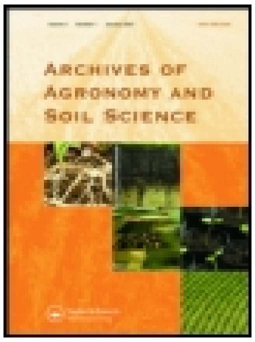

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Low-cost interventions for big impacts in dryland production systems

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ABSTRACT

A study at selected action sites in semi-arid region of Andhra Pradesh, India, showed widespread land degradation due to low levels of soil organic carbon (78% of fields) and deficiencies of available nutrients like phosphorus (34%), sulfur (93%), calcium (33%), zinc (84%), boron (73%), and copper (33%). Soil test-based addition of deficient micro- and macronutrients increased food grain production by 30–40% and straw (which is used as fodder) production by 10–30%. Micro-watershed scale low-cost cement-lined farm-ponds at smallholder farm level proved a scalable technology for drought-proofing of crops resulting into additional crop yield by more than 30% during 2015. Augmentation of water sources also facilitated farmers' to successfully diversify the production system. Shared machinery resources improved the operational and economic efficiency of farm sowing operations through higher crop yields by around 10%. We conclude that a mix of low-cost critical interventions if out-scaled in a large number of dryland small holdings through policy support may not only improve productivity and livelihoods, but also enhance their abilities to effectively cope with the climatic aberrations.

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On-farm mechanization; rainfed agriculture; rainwater management; soil health

Introduction

Dryland regions cover more than 40% of the world's land surface and support roughly 2.3 billion people which is about 30% of the world's population (CRP Dryland Systems 2018). Drylands are home to the poorest and most marginalized people in the world. In India, dryland ecosystems cover two-third of the area, contribute about 40% of the total food grain production and support two-thirds of the livestock population (CRIDA 2011; Haileslassie et al. 2016). The state of Andhra Pradesh in India, especially the Rayalseema region, represents typical semi-arid tropical drylands where present on-farm yields are 2–4 times lower than potential yield and highly variable. Moreover, the people living in such dry areas are projected to be affected the most with looming climate change (Kesava Rao and Wani 2016). Addressing the multiple issues of dryland production systems needs a huge investment of resources. Therefore, for quicker big gains, it is desirable that selected low-cost interventions that bring in maximum dividends and resilience be out-scaled in a large number of dryland farms.

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Water scarcity is one of the major factors for low crop productivity and vulnerability in dryland production systems (Wani et al. 2014). Even with irrigation expansion programs in a country like India, still around 45% of the area by the year 2050 will remain under rainfed production (Amarasinghe et al. 2007), where water scarcity is a major limiting factor and so is a major issue to be addressed as a priority. Better management of rainwater, soil moisture, and supplemental irrigation is the key to helping the greatest number of poor people, for three main reasons: (1) it cuts the yield losses from dry spells, (2) it gives farmers the security they need to risk investing in other inputs such as fertilizers and high-yielding varieties, and (3) it allows farmers to grow higher value market crops, such as vegetables or fruits (Comprehensive Assessment of Water Management in Agriculture 2007). In a scenario of variable climate and future climate change in drylands (Kesava Rao and Wani 2016), much reliance on rainfall may reduce farmers' ability to adapt to change and thereby, a key strategy is to minimize risk for dry spell induced crop failures, which requires an emphasis on rainwater harvesting systems for supplemental irrigation (Rockström et al. 2010). In a country like India, integrated watershed management is one of the tested and holistic options promoted to upgrade dryland agriculture through the integrated crop, water, soil, livestock, and other livelihood options (Wani et al. 2012, 2014). In a mix of watershed interventions, however, water augmentation at the farm level, often loses attention to the level it is desired. There are many success stories of intensification and diversification through water conservation at micro-watershed catchment (0–10 ha) scale farm-ponds in the drylands (Kumar et al. 2016; Srinivasa Rao et al. 2017). However, the spectrum of farm-pond technologies (Reddy et al. 2012), need to be aligned in the system-context to maintain low-cost and effectiveness for scaling-out. Increased access to water can have huge potential to empower and mainstream millions of dryland smallholders and so need to be the select technology to be evaluated in the system-context and scaled-out in most dryland farms. Alone with water, widespread soil degradation is another factor leading to stagnation of yields and declining water and input use efficiency. Mismanagement of soil resources in the past has led to widespread land degradation due to nutrient mining and declining soil carbon levels. Drylands are depleted not only in primary nutrients like nitrogen, phosphorus, and potassium but also secondary and micronutrients like sulfur, zinc, iron, and boron (Chander et al. 2013, 2014; Wani et al. 2015). Therefore, soil health mapping and need-based nutrient management are also a major focus intervention that can benefit the majority of the smallholders in the drylands with little investments on it. Another important issue is of the low level of on-farm mechanization which leads to the drudgery of smallholders, inefficient farm operations, and also distracts youth from farming. This is so a potential opportunity for smallholders in the drylands to not only harness economic benefits, but also reduce drudgery and time saving for farmers to engage in other productive activities.

Considering the above challenges and opportunities, the Consultative Group for International Agricultural Research led Program on Dryland Systems piloted on-farm participatory research for impact in the action sites in Andhra Pradesh, India, to improve productivity and livelihoods of the farmers. This paper attempts to evaluate the impact of low-cost context-specific interventions for enhancing productivity and resilience of smallholders' dryland production systems and their scaling up potential.

Materials and methods

Location and biophysical characteristics of study sites

Anantapur and Kurnool districts in the state of Andhra Pradesh, India (Figure 1), as action sites of the Program on Dryland Systems led by the Consultative Group for International Agricultural Research, represented the semi-arid tropical region in South Asia (ICARDA 2012). These sites were selected to represent typical farming systems in the region based on vulnerability maps (CRIDA 2011), available geospatial information like rainfall, population, soil, and expert opinion (Haileslassie et al. 2016). Two villages in each of selected districts;

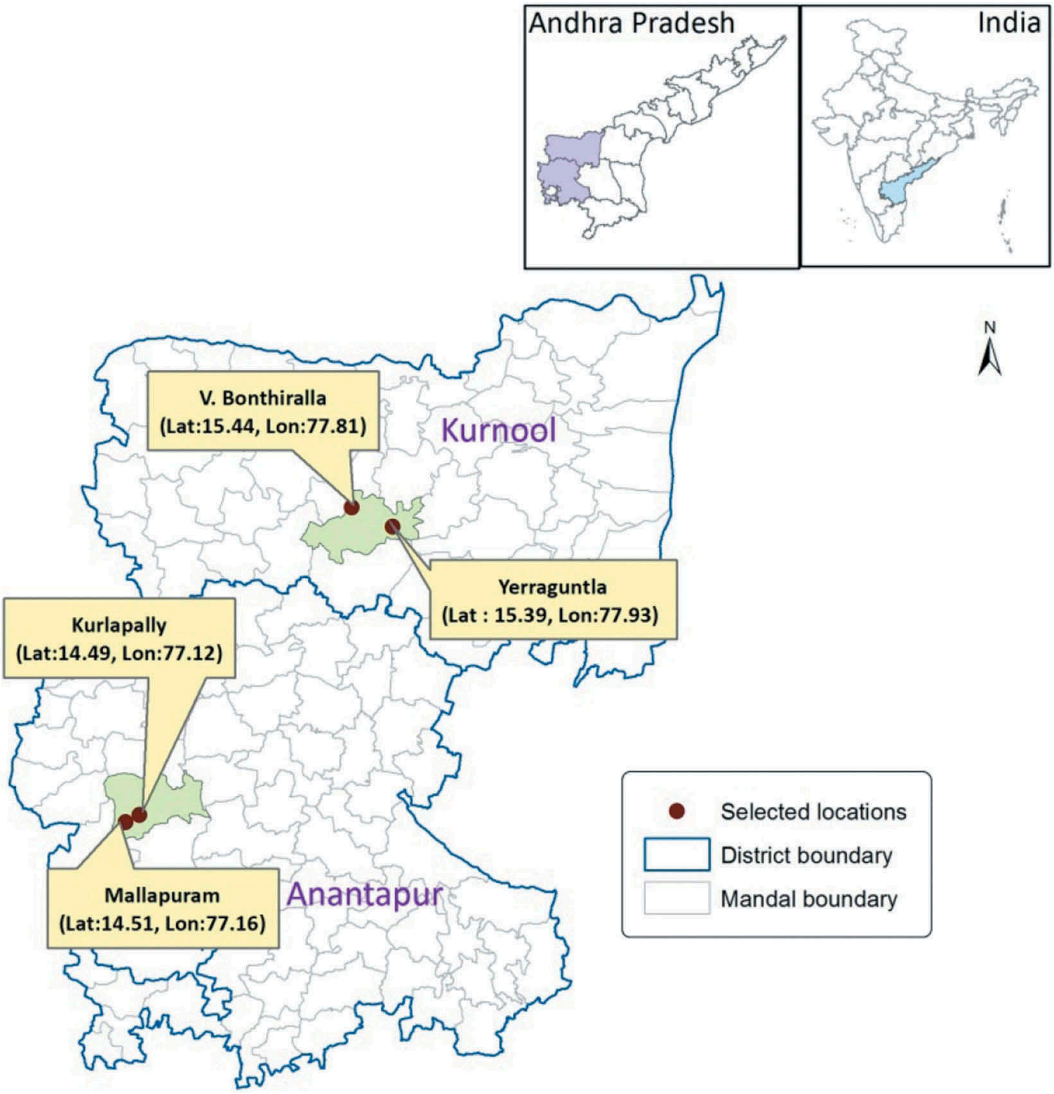

Figure 1. Location of study villages in Anantapur and Kurnool Districts, Andhra Pradesh, India.

Mallapuram and Kurlapally (Kalyandurg block) in Anantapur district and Yerraguntla and V. Bonthiralla (Dhone block) in Kurnool were identified in consultation with stakeholders. These sites were designated as action and learning sites on Dryland Systems (Figure 1). The action site villages in Anantapur and Kurnool receive only 540 mm of annual rainfall, most of it during South-West monsoon period (June–September). Rainfall variability is one of the major constraints limiting agricultural productivity in both these districts (Haileslassie et al. 2016). Annual mean maximum and minimum temperature in Anantapur is 34.2°C and 21.6°C, respectively, with comparable values recorded for Kurnool. At district scale, more than 33% of Kurnool and 78% of Anantapur land surface are dominated by red soils (or Alfisols). More than 59% of the Alfisols in Anantapur are described as shallow soils (<0.3 m depth).

Characterization of agricultural production systems in the study sites

The livelihoods of the majority of rural people in Kurnool and Anantapur districts and the study villages are dependent on agriculture. Despite the prevailing moisture stress and subsequent low crop productivity, a mixed crop-livestock agricultural system is the major source of income. The contribution of these livelihood activities to farm income shows disparities across seasons and among farmers. Groundnut (*Arachis hypogaea* L.) is the priority crop in Anantapur, while pulses such as pigeon-pea (*Cajanus cajan*) and chickpea (*Cicer arietinum* L.), in addition to groundnut, are the priority in Kurnool district (Haileslassie et al. 2013a, 2013b). Foxtail millet (*Setaria italica*) is also commonly included in cropping systems in Kurnool. The rainfed groundnut crop is mainly grown in the kharif or rainy (June to October rainfall) season, and is usually intercropped with pigeon pea or sunflower (*Helianthus annuus* L.). In Kurnool district, chickpea is also grown mostly on residual soil moisture in Vertisols (black soils) in the post-rainy season (November–April) (Haileslassie et al. 2013a, 2013b). District scale data shows that yields of rainfed crops are low, around 1000 kg ha^{-1} for groundnut in the rainy season and 2000 kg ha^{-1} in the post-rainy season under irrigated conditions (Craufurd and Haileslassie 2012; Haileslassie et al. 2013a).

Soil sampling for soil health diagnosis

For soil health mapping of study sites, soil samples were collected from farmers' fields during March–April 2014. A total of 120 surface (0–0.15 m) soil samples at the rate of 30 samples per village were collected by following a participatory stratified soil sampling method (Sahrawat et al. 2008). Under this method, we divided target villages in the districts into three topo-sequences. At each topo-sequence location, samples were taken proportionately from small, medium, and large farm-holding sizes to address the variations that may arise due to different management because of different economic status in each farm size class. Within each farm size class in a topo-sequence, the samples were chosen carefully to represent all possible soil fertility variations as judged from soil color, texture, cropping system, and agronomic management. In the selected sampling field at the farmer level, we collected 8–10 cores of surface (0–0.15 m) soil samples and mixed them together to make a composite sample. The samples were processed and analyzed for pH, EC, organic C, available – phosphorus (P) and potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) in Charles Renard Analytical Laboratory, ICRISAT (see details in 'Soil chemical analysis' section).

Soil chemical analysis

The soil samples were air dried, ground, and passed through a 2-mm sieve. For soil organic carbon, the soil samples were ground to pass through a 0.25 mm sieve and analyzed following the Walkley-Black method (Nelson and Sommers 1996). Soil pH was measured by glass electrode using soil to water ratio of 1:2. Available nutrients were extracted using the sodium bicarbonate for P (Olsen and Sommers 1982), ammonium acetate for K, Ca, and Mg (Helmke and Spark 1996), 0.15% calcium chloride for S (Tabatabai 1996), hot water for B (Keren 1996) and diethylene triamine pentaacetic acid (DTPA) reagent for Zn, Cu, Fe, and Mn (Lindsay and Norvell 1978). Available P was determined using a colorimetric method, and K, Ca, and Mg by atomic absorption spectrophotometry. Analyses of S, B, and Zn, Cu, Fe, and Mn were made using the inductively coupled plasma atomic emission spectroscopy.

Soil test-based fertilizer recommendations and participatory on-farm evaluation

On-farm participatory trials were conducted to evaluate the effects of soil test-based fertilization with prominent crops in action sites during 2015. There were two treatments: (1) farmers' practice

(FP, application of recommended N, P, and K); and (2) balanced nutrition (BN, applications of soil test-based N, P, K plus deficient S, Ca, B, Zn, Cu).

Based on soil analysis results, fertilizer recommendations were developed to apply limiting nutrients like S, B, Zn, and Cu along with N, P, and K. Soil test-based fertilizer recommendations were deduced at the village level. The critical values for delineating deficiency were 5.0 g kg^{-1} for organic C (indicates N level also), 5 mg kg^{-1} for P, 50 mg kg^{-1} for K, 10 mg kg^{-1} for S, 0.58 mg kg^{-1} for B, and 0.75 mg kg^{-1} for Zn (Sahrawat et al. 2010). For secondary and micronutrients, a full dose was added when >50% of fields in a village were deficient in a nutrient, half dose when 25–50% of fields were deficient, a one-fourth dose when 10–25% of fields were deficient and no dose when <10% of fields in a village were deficient. The recommended full doses for deficient secondary and micronutrients per ha per year were 100 kg gypsum [250–500 kg for groundnut] (S, Ca), 25 kg zinc sulfate (Zn, S), 2.5 kg borax (B), 1 kg copper sulfate (Cu, S). N, P, and K doses as per state fertilizer recommendations were added if the deficiency was in >50% fields and 75% of doses were added in case of <50% deficient fields in any nutrient in the village. As a result, 25% less P and K doses were added in the BN treatment across all the villages except Yerraguntla where a full dose of P was added as P deficiency was reported in 73% of fields. In the case of N, full doses were added except in Yerraguntla (37% fields with low soil C as the proxy for N), where a 75% dose of N was added. The state recommended dose of N, P_2O_5, and K_2O per ha were 20, 40, and 50 kg ha^{-1} for groundnut and 20, 20, and 0 kg ha^{-1} for foxtail millet, respectively. All the nutrients except N in non-legumes were added via basal fertilizer application. Nitrogen in non-legumes was added in three equal splits at sowing, 1 month after sowing and 2 months after sowing. The fertilizer sources for nutrients were urea (46% N) for N, DAP (diammonium phosphate; 46% P_2O_5, 18% N) for P and N, MOP (muriate of potash; 60% K_2O) for K, gypsum (15% S, Ca) for S and Ca, zinc sulfate (20% Zn) for Zn and S, copper sulfate (% Cu) for Cu and S, and borax (10% B) for B. The treatments were imposed on 2000 m^2 plots, without replicates on a farmer's field, side by side, and uniform crop management practices were ensured in both the treatments. Such trials were conducted with 122 farmers (79 with groundnut and 43 with foxtail millet) wherein the inputs S, B, Zn, and Cu were provided for 2000 m^2 to the participating farmers at 50% incentive (however, in the economic analysis, a full costing has been done).

Rainwater management

Water scarcity is one of the major factors for low crop productivity in dryland systems. The action sites in Andhra Pradesh receive only 540 mm of annual rainfall, most of it during South-West monsoon period. Frequent dry-spell occurrence during the growing period is even a greater risk adversely affecting crop yields. The water scarcity as identified by the stakeholders a major impediment for enhancing system level productivity, the research team in Dryland Systems action sites in Andhra Pradesh adopted a strategy to promote participatory construction of small-scale low-cost ponds at individual farm-scale for conserving rainwater (Supplemental Figure). Being at the farm scale, smallholders are at liberty to use water at will and when required without much logistics for transportation. Farmers were supported through the initiative in digging the pond and lining with cement and local sandy soil (in 1:8 ratio and 1–2 cm thick layer to check percolation losses). During 2015, about 32 farmers participated in the construction of small farm-ponds (10 m × 10 m × 2.5 m) – 6 each in Kurlapally and Mallapuram villages, and 10 each in Yerraguntla and V. Bonthirala villages (plus 8 constructed during 2014). The cost of each farm pond was about INR 25,000/- (US$373.1). Farmers also contributed their share (about 20–25% of total cost) through participating in digging farm pond and leveling the walls. Maintenance cost could be around INR 5000/- (US$74.6) on cement cost once in a period of 3–4 years for maintaining the lining. Farmers were trained for effective utilization of water for intensification, fodder development, and diversification to fruits and vegetables. Data were recorded to evaluate benefits in yields and net returns due to life-saving watering, establishment of fruit plants, and fodder and vegetable cultivation.

On-farm mechanization

To improve the operational and economic efficiency of farm operations and reduce drudgery and save the time of smallholder farmers to engage in productive work, on-farm mechanization was promoted on a custom hiring basis managed by the community. During 2015, mechanized sowing was evaluated through participatory trials in groundnut crop. Machinery was arranged through a custom hiring center and farmers met the operational costs. During 2015, 22 farmers in Kurlapally, 28 in Mallapuram, and 6 farmers in V. Bonthirala villages participated in this evaluation of mechanized sowing operations of groundnut. Data were recorded on operational costs and benefits to yield as compared with hand-sown areas.

Yield benefits and statistical and economic analysis

At maturity, the crop yield was recorded from 3 m × 3 m, i.e. total 9 m^2 in each of the treatments from which final yield per ha was calculated. Thus, in all fertilizer or rainwater or mechanization interventions conducted in farmers' fields, the improved practice treatment was compared with the farmers' practice treatment in either the same farmer's or a nearby farmer's field. Participating farmers for evaluating different interventions were spread across each village and all trials in a village for any intervention were used as replicates for statistical analysis. One-way analysis of variance (ANOVA) of the data collected on improved and farmers' practice has been done using Genstat software. As part of ANOVA, a least significant difference (LSD) was computed using Fisher's method to statistically compare the difference between mean yields of improved and farmers' practice.

To work out economic feasibility at farm level, the additional cost of micro- and secondary nutrient fertilizers was calculated for gypsum at INR 4/- (US$0.06) per kg, zinc sulfate at INR 42/- (US$0.63) per kg, copper sulfate at INR 190/- (US$2.84) per kg, and borax at INR 76/- (US$1.13) per kg. Additional returns were worked out at per kg farm gate price of INR 52/- (US$0.78) for groundnut, and INR 21/- (US$0.31) for foxtail millet (prevailing market price during 2015). The currency conversion factor is US$1 = INR 67 (7 June 2018).

Results and discussion

Soil health assessment

Soil organic C is an indicator of general soil health and 78% fields at the study locations were found to have low levels of organic C (Table 1). Three out of the four villages had a majority of fields with very low soil organic C levels. Adequate soil organic C levels are needed to regulate important soil processes, and hence the practices that augment soil organic C or enhance organic C turnover are most critical to rejuvenate degraded soils for realizing higher yields. Low levels of soil organic C also indicate N deficiency. P is the second most important nutrient from a plant nutrition point of view. Soils in study locations are in general adequate in P (only 34% deficient fields) indicating a need to optimize the use of P fertilizers. K is the third important primary nutrient from a fertilization point of view. However, the results showed all action site villages had soils with adequate K levels. The deficiencies were found in only 4% of the fields.

The use of secondary and micronutrient fertilizers by farmers in the study villages, in general, was negligible. However, S deficiencies were rampant – 93% of fields in the study areas were deficient. The results in the current scenario point out S as the most important secondary nutrient and fourth important nutrient to be considered for fertilizer application. Similarly, emerging Ca deficiencies were also observed (33% of all fields, with three out of four villages recording double-digit deficiency (27–60%) in Ca. These emerging deficiencies cannot be ignored and need to be taken care of through soil test-based application of Ca. However, with regard to Mg, the third secondary nutrient, all fields across action sites were found to have adequate levels and so there is no need to apply Mg fertilizers.

Table 1. Soil health status of farmers' fields in four study villages in Andhra Pradesh, India, 2014.

Village		pH	EC (dS m^{-1})	% fields with low soil Org C	% deficiency (range of contents) of available nutrients									
					P	K	Ca	Mg	S	Zn	B	Fe	Cu	Mn
Kurlapally	% Fields			90	20	3	43	0	83	73	77	3	27	0
	Mean	7	0.17	0.38	11.2	95	1256	249	12.7	0.68	0.45	6.50	0.67	18.9
	Range	5.9–8.2	0.03–1.19	(0.12–1.02)	(3.2–36.7)	(44–279)	(554–3912)	(113–813)	(1.7–114.8)	(0.2–1.92)	(0.14–1.53)	(0.46–15.72)	(0.31–1.75)	(4.14–37.5)
Mallapuram	% Fields			97	3	7	60	0	87	83	87	3	73	0
	Mean	7.1	0.15	0.27	10	75	1071	197	7.9	0.55	0.34	7.09	0.50	10.3
	Range	6.2–8	0.03–1.62	(0.15–1.18)	(4.8–20)	(38–237)	(372–3579	(80–771)	(1.9–87.3)	(0.26–1.12)	(0.15–1.17)	(1.3–17.76)	(0.22–1.54)	(2.86–16.58)
V. Bonthiralla	% Fields			90	40	7	27	0	100	93	90	0	27	0
	Mean	7.3	0.10	0.36	6.9	72	2123	284	3.6	0.43	0.33	8.84	0.89	13.5
	Range	6.3–8.5	0.03–0.23	(0.2–1.09)	(2.1–34.8)	(44–101)	(634–6158)	(100–747)	(1.7–9)	(0.18–3.02)	(0.15–0.9)	(2.52–18.46)	(0.31–2.69)	(3.54–27.32)
Yerraguntla	% Fields			37	73	0	3	0	100	87	40	0	3	0
	Mean	7.5	0.12	0.86	4.6	122	3121	323	5.1	0.52	0.60	5.91	1.12	16.9
	Range	7.1–7.9	0.05–0.21	(0.25–2.1)	(1.8–14)	(52–289)	(969–6393)	(134–571)	(2–9.5)	(0.14–1.16)	(0.2–1.04)	(2.7–9.6)	(0.42–1.81)	(5.62–31.42)
Total	% Fields			78	34	4	33	0	93	84	73	2	33	0
	Mean	7.2	0.13	0.47	8.2	91	1893	263	7.4	0.54	0.43	7.09	0.79	14.9
	Range	**5.9–8.5**	**0.03–1.62**	**(0.12–2.1)**	**(1.8–36.7)**	**(38–289)**	**(372–6393)**	**(80–813)**	**(1.7–114.8)**	**(0.14–3.02)**	**(0.14–1.53)**	**(0.46–18.46)**	**(0.22–2.69)**	**(2.86–37.5)**

Among micronutrients, widespread Zn deficiencies were found – 84% of fields in the Andhra Pradesh action sites. In all the study villages, a majority of fields had low Zn levels. Current situation required Zn application to be considered for harnessing yield potential. Boron is the next micronutrient widely deficient in 73% fields. Results establish B the second limiting micronutrient and therefore soil test-based addition of B is needed for getting higher yields in the dryland tropics. Copper deficiencies are also found in the study villages (33% fields). The deficiencies of micro- and secondary nutrients are apparently due to accelerated removal due to crop intensification in the recent past, while ignoring their addition into the soil (Sahrawat et al. 2010). The use of high analysis chemical fertilizers without micronutrients and decreasing use of organic manures have probably intensified the problem. The deficiencies of secondary and micronutrients are apparently the reason for the declining response to N and P fertilizers recorded by the farmers (Chander et al. 2016; Wani et al. 2016). The use of secondary nutrient S and micronutrients Zn and B has captured the attention of farmers in some tropical regions; however, the current results pointed out new deficiencies of secondary nutrient Ca and micronutrients like Cu, which also needs to be included in fertilization practices. When S is added through gypsum, the deficiencies of Ca are taken care of. But where another source of S is used, soil test-based application of Ca also needs to be practiced. New deficiencies are apparently due to progressive intensification in dryland systems. These results clearly establish the deficiencies of N, P along with S, Ca, Zn, B, and Cu as the apparent limiting factors and the need for their application.

Soil test-based nutrient management and benefits

During 2015, the crop cuttings showed yield levels of 1000–1200 kg ha^{-1} in groundnut and 700 kg ha^{-1} in foxtail millet under the farmers' practice (Table 2). Yield levels significantly increased under balanced fertilization – 1280–1570 kg ha^{-1} in groundnut and 930 kg ha^{-1} in foxtail millet, thus recording 28–32% increase in groundnut pod yield and 33% increase in foxtail millet grain yield. An economic assessment showed that small investments on soil test-based application of secondary and micronutrient fertilizers (INR 2350 (US$35.1) ha^{-1} in groundnut and INR 1550 (US $23.1) ha^{-1} in foxtail millet) brought significant additional net returns [INR 12,200 (US$(182.1) ha^{-1} to INR 16,900 (US$252.2) ha^{-1} in groundnut and INR 3300 (US$49.3) ha^{-1} in foxtail millet] for the smallholders. Every rupee spent on deficient secondary and micronutrient fertilizers returned INR 6.24 (US$0.09) to INR 8.24 (US$0.12) in case of groundnut and INR 3.13 (US$0.05) in case of foxtail millet. Similarly, straw yields also increased by 24–36% in groundnut and 15% in foxtail millet. Straw is used as fodder and its enhanced availability also strengthens livestock-based activities. There are also linkages to soil health and food (Chander et al. 2013; Sahrawat et al. 2013) and fodder (Haileslassie et al. 2013a) quality. Thus, small investments on deficient micro- and secondary nutrients significantly increased crop yields and benefits to farmers in the drylands.

Table 2. Effect of soil test-based application of micro- and secondary nutrients on crop yields, 2015.

		Pod/grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
Village	District	FP	BN	LSD (5%)	FP	BN	LSD (5%)
Groundnut							
Kurlapally	Anantapur	1000	1320	90	2190	2770	159
Mallapuram	Anantapur	1000	1280	85	2150	2660	140
V. Bonthiralla	Kurnool	1200	1570	154	2380	3240	349
Foxtail millet							
Yerraguntla	Kurnool	700	930	46	1070	1230	63

FP: farmers practice; BN: balanced nutrition.

Rainwater management

During 2015, pond farmers who could apply life-saving watering during long dry spells in groundnut recorded yields of 1230–1310 kg ha^{-1} compared to 930–1000 kg ha^{-1} by adjoining farmers without ponds (31–32% higher yields), which resulted in on an average 300 kg ha^{-1} additional yield worth INR 15,600 (US$232.8) ha^{-1} from a cultivated area of 1 ha in general of the participating farmers (Table 3). Along with grain, straw yield also increased by 18–21% and enhanced fodder availability as such. Life-saving watering thus helped farmers save crop yield losses during 2015 season with long dry spells, and the gains in groundnut pod yield itself covered most of the cost of the pond in season-1 itself. Similarly, water availability facilitated pond farmers to establish mango plantations in adjoining marginal areas and diversify to vegetables and green fodder on the small piece of land. An economic analysis of existing ponds in the region (Anantapur and Chittoor districts) by Srinivasa Rao et al. (2017) also showed similar yield benefits of >25% and additional returns in the range of INR 3000 (US$44.8) to INR 20,000 (US$298.5) ha^{-1}. Retaining water in the pond in light soil is a major challenge, and customization of using local sandy soil along with cement as lining material significantly reduces costs by >50% compared to other options of cement along with sand or bricks (Wesley et al. 2010). However, the lining may not be necessary in heavy soils where percolation losses are minimal (Osman et al. 2010; Srinivasa Rao et al. 2017).

A micro-watershed (up to 10 ha) catchment scale low-cost cement-lined small pond can effectively store about 200 m^3 water for which there are little opportunity costs because most of the water during short rainy period is drained out through nullahs/rivulets without any proper diversion into productive transpiration; however, this needs detailed studies with regard to impacts on downstream farmers. Smallholders can use this for one or two life-saving watering during drought spells, to significantly enhance crop productivity in drought-prone regions in Andhra Pradesh or elsewhere in the tropics. Low cost makes it a scalable technology with a potential to kick-start growth engine of agriculture in a large number of farmers' fields.

On-farm mechanization

Mechanized sowing not only saved cost by around INR 1000 (US$14.9) ha^{-1} compared to traditional sowing [INR 2000 (US$29.9) ha^{-1} vs. INR 3000 (US$44.8) ha^{-1}], but also recorded higher groundnut pod yields by 8–12% (Table 4) worth on an average of INR 5500 (US$82.1) ha^{-1}. The yield advantage through mechanization was apparently due to uniform spacing and line sowing

Table 3. Effect of life-saving watering on groundnut crop yields through rainwater conservation in low-cost farm ponds in Andhra Pradesh, 2015.

		Pod yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
Village	District	FP	IP	LSD (5%)	FP	IP	LSD (5%)
Mallapuram	Anantapur	1000	1310	300	2120	2500	328
V. Bonthiralla	Kurnool	930	1230	-	2120	2560	-

FP: farmers practice; IP: irrigation ponds.

Table 4. Effect of mechanized sowing operation on groundnut (*Arachis hypogaea* L.) yield, 2015.

		Pod yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
Village	District	FP	MS	LSD (5%)	FP	MS	LSD (5%)
Kurlapally	Anantapur	910	1000	47	1900	2060	120
Mallapuram	Anantapur	980	1100	38	1990	2130	107
V. Bonthiralla	Kurnool	1000	1110	96	1870	1960	140

FP: farmers practice; MS: mechanized sowing.

implemented, and completion of sowing in a very short span to provide a long duration for the seed to exploit the available soil moisture. With the total benefit of INR 6500 (US$97.0) ha^{-1} due to cost saving and yield advantage, the initial cost of sowing machinery is covered in year one itself if scaled out over more than 10 ha. On-farm mechanization is a desirable technology for smallholders to improve incomes and save time for productive works; however, a business model of sharing machinery resources like custom hiring centers need to be promoted through policy support in the public/private sector and that will also attract youth in modern agricul ture.

Conclusions

This research for development study in Andhra Pradesh has demonstrated that soil fertility degradation is one of the major limiting factors for low crop yields, and application of deficient micro- and secondary nutrients are one of the low hanging technologies to improve productivity and livelihoods. Most importantly, water scarcity and dry spells in dryland agriculture pose a major challenge for bringing the desired impacts in the sector. In this context, micro-watershed (0–10 ha) scale farm-ponds at the individual smallholder level proved effective to cope with the long dry spells while empowering farmers to intensify and diversify production systems. This contributed not only to production resilience, but the economic resilience of the smallholders. Low cost lined ponds were found effective in storing water in red soils with high percolation rates and so is a scalable technology. Desired policies to promote such low-cost but critical interventions are needed to benefit large numbers of smallholding farms, that may increase their abilities to put their farms on the growth trajectory. Taking leads, policymakers are putting emphasis on farm-level water harvesting; e.g. government of Andhra Pradesh has piloted the construction of about 600,000 farm ponds during 2016–2017. Such efforts need to cover large areas and farmers of the drylands in particular. Similarly, farm mechanization sowing options proved beneficial in enhancing operational and economic efficiency, reducing drudgery and improving productivity through proper and timely sowing. However, smallholders are not in a position to maintain machinery at the individual farm level, and therefore a farm machinery custom hiring business model with the provision of initial capital support is needed. We conclude that small investments and policy support in system-context technologies can substantially improve productivity and livelihoods of a large number of smallholders in drylands, while contributing to resilience against climatic variability.

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Disclosure statement

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