant Production Sciences*, 9 (4), 446-456.

[26] Harris D., Pathan A.K., Gothkar P., Joshi A., Chivasa W. and Nyamudeza P. (2001a) *Agriculture System*, 69 (1-2),151-164.

[27] Harris D., Joshi A., Khan P.A., Gothkar P. and Sodhi P.S. (1999) *Experimental Agriculture*, 35, 15-29.

[28] Harris D. and Mottram A. (2005) *In: Seed Science and Technology trends and advances (Ed. A.S. Basra) pp. 724-734. (The Howarth Press: New York).*

[29] Clark L.J., Whalley W.R. and Jones J.E. (2001) *Seventh Eastern and Southern Africa Regional Maize Conference,* 268-273.

[30] Harris D., Rashid A., Ali S. and Hollington P.A. (2004) *In "proceedings of the 8th Asian regional maize workshop: New technologies for the new millennium", pp.316-324. August 5-8, 2002, Bangkok, Thailand, Mexico, D.F: CIMMYT.*

[31] Gaur A., Rana J., Jalali B. and Chand H. (1990) *In: The National Conference on Mycorrhizae (1990; Hisar, India). Proceeding, Hisar, India, Trends in Mycorrhizal Research.*

[32] Basaglia M., Casella S., Peruch U., Poggiolini S., Vamerali T., Mosca G. and Vanderleyden P. (2003) *Plant and Soil*, 259, 71-75.

[33] Vessey J.K. (2003) *Plant and Soil*, 255, 571-586.

[34] Auge R.M., Stodola A.J.W., Tims J.E. and Saxton A.M. (2001) *Plant and Soil*, 230,87-97.

[35] McCully M.E. (2001) *Australian Journal of Plant Physiology*, 28, 983-990.

[36] Penrose D.M. and Glick B.R. (2003) *Physiology of Plant*, 118, 10-15.

[37] Woodard H.J. and Bly A. (2000) *Journal of Plant Nutrition*, 23 (1), 55-65.

[38] Casanovas E.M., Barassi C.A. and Sueldo R.J. (2000) *Cereal Research and Communication*, 28 (1-2), 25-32.

[39] Wu S. C., Cao Z. H., Li Z. G., Cheung K. C. and Wong M. H. (2005) *Geoderma*, 125, 145-154.

[40] Dobbelaere S., Croonenborghs A., Zhys A., Ptacck D. and Vanderleyden J. (2001) *Australian Journal of Plant Physiology*, 28, 871-879.

[41] Casanovas E.M., Barassi C.A., Andrade F.H. and Sueldo R.J. (2003) *Cereal Research and Communication*, 31 (3), 395-402.

[42] Gupta N., Rautaray S. and Basak U.C. (2006) *Mycorrhiza News*, 18 (3), 15-23.

[43] Aher R.K. (2003) *Mycorrhiza News*, 15 (3), 12-14.

[44] Egamberdiyeva D., Juraeva D., Gafurova L. and Hoflich G. (2002) *Proceedings of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, pp*. 239-244.

[45] Dobbelaere S., Croonenborghs A., Zhys A., Ptacck D. and Vanderleyden J. (2001) *Australian Journal of Plant Physiology*, 28, 871-879.

[46] Jacoud C., Job O., Wadoux P. and Bally R. (1999) *Canadian Journal of Microbiology*, 45, 339-342.

[47] Bertrand H., Plassard C., Pinochet X., Touraine B., Normand P. and CleyetMarel J.C. (2000) *Canadian Journal of Microbiology*, 46, 229-235.

[48] Zemrany H.E., Hallett P.D. and Bally R. (2007) *Plant and Soil*, 29, 109-118.

[49] Ganguly T.K. and Manna M.C. (1999) *Agriculture Review*, 20 (3/4), 220-228.

[50] Casanovas E.M., Barassi C.A. and Sueldo R.J. (2000) *Cereal Research and Communication*, 28 (1-2), 25-32.

[51] Laxminarayana K. (2001) *Indian Journal of Hill Farming*, 14 (2), 134-137.

[52] Raghuwanshi K.S., Pawar K.B. and Patil J.D. (1998) *New Phytology*, 139, 643-650.

[53] Dobbelaere S., Croonenborghs A., Zhys A., Ptacck D. and Vanderleyden J. (2001) *Australian Journal of Plant Physiology*, 28, 871-879.

[54] Basaglia M., Casella S., Peruch U., Poggiolini S., Vamerali T., Mosca G. and Vanderleyden P. (2003) *Plant and Soil*, 259, 71-75.

[55] Hameeda B., Harini G., Rupela O.P. and Reddy G. (2007) *Int. Sorghum Millets Newsletter*, 6 (1), 9-12.

[56] Gupta N., Rautaray S. and Basak U.C. (2006) *Mycorrhiza News*, 18 (3), 15-23.

[57] Wu S. C., Cao Z. H., Li Z. G., Cheung K. C. and Wong M. H. (2005) *Geoderma*, 125, 145-154.

[58] Saini V.K., Bhandri S.C. and Tarafdar J.C. (2004) *Field Crops Research*, 89,39-47.

[59] Saini V.K., Bhandri S.C. and Panwar J. (2005) *Indian Journal of Microbiology*,45 (2), 147-150.

[60] Ribando C.M., Paccusse A.N., Rondanini D.P. and Cura J.A. (2001) *Agricultura Tropica et Subtropica*, 31, 61-70.

[61] Ponmurugan P. and Gopi C. (2006) *African Journal of Biotechnology*, 5 (4), 348-350.