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Optimisation of Seedball Technology for Pearl Millet (*Pennisetum glaucum*) Production in the Sahel

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Introduction

Climatic factors (Graef and Haigis, 2001) and poor soil chemical fertility pose direct negative effects on pearl millet (*Pennisetum glaucum*) seedling establishment in the African Sahel and consequently reduce crop yield. The application of mineral fertilizers (Bationo *et al*., 1993), irrigation systems (Singh and Singh, 1995) and seed treatments (Rebafka *et al*., 1993; Bürkert, 1998) represent potential options to enhance seedling establishment. However, subsistence farmers cannot afford the cost of irrigation systems and mineral fertilization due to resource scarcity. The partially sophisticated skills required for seed priming and other treatments disable the local farmers. For instance, the seed treatment applied by Rebafka (1993) that significantly increased pearl millet yield requires a special seed coating machine. In addition, farmers' practice of dry sowing includes the risk of crop failures due to dry spells in the early season. The labour bottleneck associated with re-planting is resource demanding and toilsome. Resource-poor farmers, in particular the females, are thus discouraged from partaking in the production system.

As recommended by Schlecht *et al*. (2006), innovations addressing subsistence farmers should be as simple as possible. Cheap and free local materials are recommended. For instance, wood ash increased biomass production in tomatoes (Owolabi *et al*., 2003); charcoal and compost manure application increased rice and sorghum yield on highly weathered soils (Steiner *et al*., 2007). Fukuoka and Korn (2009) combined loamy soil, compost manure, water, and rice seeds to produce what he called the seedballs to be applied with dry sowing in semi-arid and arid areas. To date, there is no published information on how this technology needs to be designed in order to improve subsistence farmers' crop yield.

The present study was conducted to demonstrate the potential of "*the seedball technology*" - based on local materials - in improving pearl millet seedling establishment. The reasoning behind using this technology is that it can; i. increase the crop yield by effectively prolonging the growing period, ii. reduce the labour requirements for re-planting after crop failures arising from dry spells at the commencement of the rainy season, iii. reduce seed wastages through inserting a known amount of seeds into the planting pocket, iv. introduce other yield enhancing components like fertilizers and pesticides sensu lato.

Material and Methods

We conducted five pot experiments in the green houses and climate chambers of the University of Hohenheim, Germany. Herein, we report only the key methodologies and findings of our most important trials.

The growth media comprised of sandy soil collected from the subsoil of an Arenosol according to WRB (2007) close to Sandweier (48° 49' N, 8° 11' E), Germany. This material was chosen since it is extremely sandy (>90 w% sand) and chemically poor at low pH

(pH_{CaCl2} of 4.5), thus comparable to Arenosol material in the Sahel (Herrmann, 1996). Loam as binding agent was collected from the subsoil of a Luvisol (WRB 2006, FAO/ISRIC 2007) at the University of Hohenheim. The soil material was completely air-dried and sieved through a 2mm mesh.

Seven days filter paper and petri-dish germination test experiments were conducted on the pearl millet seeds prior to the seedball experiments. The latter were conducted in a completely randomized design, of six replicates per block. Sand, loam, and water were combined in different gravimetric ratios to obtain a paste that could then be formed into small seedballs. Afterwards ten pearl millet seeds were inserted. Normal sowing (sowing pocket) as used by the Sahelian farmers served as the absolute control (Ca). The seedball control did not receive any additives (Cb). As treatments, different levels of wood ash, charcoal, manure, NPK 15:15:15 mineral fertiliser, calcium nitrate tetrahydrate (CNT), and cattle urine were added to the seedballs. Balls of 1.0, 1.5, 2.0 and 2.5cm diameter size were produced and dried in less than 24 hours under ambient temperature to avoid germination of the seeds prior to the seedball sowing. Seedlings emergence, nutrient content and biomass variables were assessed after sowing. The investigated seedling establishment variables were the number of germinated seedlings, shoot dry matter, root length, and root dry matter. The number of germinated seedlings was manually counted. The shoots were carefully cut off and put in an envelope at harvest. The roots were carefully washed through a 2mm mesh, dried with lab tissue papers. Both materials were immediately dried at 58 – 60°C for 72 hours. For the root length assessment, the washed fresh roots were stored in 50% ethanol in plastic containers for two days. The stored roots were scanned with an EPSON Perfection V700 PHOTO dual lens scanner and the values of the root length obtained with WinRhizo software V2009c (Regent Instruments, Nepean, Canada). Each experiment had <40 days duration.

First Results

Our pre-germination tests showed high germination percentage of over 90% (Table 1). Most of the emerged seedlings were healthy with readiness to continue growing as was observed on the final germination count day.

Table 1: Germination percentage of the pearl millet seeds used for the seedball experiments

	Number of	Germinated	Not germinated	Germination
Test 1	400	374	26	93.5
Test 2	600	558	42	93.0

Based on pre-tests (Butzer, 2014), 80g sand + 50g loam + 25 ml water was considered the optimum gravimetric combination to produce seedballs. This way, the seedballs dried as fast as in twelve hours under ambient room temperature with no seeds germinating. The smaller the seedballs, the better the emergence rate (Fig. 1a). Consequently a diameter of 1-2 cm was considered optimum. Random spatial distribution of seeds within the seedballs proved to be optimal, too (Butzer, 2014). In contrast, arabic gum as binding agent highly inhibits germination (Fig. 1b) and should be avoided as a seedball additive (Mühlena, 2013). Significant increase in root (Fig. 2a) and shoot (Fig. 2b) dry matter was observed when adding sufficient N (1g NPK or 0.5g calcium nitrate tetrahydrate) or wood ash (as multi-element fertilizer with emphasis on water soluble K and P). Further results not shown here proved that wood ash and NPK as seedball additives, do not only enhance phosphorus and potassium nutrient uptake of seedlings but also augment root length and root diameter, and are therefore recommended as seedball additives.

Discussion

Seedballs with the right type and amount of additives improved nutrition and physiology of pearl millet seedlings, once emergence is achieved. The additive choice is important due to the

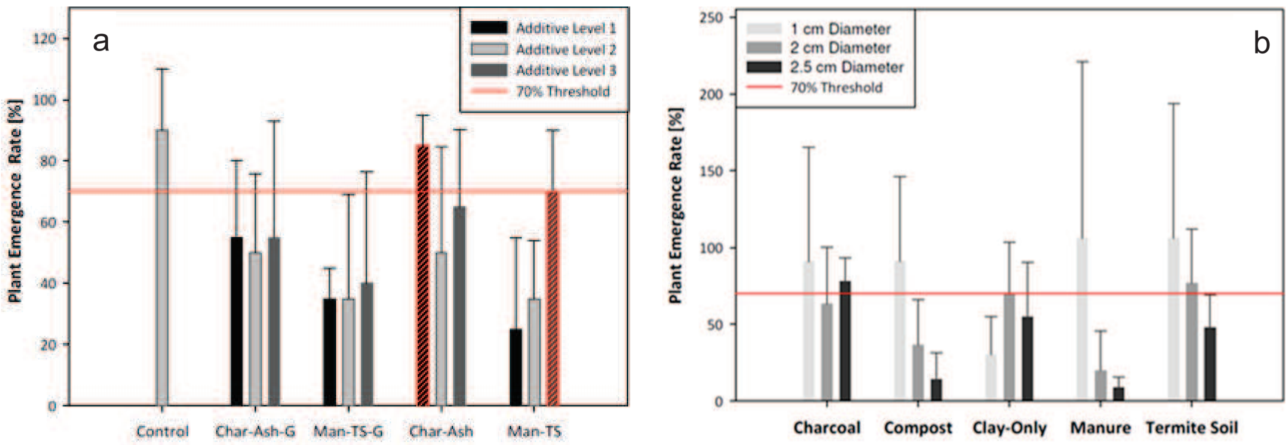

Figure 1: The graphs above show seedlings emergence of different seedball types at 70% threshold as affected by (a) seedball diameter size and (a,b) different additives. Bars show arithmetic means of n = 4 replicates and their standard deviations. Number of plants was counted 8 days after 15 mm rainwater simulation irrigation. Control was 5 seeds at 3 cm sowing depth while 1 cm, 2cm and 2.5 cm had 3, 8 and 14 seeds respectively. G = arabic gum, TS = termite soil, Man = manure Char = charcoal, and Ash = wood ash.

different effects. E.g. calcium nitrate tetrahydrate (CNT) containing seedballs produced a high biomass, but very weak seedlings. This is probably due to the lack of other essential nutrients. Early growth of pearl millet under Sahelian conditions is usually hampered by P and N deficiency (Rebafka et al. 1993, Herrmann 1996, Bürkert et al. 1998,). NPK fertilizer offers both nutrients, while wood ash contains small amounts of water soluble P, greater shares of water soluble K and increases the pH. Nutrient balancing should therefore be considered while selecting seedball additives.

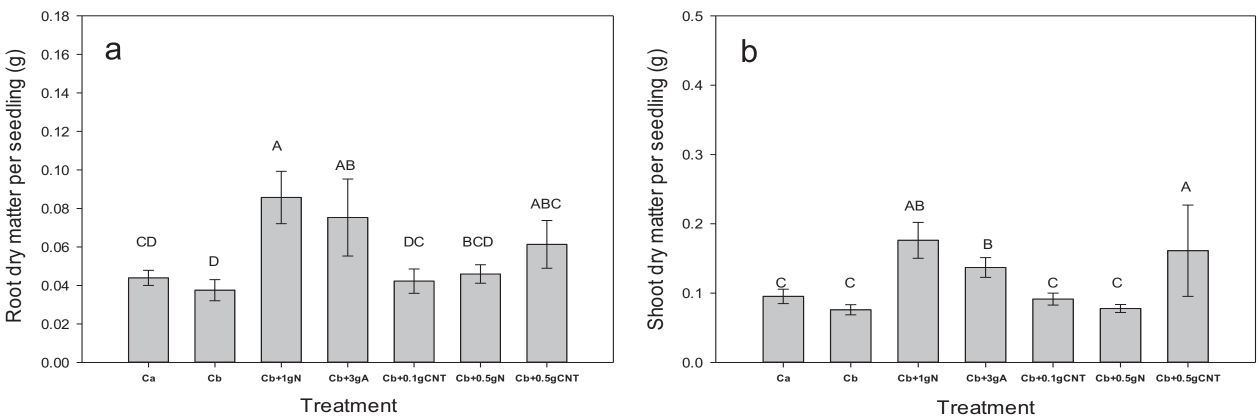

Figure 2: Graph of (a) root dry matter and (b) shoot dry matter per seedling of different treatments. Bars show arithmetic means and standard deviations, n = 6, comparison performed with one-way ANOVA. Different letters indicate significant difference (Tukey test, $p < 0.05$). Ca = non-pelleted seeds, Cb = 80g sand+50g clay+25g water, N = 15:15:15 NPK-mineral fertiliser, A = wood ash, and CNT = calcium nitrate tetrahydrate).

Summary and Outlook

The results of these studies proved that the right combination of clay, sand, and water, amended with the right doses of NPK 15:15:15 mineral fertiliser or wood ash as nutrient additives, at 1 to 2 cm seedball size and correct spatial seed arrangement (random) are effective in producing well-performing pearl millet seedlings compared to the traditional sowing method. Though only very low amounts of nutrients are introduced into the system this way, these are able to enhance early plant growth. The latter is of utmost importance under the given Sahelian climate and site conditions with a short growing season and extremely poor soil chemical conditions. Further experiments not shown here revealed that urea and ammonia containing fertiliser sensu lato should not serve as nutrient additives in the seedballs since these components inhibit germination. In the following, field trials in target Sahelian countries like

Senegal and Niger are to be conducted to ascertain the findings of these climate-controlled experiments before introducing the technology to Sahelian farmers.

The germination inhibition by arabic gum was attributed to two effects: i. the uptake of large water amounts by the gum before the water could reach the seeds (competition effect), and ii. the "hardening" effect that prevented the plumule and radical from extruding (physical effect). This adverse effect on germination was obvious in all the arabic gum containing seedball variants.

Ammonium that forms via hydrolysis of urea in the soil has been reported to inhibit germination (Bremner and Krogmeier, 1989). This could also be observed in ammonium and urea containing seedballs (Mühlena, 2013). Therefore, these N-sources should not be used in seedballs itself but can be applied to the seed pockets.

In conclusion, physically and chemically optimized seedballs produced healthier seedlings than the traditional planting method. This result is in agreement with the findings of Rebafka *et al.*, (1993) and Buerkert et al. (1998), who also reported healthier seedlings to significantly increase pearl millet overall yield in the field.

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