Does Adoption of Soil *Bund* Increase Sorghum Productivity? Some Empirical Evidence from Drought Prone Areas of Karnataka, India

by Suresh Kumar, Dharam Raj Singh, B. Mondal, P. Venkatesh, and Anil Kumar

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Abstract

This paper examines factors affecting the adoption of soil *bund* and its impact on sorghum productivity in Karnataka, which witnesses frequent droughts. Following a combination of purposive and multistage simple random sampling, primary data from 444plots were gathered and analysed. To assess the impact, endogenous switching regression model (ESRM) was used to manage the issue of selection bias stemming from observed as well as unobserved characteristics. Results show that 'access to credit', 'social networks', 'training of farmers', and 'extension services' are key factors determining adoption of soil *bunds*. Therefore, these factors are needed to be strengthened and internalized in soil conservations programmes to improve the up-take of the technology. The estimated values of ATT (average treatment effect on treated) is303 kg per ha, which is around 36 per cent higher than its counterfactual. Similarly, for non-adopters (untreated), ATU (average treatment effect on untreated) is 157 kg per ha, showing a positive change in sorghum yield. With this, our findings emphasized the need for critical investments for taking-up of soil *bunds* in particular and soil and water conservation technologies in general in drought prone areas for sustaining the natural resources, and improving the livelihood of resource poor farmers.

Keywords: soil and water conservation; soil *bunds*; adoption; impact; drought prone areas; Karnataka

JEL codes: Q1, Q5, Q010

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1. Introduction

Soil erosion is a major hazard and challenge to agricultural sustainability in India(Narayana and Babu 1983; Bhattacharyya et al. 2015; Biswas et al. 2019). The situation in rainfed areas is grim, which along with soil and land degradation, also suffering from water scarcity, frequent droughts, climate change variability, inadequate infrastructure, low level of technology adoption, poor soil fertility etc. Consequently, these areas are in the grip of vicious cycle of land degradation-poverty(Rao et al. 2015;Venkateswarlu and Singh 2015).In India, Karnataka is one of the hot-spot state as far as proneness to droughts is concerned,witnessing frequent droughts of moderateto severe degree (Ray et al. 2015).In addition to this, the sustainability of agriculture in the state is under threat due to multiple factor such as wide-spread soil erosion; erratic and uncertain rainfall; depleting groundwater resource anddeteriorating natural resources; all these factors are limiting crop productivity potential. As a result, average yields of most common crops are 2-5 times less than optimalin the region (GoK 2006;Wani 2012). Moreover, in the state due to water erosion the crop loss is INR 32429 million (at 2014/15 prices), which is the second highest (after Madhya Pradesh) in the county (TERI 2018).Therefore, for sustaining agriculture, improving land productivity and environmental sustainability, the state has for long been making efforts for scaling up conservation efforts with help of watershed development progarmmes (GoK 2020), which arecrucialfor rural development in general and agricultural advancement in particular in rainfed areas for sustaining the livelihood of resource poor farmers of the region (Wani et al. 2011). In the view of above-mentioned environmental challenges, and increasing threats of climate change and variability (Initiative–Karnataka 2011; Kattumuri et al. 2017; Kumar et al. 2017), soil and water conservation measures are of prime importance due to their various synergetic positive effects for improving productivity as well as improving sustainability of agriculture(Pathak et al. 1989; Kato et al. 2011; Bhattacharyya et al. 2015;

Narayan et al. 2019; Naveena et al. 2019). The most common recommended*in-situ*soil and water conservation (SWC) practices for the region are: broad bed and furrow, contour *bunding*, graded *bunding*, compartment *bunding*, ridges and furrows, tied ridging, contour cultivation, set furrow cultivationetc.(Pathak et al. 1989; Vittal et al. 2004; Sharma and Guled 2012; Mishra et al. 2018). Among these, soil bunds (contour *bunding*) is the most widely practiced in semi-arid tropics (Pathak et al. 1989; Bhattacharyya et al. 2015; Narayan et al. 2019; Naveena et al. 2019).Soil *bunds* helps in reducing soil loss and runoff, and improve the soil moisture and fertility,which in turn increasecrop productivity(Kerr and Sanghi 1992; Gebrernichael et al. 2005; Rajkumar and Satishkumar 2014).However, in spite of well documented benefits of SWC measures(Gebremedhin et al. 1999; Shiferaw and Holden 2001; Kassie et al. 2008)and the concerted efforts of government, the adoption rates of SWC technologiesis very low, particularly outside the project area locations(Kerr and Sanghi 1992; Pender and Kerr 1998). To our knowledge, in the drought prone areas, studies relating to evaluation of theeffects of SWC technologies in general and of soil *bunds* in particular on crop production are scarce. Therefore, this study positionsitself in this respect to fill the research gap.In this study, we have used plot-level data combining physical featuresalong with households' level socio-economic variables. We specifically used endogenous switching regression model (ESRM) to control selection bias arising from observedas well as unobservedfactorsand, to ascertain the differential effects of taking-upof soil *bunds* on adopters and non-adopters. Moreover,ESRMalsohelps in examiningthe factorsaffecting the adoption of soil *bund*, as well as its impact on yields.Sorghum was selected for study since it is an important crop for food and fodder in the rainfed areas. With around 18 and 22% share in total area (6 million ha) and production (4.3million tonnes) of the country, respectively, Karnataka state is the second largest sorghum producer in India, after Maharashtra.The outcome of the study is expected to help in designing polices and schemes foreffective conservation progarmmes and plans for drought prone areas.

2. Data and methodology

Surveywas carried out in 2019/20 for collecting the plot level data from the drought prone areas of the Karnataka state. Households were selected following the multistage random sampling design. In the first step, the drought prone areas mainly spreading over four agro-climatic zones of the state *viz.*,central dry zone, north-eastern transition zone, northern dry zone and north eastern dry zone, which were selected purposively. Then, from each zone, one sub-watershedwas selected randomly. Then from each sub-watershed (treated area having bunds), and nearby untreated areas (control area), the adopter and non-adopter farmers, respectively were selected randomly. A total of 324 households growing sorghum on 444 plots were randomly surveyed using a semi-structured data collection format. Before conducting formal survey, an informal group discussion was carried out with all the stakeholders, like office bearer of project implementing agency, agriculture department, field functionaries, farmers etc., which helped us in preparing the formalquestionnaire. Soil *bunds* were taken-up by 43.5% of the total sample. A plot was considered as treated if it is having soil *bund*, non-adopter otherwise. Our choice of variable is based on the prior studies related to adoption of soil and water conservation technologies(Ervin and Ervin 1982; Adesina and Baidu-Forson 1995; Pender and Kerr 1998; Lapar and Pandey 1999; Mbaga-Semgalawe and Folmer 2000; Bekele and Drake 2003; Tenge et al. 2004; Sidibé 2005; Amsalu and De Graaff 2007; Teshome et al. 2013; Willy and Holm-Müller 2013; Abdulai and Huffman 2014; Atnafe et al. 2015; Song et al. 2018). In most of studies the factors affecting the adoption of soil and water conservation technologiescould be broadly categorized into: household level socio-economic, physical and institutional factors(Ervin and Ervin 1982; Pender and Kerr 1998; Shiferaw and Holden 1998; Lapar and Pandey 1999). In addition to these, some other factors which are relevant to the study area such as exposure visits, perceived benefits of soil *bunds* and perception of risk were also included. The exposure visits are conducted by the watershed implementation agency forexposing farmers to successful watershed areas so that farmers can have the real field experience of conservation efforts, and also can interact with the beneficiaries. Therefore, it was hypothesized that exposure visits affect the farmers' adoption behavior. Further, since, the study is related to drought prone areas where crop failure is common, therefore, it is presumed that risk perception of farmers also can influence the adoption decisions.

2.1 Econometricapproach for impact assessment

While assessing the impactof adoption of agricultural technologies, the major challenge is that the situation before adoption and after adoption cannot be observed together(Alene and Manyong 2007). To overcome this problem, instead of following with and without approach, researchers usually compare farmers who are adopted particular technologies with non-adopters (Fuglie and Bosch 1995). Generally, the decision oftaking-up of soil *bunds*ispresumed to be associated with personal and household level fcharacteristicsincludinginputs ofcrop production. Generally, to identify the key factors governing the adoption of soil and water conservation technologies, dichotomouschoice models such as logit and probit are used. Further, for examiningimpact of soil *bund*on crop productivity, the simplest method is to include a dummy variable for adoption in the matrix of independent variables. Then, marginal effect of soil *bund* can be estimated using ordinary least squares (OLS).However, OLS canresult in biased estimates since inthis approach adoption of soil *bund* is assumed as exogenous. However, in reality adoption of soil *bunds* is endogenous in nature, thereby leading to issue of self-selection bias. Therefore, while estimating the impact of soil *bunds* on the crop productivity, there is a need to manage the issue of self-selection bias. For this, a method which factors-in the influence of observed as well as non-observed factors needs to be chosen for estimating the differential impact of soil *bunds* on the crop productivity. Mostly, to over-come the issue of self-selection bias, propensity scores matching (PSM) is used for estimating the causal effects of agricultural technologies (Rosenbaum and Rubin 1983; Nkala et al. 2011; Amare et al. 2012). However, limitation of PMS is that it does not control the influence of unobserved variables on the crop productivity (Dehejia and Wahba 2002). Therefore, under such conditions, the PSM estimates could be biased as influence of unobserved variable could persist in the estimation (Smith and Todd 2005).

Keeping this view, in this paper, endogenous switching regression model (ESRM) was used to factor-in the potential influence of both observed and unobserved variables/factors. In the estimation of ESRM, there should be at least one instrumental variable (IV) which is highly associated (correlated) with adoption of soil bunds and does not directly influence on the crop productivity i.e. yield of sorghum in this case. Chosen IV helps in identification of outcome model from the selection model. We used'perception of benefits of soil and water conservation (SWC)technology(benefits perception index)' and 'exposure visits'and 'number of livestock units' as IVs in analysis. It has been observed that farmers can easily recognize the soil loss and runoff from their fields; hence the benefits of preventing soil loss and runoff could also be easily perceived by farmers. Therefore, it was hypothesized that perception of farmers relating to benefits of SWC technology may encourage farmers totake up soil *bunds*as farmers mighthave a positive orientation about the multiple benefits such as improving the soil moisture and fertility, and reducing the runoff and soil loss from their plots. Further, watershed implementation agencies, conduct the exposure visits of farmers to model watersheds, a successfully implemented watershed having noticeable impacts, to provide real field experience of conservation measures following the principle of 'seeing is believing'. Therefore, it was also assumed that such visits can have positive effects on the adoption of soil *bunds*. Lastly, the rainfed-drought prone areas face problems of fodder scarcity (Kattumuri et al. 2017), and sorghum crop is a mainsource of fodderfor livestock. Further, livestock isan integral part of rainfed farming system. Therefore, for rearing livestock, farmers adopt the soil bunds for better growth of crops for getting sufficient amount of fodder.Keeping this in view, number of the livestock units was used as third IV. The validity of the IVs was tested by carrying outfalsification test(Di Falco et al. 2011).

Soil *bund* is an earthen embankment constructed along the boundary lines of the individual plot to conserve soil and moisture in the plot itself. The plot with soil *bund* is considered as treated, and termed as adoption, and plots without soil bund is non-adoption.

We assumed that taking-up of soil *bund* is a binary choice, where a farmer decides to adopt soil *bunds*when there is a positive difference between the marginal net benefits from adopting this technology to non-adoption.

$$\text{Sample selection equation} D_i^* = Z_i\, \alpha + \mu_i \; with \; D_i = \begin{cases} D_i^* if \; D_i^* > 0 \\ 0 \; therwsie \end{cases} \text{........(1)}$$

$$\text{Outcome equation} = y_i = X_i\beta + \delta D_i + \varepsilon_i \;\dots\dots..(2)$$

where,

$D_i^*$is latent varaibale capture the expected benefits of use of soil and water conservation technologies. $Z_i \; and \; X_i$are a set of explanatory variables used in selection and outcome equations, respectively, and $\beta \; and \; \alpha$ are the parameter vectors which are to be estimated. $\delta$is scalar parameter showing the adoption of soil *bunds* or not.$\mu_i$andε_i are the error terms following bivariate normal distribution with mean zeroand variance-covariance is given by matrix $\sum_1$.

ESR model is consists of two stages. Selectionequation is estimated in the first step as shown in equation (1). Two regimesof outcomes; one for adopter and another for non-adopters of soil *bund* are the part of second stage estimation.

$$\text{Regime 1} = y_{1i} = X_{1i}\beta_1 + \bar{X}_{1i}\theta_1 + \varepsilon_{1i} \quad if \; D_i = 1 \dots\dots..(3)$$

$$\text{Regime 2} = y_{2i} = X_{2i}\beta_2 + \bar{X}_{2i}\theta_2 + \varepsilon_{2i} \quad if \; D_i = 0 \dots\dots..(4)$$

Whereβ_1 and β_2 are parameter vectors in outcome as shown in equation 3 and 4, respectively. To get consistent estimates, a vectors of average of plot varying variables (plot soil fertility, erosion and type of soil and slope of plot), indicated by $\bar{X}$ was included. This helps in minimizing the issue of unobserved heterogeneity(Mundlak 1978; Wooldridge 2002). Error terms in selection and outcome equations follow a trivariate normal distribution with zero mean and variance-covariance matrix given by $\sum_2$,

$$\sum_2 = \begin{bmatrix} \sigma_\mu^2 & \sigma_{1\mu} & \sigma_{2\mu} \\ \sigma_{1\mu} & \sigma_1^2 & \sigma_{12} \\ \sigma_{2\mu} & \sigma_{12} & \sigma_2^2 \end{bmatrix}$$

wherethe variance-covariance equation1, 3, 4 are denoted by σ_μ^2, σ_1^2 and σ_2^2,respectively.

Further

$$\rho_{1\mu} = \frac{\sigma_{1\mu}}{\sigma_1 \sigma_\mu}$$

$$\rho_{2\mu} = \frac{\sigma_{2\mu}}{\sigma_2 \sigma_\mu}$$

$\rho_{1\mu}$ is coefficient of correlation between $\mu$and ε_1

$\rho_{2\mu}$ is coefficient of correlation between $\mu$and ε_2

When the$\rho_{1\mu}$ and $\rho_{2\mu}$ is statistically significant, it can be stated that there is a decision to take-up of soil *bunds* and the outcome are correlated, leading to rejection of null hypothesis indicating the nonexistence of sample selection bias (Abdulai and Huffman 2014; Song et al. 2018).Owing to correlation between errors, the expectation of ε_{1i} and ε_{2i} are non-zero, therefore, the truncated error terms can be given as follows:

$$E[\varepsilon_{1i}|D_i = 1] = \sigma_{1\mu} \frac{\phi(Z_i\, \alpha)}{\Phi(Z_i\, \alpha)} = \sigma_{1\mu}\lambda_{1i} \ldots \ldots \ldots (5)$$

$$E[\varepsilon_{2i}|D_i = 0] = -\sigma_{1\mu} \frac{\phi(Z_i\, \alpha)}{1-\Phi(Z_i\, \alpha)} = \sigma_{2\mu}\lambda_{2i} \ldots \ldots \ldots (6)$$

The ratios of $\phi(.)$indicate the standard normal probability density function (PDF)and $\Phi(.)$ denotesstandard normal cumulative density function (CDF), whichare evaluated at $Z_i\,\alpha$for obtaining Inverse Mills Ratios (IMR), λ_{1i} and λ_{2i}.In the ESR model, adoption of soil bund is assumed to be regime shifter.The significance correlation coefficients is tested to see the problem of endogeneity (Lokshin and Sajaia 2004) between μ_i and ε_{1i} (indicated as $\sigma_{1\mu}$) and between μ_i , and ε_{2i} (indicated as $\sigma_{2\mu}$).

2.2 The conditional expectations and heterogeneity effects

The ESR model was employed toassess theestimated benefit of adopters of soil *bunds*. For the end, the counterfactual cases for adopters and non-adopters were estimated as given below.

$$E[y_{1i}|D_i = 1] = X_{1i}\beta_1 + \bar{X}_{1i}\theta_1 + \sigma_{1\mu}\lambda_{1i} \ldots\ldots\ldots.(5a)(Real)$$

$$E[y_{2i}|D_i = 0] = X_{2i}\beta_2 + \bar{X}_{2i}\theta_2 + \sigma_{2\mu}\lambda_{2i} \ldots\ldots\ldots.(5b)(Real)$$

$$E[y_{2i}|D_i = 1] = X_{1i}\beta_1 + \bar{X}_{1i}\theta_1 + \sigma_{2\mu}\lambda_1 \ldots\ldots\ldots.(5c)\ (Hypothetical)$$

$$E[y_{1i}|D_i = 0] = X_{2i}\beta_2 + \bar{X}_{2i}\theta_2 + \sigma_{1\mu}\lambda_{1i} \ldots\ldots\ldots.(5d)(Hypothetical)$$

Cases (5a) and (5b) indicates the observed values for sub-sample of adopters of soil bunds and non-adopters, and their respective counterfactuals are givenby (5c) and (5d), respectively.The effect of the soil *bunds*on those who adopted (average treatment-effect on the treated, ATT) can be computed by taking difference between (5a) and (5c) as given by equation 6 as follows:

$$\text{ATT} = E[y_{1i}|D_i = 1] - E[y_{2i}|D_i = 1] = X_{1i}(\beta_1 - \beta_2) + \bar{X}_{1i}(\theta_1 - \theta_2) + \lambda_{1i}\left(\sigma_{1\mu} - \sigma_{2\mu}\right)..(6)$$

Equation 6 gives the impact of soil *bunds* for adopter farms while factoring-in or controlling the influences of all other variables by holdingλ_{1i} constant and taking the differences in effects $(\sigma_{2\mu} - \sigma_{1\mu})$, we were able to eliminate the influence of unobserved variables. Therefore, the estimated productivity can solely be attributed to soil *bund*. Therefore, ATTcan be stated as the differences in the coefficients of equations (3) and (4). Further, we also calculated the average treatment-effect on the untreated (ATU) for the non-adopter of soil *bunds*as difference between (5d) and (5b) as below,

$$\text{ATU} = E[y_{2i}|D_i = 0] - E[y_{1i}|D_i = 0] = X_{2i}(\beta_1 - \beta_2) + \bar{X}_{2i}(\theta_1 - \theta_2) + \lambda_{2i}\left(\sigma_{1\mu} - \sigma_{2\mu}\right)..(7)$$

Further the ‘base heterogeneity’ (BH) effect can be computed using the equation 8 and 9 for adopters of soil *bunds* and non-adopters, respectively.

$$\text{BH}_1 = E[y_{1i}|D_i = 1] - E[y_{1i}|D_i = 0] \ldots \ldots . \ldots .(8)$$

$$\text{BH}_1 = E[y_{2i}|D_i = 1] - E[y_{2i}|D_i = 0] \ldots \ldots . \ldots .(9)$$

3. Results

3.1 Descriptive statistics

The descriptive summary of the variables selected for the study is presented in Table 1. Soil *bunds* areadopted by 43.5% of the total sample plots (444 plots). In case of household level characteristics, most of the variables arehaving statistically no difference between those adopted the soil *bunds* and not adopted. However, the adopters had a greater number of livestock units, and relatively higher proportions of adopters had source of off-farm income and access to credit. Further, the plots level features (slope of plot, type of soil, soil erosion and fertility of plot) of the adopters' plot are significantly differentthan that of non-adopters. Perception relating 'risk of crop failure' and benefits of the soil *bunds*, which is measured in terms of 'benefits perception index' are also systematically and significantly different for adopters when compared with non-adopters.Moreover, as for 'access to extension services' and 'training services' the adopters had relatively higher number of exposure visits and had also a higher number of persons who received training on soil and water conservation.Similarly, for the indicators of social network and inputs of production, the farms who adopted the soil *bunds* are significantly different than that of those who not adopted. Further, the average productivity of sorghum of adopter plots is more than those of non-adopters.The Kolmogorov-Smirnov test (D = 0.089, p-value = 0.352) also indicates that adopters of soil *bunds* and non-adopters have the same distribution of sorghum yields. However, the simple difference in the mean sorghum yields should not be attributed the adoption of soil *bunds* since the adopters are different from their counterparts (those who not adopted) in terms of their household level, plot level characteristics and other variables. Therefore, these differences should be control for to estimate the impact of soil *bunds* on the productivity.

<Table 1>

3.2 ESR estimates

Results of validity testing of instrument variables (IVs) and FIML (full information maximum likelihood) estimate of the selection and outcome equations are given in Table 2 and 3, respectively.

3.2.1 The validity of instrument variables

Firstly, validity of instrument variables (IVs) is required to be tested in terms of whether IVs have significant influence on the adoption of soil *bunds* but not the outcome i.e. yields. For this, following the test suggested by Di Falco et al. (2011), which is known as falsification test was carried out. It can be seen that IVs used in the study *viz.,*'benefit perception index', 'exposure visits' and 'number of livestock' are having significantly positive effects on the adoption of soil *bunds* but all these are insignificant in case of outcome equation of the non-adopters. Therefore, it can be stated that the selected instruments are valid.

<Table 2>

3.2.2. Factors influencing the adoption of soil bunds

Regression coefficientsof selection equations show that household variables *viz.*,off-farm income and access to credit are positively andsignificantly associated with the decision to adopt soil *bunds*, and the coefficients are significant at 1 and 5% level, respectively. Further in case of plot level characteristics,expectedly the slope of plotshad a significantly positive effect on adoptionof soil *bunds*. Further, contrary to our anticipation, the coefficients of high and medium level of fertility of plot are significantly showing a positiveinfluence on the adoptionof soil *bunds*. In line with a prior expectation, risk perception has positive effects (significant at 1% level) on decision of adoption of soil bunds. The result also indicates that farmers who had undergone training in soil and water conservationwere observed to have higher probability of adoption. The likelihood of adoption was found to be relatively higher for the farmers to had higher frequency of interaction relating to conservation effortswith other farmers. Further, the coefficient of variety, bullock labour and FYM were found to have a positive bearing on the adoption. Among the instrument variable namely, benefit perception index, number of exposure visits and number of livestock units used in the study, first two have significantly positive effect on adoption.

<Table3>

3.2.3 The determinants of crop yield

Significance level of the coefficientsσ_1 and σ_2 shows the presence of the selection bias (Lokshin and Sajaia 2004), leading to rejection of null hypothesis stating nonexistence of sample selectionbias (Abdulai and Huffman 2014). Hence, it can be stated that unobserved variables are influencingtaking up of soil *bunds* and crop yields. Therefore, use of ESRM is appropriate over the OLS method. Another important finding is direction and significance of the correlation coefficients $\rho_1$and ρ_2. The estimates are having alternate signswhich arenegative for adopters and positive for non-adopters, indicating the case of positive selection bias. This implies that farms undertaking soil *bunds* based on their comparative advantage (Alene and Manyong, 2007). Hence, those who adoptedreapedabove-mean sorghum productivity from adoption of soil *bunds*over non-adopter. Level of education and farm assets had significant and positive effectson the yield for the adopters of soil *bunds*and non-adopters, respectively. The coefficients were significant at 1 and 10% level, respectively. In case of the plot level characteristics, size of the plot has significantly and negativelyaffect the yield for both the groups i.e. adopters and non-adopters. The level of erosion hada significantly negative affect onyield for non-adopters;however, its coefficient was insignificant for adopters. Number of visits to KVK (*KrishiVigyan Kendra*) and RSK (*RythuSampark Kendra*), which were used to capture the access and use of extension services,was observed to havea significant and positive effect on the yield for adopters.Social network, as expected, had positive influence on the yield, however, it was significant in case of non-adopters only. The usefulness of the interaction with other farmers was significant for both adopter and non-adopters. Further, for inputs of production, use of improved variety had the positive impact on yield. Quantity of seed and farm machine had negative and positive effects on yield, receptively. However, the effect of seed was significant in case of adopters, and farm machinehad significant impact on yield for adopters and non-adopters.

3.2.4 Effects of adoption of soil *bunds*on crop productivity

Simple mean difference in yield does not give the actualproductivity impact of soil *bund* since there are systematic differencesbetween adopters and non-adopters in both observable and unobservable covariates.Therefore, impact of soil *bunds* can be given by estimate of average treatment effect on the treated (ATT) plots. ATTs show the increase/ decrease in productivity of sorghum after accounting for sample selectivity bias.Table4 shows the estimates of expected yields and average treatments effects.Observed sorghum yield for adopters and non-adopters are presented in (P) and (Q), respectively. Further, the counterfactual cases for adopters and non-adopters are given in cells (R) and (S), respectively.

The value of ATT (303 kg per ha) suggests that the adoption of soil *bund*significantly increases crop yield, which is around 35.73 per cent higher as compared toits counterfactual case. Here counterfactual case indicates the situation as if farms had not adopted the technology. Further, the result for ATU (average treatment effect on untreated) reveals that the adoption of soil *bunds* also significantly increases crop yield by almost 14.33 percent for non-adopters if they had adopted. Further, the negative transitional heterogeneity effects indicate that those who did not adopt would have benefited the most in terms of gain in yield from adoption of soil *bunds*.

<Table 4>

4. Discussion

4.1 Factors affecting the adoption of soil bunds

This paper deals with assessing the impact of soil *bund* on an important food and fodder crop in the drought prone areas of the Karnataka state. It was found that off-farm income and access to credit arepositively associated with decision to adopt soil *bunds*. The results are in agreementwith the findings of earlier studies (Ervin and Ervin 1982; Lapar and Pandey 1999). It was argued that having a higher income fromoff-farm sourceshelps in overcome the liquidityconstraints. This is particularlytrue for drought prone areas wherein farmers are resource poor havinglimited capacity to invest for conservationmeasures (Rao et al. 2015). Although, the negative effect of off-farm income on the soil and water conservation investments was also reported by other researchers(Pender and Kerr 1998; Mbaga-Semgalawe and Folmer 2000; Gebremedhin and Swinton 2003; Ma et al. 2004; Tenge et al. 2004; Amsalu and De Graaff 2007; Bakker et al. 2007; Pender and Gebremedhin 2008), they argued that farmers having off-farm income might be less interested in improving land quality because of their relatively higher orientation towards off-farm income opportunities, whichin turn, reduces their dependence on farm income(Ervin and Ervin 1982; Norris and Batie 1987; Bravo-Ureta et al. 2006; Teklewold and Köhlin 2011). Furthermore, if there is migration for off-farm earnings, then this shifts household labour away from farm leading a shortage of labor, which was also identified as a major reason for not adopting soil conservation(Di Falco et al. 2011).However, in our case, a positive impact of off-farm income is due to fact that generally, one or two members of a farm family work in off-farm activities largely on seasonal basis. Consequently, for a substantial part of total income family depends on agriculture income for their livelihood; therefore, invest in conservation efforts.

In the semi-arid drought prone areas, itwas observed that farmers face credit constraints because of imperfections in agricultural and financial markets,and which in turn affects the taking up of new practices, particularly which are capital intensive(Abdulai and Huffman 2014). Furthermore, in the region, most of the farmers are resource poor-smallholders,unable to generate enough from agriculture activities, under such situation, inaccessibility to credit aggravates the situation of financial hardship, and thereby adversely affects conservation efforts(Malathesh et al. 2009).Therefore, asanticipated, ourresults show that ‘access to credit’enhances the chances of adoption of soil *bunds*. Result is in agreement with earlier studies (Pattanayak et al. 2003; Abdulai and Huffman 2014; Abebe and Sewnet 2014). Theyargued that easyand timely access to credit indirectly also affects the adoption of conservation efforts by facilitatingpurchasequality inputs particularly fertilizer and seeds of improved crop varieties. Therefore, for realizing the potential of these purchased inputs, farmers tend to invest in conservations efforts.

Slope of plot is a one of the major determinants of soil erosion, from a plot of higher slope the chances of washing-off the top-layer of soil due to water erosion is very high, as a result, plot becomes less fertile, particularly when soil depth is very low. Therefore, to maintain the soil health of such plots, farmers tends to use the conservation measures. As expected, we also found a positive association between the slope of plot and adoption of soil *bunds,* confirming the findingsof other studies(Ervin and Ervin 1982; Shiferaw and Holden 1998; Mbaga-Semgalawe and Folmer 2000; Bekele and Drake 2003; Amsalu and De Graaff 2007; Kassie et al. 2013). The coefficient of level of fertility had negativeeffects on adoption, implying that plots with the low fertility level had higher chances of taking up soil *bunds*. Itis consistent with earlier findings(Amsalu and De Graaff 2007; Kassie et al. 2013; Tesfaye et al. 2014). However, contrary to it, Bekele and Drake (2003) argued that soil fertility is likely to have a direct and positive impact ontaking up conservation measures. For this, it was argued that on more fertile plots the extent of avoided production loss ismore, therefore to avoid such losses farmers use the conservation measures(Turinawe et al. 2015).

In fact, natural resource management technologies are knowledge-intensive(Barrett et al. 2002), therefore, technical assistance is an important determinant of their adoption. It was observed that technical support positively affects the adoption of conservation measures (Bekele and Drake 2003; Sidibé 2005; Dessie et al. 2012; Asfaw and Neka 2017). Our finding mirrors the same as we also observed a positive association between the adoption and training of farmers.

Social capital is indeed important factor determining the access to inputs, marketing, credit facilities and conservationtechnologies (Khonje et al. 2015). Social networks enable farmer-to-farmer shareinformation especially in the areas lacking such information (Kassie et al. 2013). Further a higher intensity of 'farmers to farmers contacts' enhances the possibility of collective learning(Adegbola and Gardebroek 2007), enabling them to take-up appropriate soil conservation practices suitable to local conditions (Willy and Holm-Müller 2013). We tried to capture the level and intensity of farmers to farmer's contacts by scoring the frequency of interaction with other farmers and their perceived usefulness. We observed that there is positive effectof social networks on the adoption of soil *bunds*, and result are in conformitywith previous studies(Nyangena 2008; Teshome et al. 2013).

A positive association between the perceived benefits and adoption of SWC measures was observed, this is in conformity with other studies(Adesina and Baidu-Forson 1995; Shiferaw and Holden 1998; Baidu-Forson 1999; Mbaga-Semgalawe and Folmer 2000), arguing that perception of farmers relating to expected benefits from the use of technologies plays an important role in adoption. Moreover, financially viable SWC measures not only encourage adoption but also an important factor for continued use of SWC measures(Teshome et al. 2013).Number of exposure visits to successful watershed had a positive bearing on the likelihood of adoption as farmers themselves can see the benefits of adoption of SWC measures in the real field, which also helps them to build their trust about the likely benefits of conservation efforts.

4.2 Impact of soil *bunds* on productivity

For non-adopters, we found that level of erosion had significantly negative impact on yield, which is due to the fact that it degrades soils that in turn affects the crop growth by affecting the soil functions such as supply of water and nutrients(Bakker et al. 2007). However, the coefficient was insignificant for the adopters, showing that due to adoption of soil *bunds*, soil erosion not affecting productivity at their plots. Number of visits to KVK and RSK washavinga significantly favorable impacton the productivityfor adopters. This is due to the fact that farmers who are regularly visiting extension agencies have higher probability of using modern agricultural inputs because of their higher exposure and awareness(Khonje et al. 2015). Moreover, drought prone areasarehaving considerable spatial and temporal variations in rainfall, therefore, a continuous and frequent visits to extension offices facilitate to get the information about the improved seeds, likely incidence of pest and disease and their management options, and advisories for adjustments in sowing time and other cultural operations, whichhelps to ward-off yield losses. The value of ATT (303 kg per ha) suggests that the adoption of soil *bund* significantly increases crop yield, which is around 35.73 per cent, when compared with their counterfactual case. Further, for non-adopters, the result for ATU reveals that adoption of soil *bund* also significantly increases crop productivity, which is around 14.33 percent.Our finding is in conformity with earlier studies(Kassie et al. 2008; Abdulai and Huffman 2014; Nkegbe 2018; Song et al. 2018), which showed that conservation efforts had a positive impact on crop productivity.

5. Conclusions

This study assesses the adoption and impacts of soil bund on sorghum productivity in dry areas of one of the most drought prone states of India. For this study, cross-sectional data of 444 plotswas used. Endogenous switching regression model was employed for assessing the impact of *bunds* on the sorghum productivity. Theresults suggest thattaking up ofsoil *bund* is governedby off-farm income and access to credit, social networks, training of farmers, benefit perception of the farmers and exposure visits. Specific policy implicationsare: (a) concerted efforts should be made to promote adoption of soil *bund* bystrengthening the social networks and extensions services and, facilities for trainings; (b) emphasis should be on the provision for exposure visits of farmers for exposing them to areas wherein the successful soil and water conservation related work has been implemented, for bring about desirable changes in the perception of farmers regarding the potential benefits of soil and water conservation efforts, which will also further encourage farmers to take-up soil and water conservation technologies; and (c) theestimates of average treatment effect on treated (ATT) and average treatment effect on untreated (ATU) show there is significant increase in productivity of sorghum due to adoption of soil *bund*, which are around 36 and 14% higher than the their respective counterfactuals for adopters and non-adopters, respectively.Therefore, broadly, it can be suggested that soil and water conservation technologies particularly soil *bunds* can contribute significantly to improve productivity, emphasizing the need for wide spreadof adoption of soil *bund*for better management of natural resources, and thereby sustaining agriculture and livelihoods of resource-poor famers in the drought prone areas facing multiple environmental challenges.

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Table 1: Descriptive summary of sample plots cultivating sorghum

Variables		Prior expectation	Full sample (N=444)	Adopter (N=193)	Non-adopters (N=251)
Household level characteristics					
Head (male=1; otherwise 0)		+	0.82(0.39)	0.79 (0.41)	0.84 (0.37)
Age (years)		+/-	50.0 (12.3)	50.2 (11.7)	49.8 (12.8)
Education (number of schooling years)		+	5.3 (4.5)	5.3 (4.3)	5.3 (4.6)
Family size (number of members)		+/-	5.1 (1.8)	5.1 (1.8)	5.0 (1.8)
Size of land holding (ha)		+	2.5 (2.0)	2.4 (1.9)	2.5 (2.1)
Livestock (number of animals)		+	4.4 (2.7)	4.9 (2.9)	4.0*** (2.5)
Off-farm income (if yes=1; 0, otherwise)		+/-	279 (62.8)	166 (86.0)	113*** (45.0)
Dependency ratio (area per capita)		+/-	0.5 (0.5)	0.5 (0.4)	0.5 (0.5)
Farm asset index#(if yes=1; 0, otherwise)		+	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
Access to credit(if yes=1; 0, otherwise)		+	271 (61.0)	144 (74.6)	127*** (50.6)
Farm/plot level characteristics					
Size of plots (ha)		-	0.8 (0.6)	0.8 (0.6)	0.8 (0.5)
Tenure (if own=1; 0, otherwise)		+	310 (69.8)	129 (66.8)	181 (72.1)
slope of plot (if high=1; 0, otherwise)		+	309 (69.6)	174 (90.2)	135*** (53.8)
Type of soil (if red=1; 0, otherwise)		+	137 (30.9)	72 (37.3)	65** (25.9)
Type of soil (if black=1; 0, otherwise)		+	208 (46.8)	92 (47.7)	116 (46.2)
soil erosion perception (if high=1; 0, otherwise)			262 (59.0)	124 (64.2)	138* (55.0)
soil erosion perception (if medium=1; 0, otherwise)		+	92 (20.7)	37 (19.2)	55 (21.9)
Fertility of plot (if high=1; 0, otherwise)		-	178 (40.1)	96 (49.7)	82*** (32.7)
Fertility of plot (if medium=1; 0, otherwise)		-	246 (55.4)	89 (46.1)	157*** (62.5)
Perception of farmers					
Risk perception (chances of crop failure)		+	4.8 (1.4)	5.4 (1.5)	4.3*** (1.1)
Benefit perception index$^{\Psi}$(number)		+	3.3 (0.7)	3.2 (0.7)	3.4** (0.7)
Extension and training services					
Number of visits of KVK and RSK		+	3.0 (1.6)	3.0 (1.5)	3.0 (1.6)
Exposure visits (if yes=1; 0, otherwise)		+	1.1 (0.9)	1.5 (0.8)	0.8*** (0.9)
Training (If yes=1; 0, otherwise)		+	284 (64.0)	144 (74.6)	140*** (55.8)
Social Network					
Interaction	1= sometimes	+	152 (34.2)	43 (22.3)	109**8 (43.4)
	2=occasionally		140 (31.5)	61 (31.6)	79 (31.5)
	3= very frequently		152 (34.2)	89 (46.1)	63 (25.1)
Usefulness	1 = not useful,	+	143 (32.2)	23 (11.9)	120*** (47.8)
	2=useful		179 (40.3)	92 (47.7)	87 (34.7)
	3=very useful		122 (27.5)	78 (40.4)	44 (17.5)
Inputs for Production					
Variety (if yes=1; 0, otherwise)		+	273 (61.5)	137 (71.0)	136*** (54.2)
NPK (kg per ha)		+/-	90.7 (71.6)	89.4 (67.4)	91.7 (74.8)
Seed (kg per ha)		+/-	12.9 (9.7)	12.2 (8.2)	13.5 (10.7)
Human labour (man days per ha)		+	66.4 (23.1)	69.5 (22.1)	64.1** (23.6)
Bullock labour (man days per ha)		+	15.5 (7.8)	16.4 (6.2)	14.9** (8.8)
Farm machine (hours per ha)		-	14.9 (7.0)	15.9 (5.7)	14.1*** (7.8)
FYM (tonnes per ha)		+	2.4 (4.0)	2.3 (3.9)	2.4 (4.1)

Notes:*, **, and *** indicate statistical significance at the 10, 5, and 1% levels, respectively; figures in parentheses are standard deviation for continuous variable and percentage for dummy variables. #Farm assets index is construct using principal component analysis (PCA) representing the status of farm implements and machineries; Ψ Benefit perception index is including the perception relating to benefits of *bunding* on improving the soil moisture, fertility and groundwater, and reducing the soil loss and runoff.

Table 2: Falsification test for validity of selected instruments

Variables	Non-adopter		Selection equation	
	Coefficient	Std. Error	Coefficient	Std. Error
Constant	11.152***	1.642	0.410***	0.111
Benefit perception index	0.121	0.458	0.078**	0.031
Exposure visits	0.181	0.354	0.199***	0.023
Livestock	-0.187	0.123	0.016**	0.008
$\chi^2(3)$	0.831		31.720***	
Observation plots	251		444	

Notes:∗, ∗∗, and ∗∗∗ indicate statistical significance at the 10, 5, and 1% levels, respectively

Table 3: Maximum likelihood estimates of endogenous switching regression model for adoption and impact of adoption on sorghum yield

Variables	Selection		Adopters		Non-Adopters	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	-7.892***	1.208	-6.169	5.856	10.742***	3.646
Household level characteristics						
Head	-0.505**	0.248	0.438	0.813	0.154	0.779
Age	-0.005	0.008	0.024	0.030	-0.001	0.023
Education	0.010	0.022	0.213***	0.077	-0.035	0.065
Dependency ratio	-0.262	0.237	0.025	0.780	0.966	0.600
Off-farm income	1.333***	0.224	0.100	1.030	-0.139	0.721
Farm asset index	0.159	0.797	0.004	0.061	0.065*	0.040
Access to credit	0.500**	0.215	0.374	0.810	0.162	0.655
Farm/plot level characteristics						
Tenure	0.279	0.216	3.475	2.492	0.646	2.474
Size of plot	-0.043	0.172	-0.221**	0.098	-0.086*	0.055
slope of plot	1.233***	0.238	1.585	1.182	-0.449	0.715
Red soil	0.223	0.286	-0.058	1.038	-0.763	0.823
Black soil	0.250	0.277	0.365	1.036	-0.370	0.773
Soil erosion (high)	0.238	0.270	1.144	0.866	-1.459*	0.783
Soil erosion (medium)	-0.221	0.301	-0.234	1.034	0.627	0.859
Fertility of plot (high)	-0.907*	0.474	1.466	1.628	1.412	1.462
Fertility of plot (medium)	-0.998**	0.451	1.776	1.649	1.752	1.415
Extension and Training services						
Visits to KVK and RSK	0.090	0.061	0.676***	0.251	0.097	0.317
Training	0.376*	0.206	0.451	0.765	0.403	0.603
Perception of farmers						
Risk Perception	0.351***	0.075	-0.312	0.776	0.661	0.707
Social network						
Interaction with other farmers	0.484***	0.129	0.241	0.461	0.724*	0.383
Usefulness of interaction	0.939***	0.143	1.108**	0.544	0.940**	0.466
Inputs for production						
Variety	0.540**	0.208	1.953***	0.732	0.672*	0.220
NPK	0.002	0.002	0.008	0.005	0.003	0.004
SEED	-0.013	0.013	-0.161***	0.050	-0.019	0.034
Human labour	0.006	0.004	0.014	0.016	-0.029**	0.014
Bullock labour	0.043***	0.014	0.524	0.541	-0.746	0.549
Farm machine	0.022	0.015	0.112**	0.057	0.126***	0.037
FYM	0.070***	0.027	-0.025	0.225	-0.184	0.181
Regional dummy						
Central dry zone	-0.642**	0.284	-0.161	0.907	0.923	0.827
North-eastern transition zone	-0.425	0.260	1.997**	0.911	3.824**	0.812
Northern dry zone	-0.228	0.277	0.151	1.019	3.670**	0.812
Benefit perception	0.217*	0.131				
Exposure visits	0.447***	0.116				
Livestock	-0.024	0.039				
Sigma (σ_j)			4.252***	0.238	4.317***	0.302
Rho (ρ_j)			**-0.498***	0.284	**0.608*****	0.208
Joint significance of plot level characteristics	32.78**					
Model Wald chi2 (F) test	147.1***					

Notes:∗, ∗∗, and ∗∗∗ indicate statistical significance at the 10, 5, and 1% levels, respectively

Table 4: Summary of conditional expectations, treatment and heterogeneity effects

Sub-sample	Decision				Treatment Effects	Change (%)
	Adopters		Non-adopters			
Adopters	(P)	1151 (209)	(R)	848 (227)	ATT=303***	35.73
Non-adopters	(S)	1252 (217)	(Q)	1095 (229)	ATU=157*	14.33
Heterogeneity Effects		-101(23)		-247(21)	ATH=146	

Source: Adapted from Di Falco et al. (2011). TT = the effect of the treatment on the treated. TU = the effect of the treatment on the untreated, .BH = the effect of base heterogeneity for adopters (i = 1), and non-adopters (i = 2).TH = (TT - TU), i.e., transitional heterogeneity;