

Article

Determination of the Key Factors to Uncover the True Benefits of Embracing Climate-Resilient Napier Grass Among Dairy Farmers in Southern India

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Abstract: Insufficient access to high-quality feed in sufficient amounts is hindering the sustainable growth of the Indian cattle sector. The feed supply is negatively impacted by increased cropping intensity, limited grazing land, and the effects of climate change. Therefore, developing cost-effective methods to improve feed availability year-round is crucial. Improved planted forages, such as Napier grass, are recommended to address feed shortages in semi-arid agroecological regions in India. The study, using the PSM approach, investigates the socioeconomic factors that impact Napier adoption, its influence on enhanced milk output, time saved in livestock farming, farmers' well-being, and livestock health. This study employed a multistage sampling method to choose 309 participants for the questionnaire survey. Our analysis shows that Napier adoption resulted in a 24.6% rise in daily milk output/cow and a 61.2% overall improvement in total milk production/year/cow when compared with baseline data. Napier's adoption decreased livestock farming times by 30 min/cow. Additionally, women's involvement in livestock farming improved with Napier farming, and farmers who have switched to Napier have seen a remarkable increase in their net income, with a monthly boost of Rs. 2044–2555 per cow. Additionally, daily milk consumption has also skyrocketed, with a remarkable enhancement of 143–153 mL per person daily. Our study highlights that the farmer's age, education level, livestock unit, and land holding play a crucial role. Additionally, the availability of extension services and farmer group participation can further impact the adoption process. Furthermore, our study explores how these factors shape the decision-making process and drive the successful integration of Napier grass into farming practices. However, considering the spatial limitations and reliance on self-reported data in this study, we suggest future research examining the long-term effects of Napier grass adoption on climate-smart agricultural practices, soil moisture, and socioeconomic benefits, involving field experiments, modeling, and farmer participation.

Keywords: Napier; milk productivity; women's engagement; farmers' income; livestock health; household welfare; propensity score matching approach



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1. Introduction

A climate-smart agriculture approach with integrated livestock in any agrarian system fosters sustainable diversification and improves environmental services [1]. An integrated system of crop–livestock can benefit impoverished farmers and increase their income and net production while diminishing the negative environmental impacts [2–5]. Furthermore,

mixed crop–livestock systems are also preferred due to their inherent resource sufficiency, the ability to recycle nutrients, and reduced cash flow fluctuations due to the synergy between enterprises, the diversity of produce, and environmental sustainability [6–8]. However, the lack of climate-smart fodder varieties binds the producers to suboptimal production and sales activities [9]. The lack of feed for cattle has gotten worse, as open grazing areas have shrunk dramatically [10]. The adoption and utilization of enhanced planted forages are the primary alternatives that can be utilized to increase the dairy sector’s output [11]. Alternative feeds and additives may enhance total digestibility, significantly improving animal performance and reducing emissions [12,13]. The feasibility of utilizing alternative feeds is contingent upon the nutritional value, the responses of animal production, and the comparative costs of these feeds relative to conventional options [14]. Enhanced planted forages, such as Napier grass (*Pennisetum purpureum* Schumach.), have the potential to meet these criteria and mitigate feed scarcity [15]. Napier grass has received much attention as a promising resolution to the issue of feed shortages in livestock farming. It is a high-yielding forage crop that is rich in nutrient content. It produces more biomass per unit area than other forage crops [16]. Adopting Napier grass may result in a higher milk yield, reduced livestock rearing costs, and increased income and per capita milk consumption.

Napier grass is the predominant tropical perennial C4 grass native to Sub-Saharan Africa [17–19]. The crop serves as a suitable fodder option for various agro-climatic conditions in India, attributed to its optimal water usage efficiency, capacity to thrive in diverse soil types, resilience to intermittent drought, and substantial yields [20–22]. It possesses a significant dry-matter output potential of 78 tonnes per hectare per year [23,24]. Given the limited availability of land, Napier offers a lasting and sustainable solution for cattle food security and the enhancement of milk production [25,26].

Notwithstanding these benefits, the dissemination and acceptance of Napier grass are constrained in India. Cattle and small ruminants constitute the predominant livestock species, comprising 55–65% of India’s livestock population in semi-arid regions [27–29]. Crop residues serve as the primary source of livestock feed in India, while cultivated fodder is less prevalent [29]. Andhra Pradesh, a semi-arid region, ranks among India’s top five states in milk production, yielding an annual output of 15.69 million metric tonnes [30]. However, over 25% of farmers in the irrigated regions of coastal Andhra Pradesh traditionally feed green grass, which is inadequate for the 336 million buffalo that produce 956 million tonnes of milk annually [31].

In the early stages, it was assumed that a promising alternate feed to traditional green grass varieties would diffuse through farmer-to-farmer exchanges with venturesome adopters and their efforts. However, it was gradually realized that the innovator- or early adopter-focused approach did not allow for consideration of the constraints to widescale adoption, many of which were determined by the behavior and influence of other actors in the system [32]. Therefore, it is necessary to analyze the attitude, subjective norms, and perceived behavioral control determining the constraints in widescale adoption [33] of alternatives to conventional grass (for instance, Napier). Furthermore, to analyze the perceived usefulness of the Napier technology, it is important to analyze the baseline data for direct benefits (e.g., milk and the number of milch cattle).

Our baseline data (Table S1) show that the number of milk-producing buffalos, a major milk source in the state, has decreased significantly compared to 2016–2017 (Figure 1). This might be because of the low milk yield affecting the unit economics of farmers. However, in year 2017–2018, supportive government policies like the Dairy Development Cooperative Society Act, the drive for artificial insemination and high-quality feed supplements, and awareness creations among farmers regarding the importance of good feeding practices

and animal husbandry significantly enhanced the per capita milk production (Figure S1) for milch cattle, which improved milk production (Figure S2) by 25–27% in 2017–2018 [34]. However, the milk yield of the buffaloes has been stagnant since 2017–2018 (Figure 2). This stagnancy in milk production since 2017–2018 (Figure 3) can be broken with highly nutritious fodder [35]. In addition, adoption and utilization of Napier grass can be utilized to increase the dairy sector's output [36,37].

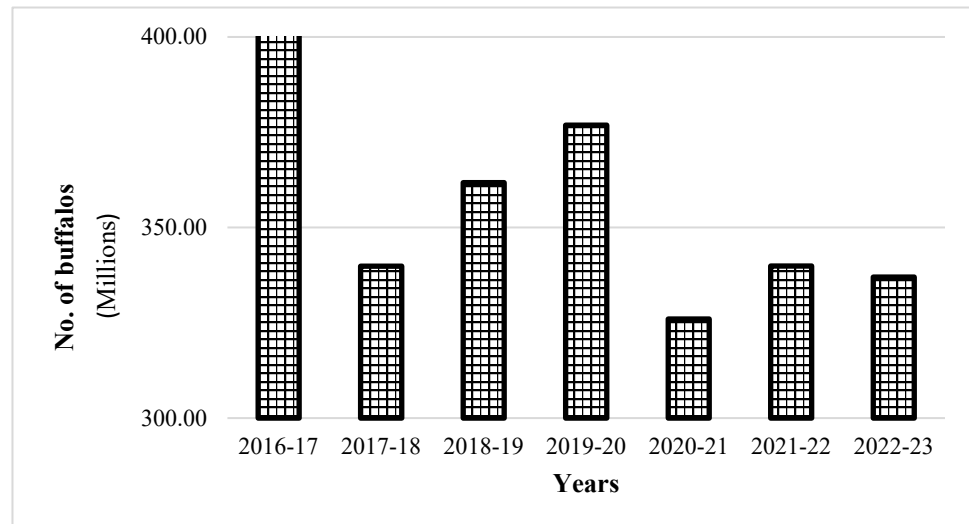


Figure 1. Number of milk-producing buffaloes in Andhra Pradesh represented year-wise to compare the changes across the years. The graph shows that policy interventions can decrease the necessity to keep more cattle, as higher outputs can be obtained from a lower number of cattle (source: baseline data form, Government of Andhra Pradesh, see Supplementary Table S2).

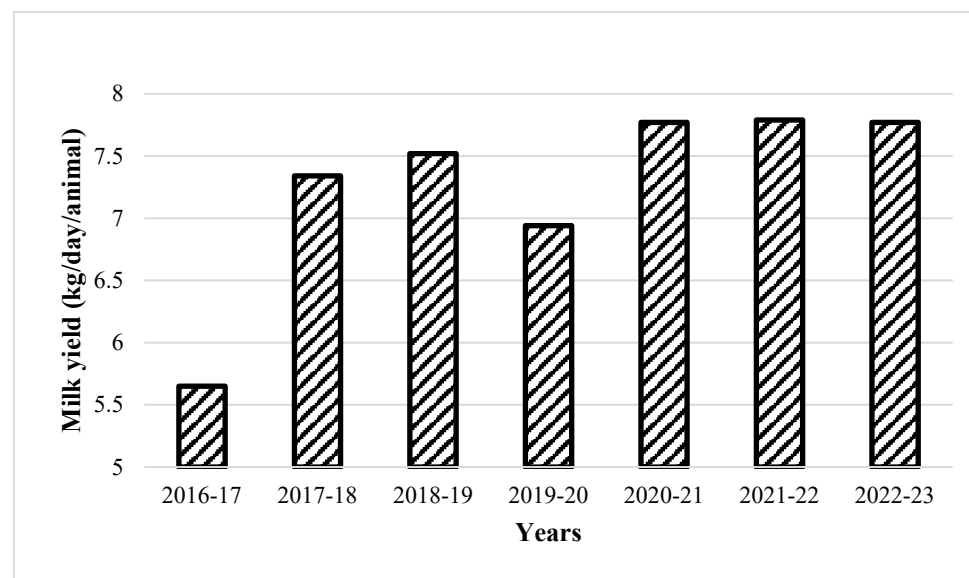


Figure 2. Year-wise average milk productivity (kg/day/animal) in Andhra Pradesh. The graph shows the effect of measures taken by the government on per capita milk yield (source: baseline data form, Government of Andhra Pradesh, see Supplementary Table S3).

Napier grass is abundant in protein, carbs, and minerals, which are vital for dairy animals. Dairy producers can reduce their reliance on external feed sources by cultivating more nutritious Napier grass, thereby advancing various sustainable development goals (SDGs), resulting in cost savings and improved self-sufficiency [38]. The implementation of Napier grass results in increased milk production, reduced livestock maintenance costs, and

heightened income, contributing to poverty alleviation (SDG 1). Additionally, improved per capita milk consumption ensures nutritional security and addresses malnutrition, thereby advancing hunger eradication (SDG 2). Furthermore, this practice promotes health and well-being (SDG 3), while cultivation enhances local biodiversity and mitigates soil erosion, supporting responsible consumption and production (SDG 12) and the conservation of terrestrial ecosystems (SDG 15).

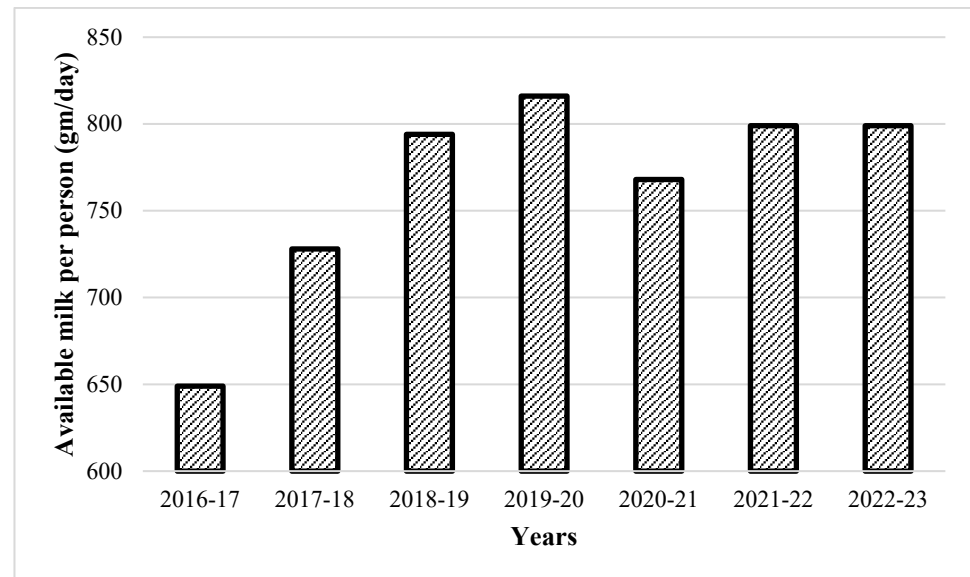


Figure 3. Year-wise per capita milk availability (gm/day) in Andhra Pradesh. The graph shows that the improved output from cattle ensured the better availability of milk per person, which showed little variation after the year 2018 (source: baseline data form, Government of Andhra Pradesh, see Supplementary Table S4).

However, there is a further need for research on the suitability of Napier grass in livestock farming in India, as there are various constraints reported by Kabirizi [38] and co-authors. At the same time, there is a dearth of comprehensive reports on Napier grass adoption in India. Devendra [39] highlights the alarming fact that numerous dairy farmers remain oblivious to the potential of Napier grass in regard to significantly boosting their income. There is a dearth of comprehensive training programs on the proper cultivation, harvesting, and storage techniques for Napier grass. Furthermore, the initial costs of quality Napier grass planting material can be prohibitive for small-scale farmers. Moreover, a lack of adequate training and support, coupled with insufficient irrigation, storage, and transportation infrastructure, further hinders its adoption [39]. In regions with limited land availability, allocating land for fodder cultivation can be challenging. Small-scale dairy farmers, often burdened by financial constraints and limited land access, face credit barriers to implementing Napier grass cultivation [39]. This study seeks to bridge the knowledge gap by investigating the socioeconomic factors and forms of institutional support that influence Napier grass adoption. This study specifically aims to evaluate the factors influencing Napier grass adoption and its subsequent impact on feed sufficiency and milk production in Andhra Pradesh, India.

2. Materials and Methods

2.1. Econometric Framework

We use the two-stage PSM methodology to quantitatively assess the effect of Napier adoption on milk yield, income, time-saving, women's participation, and per capita daily milk consumption. First, a probit regression method quantifies the probability of adopting

Napier grass. Farmers' adoption of Napier grass is designated as a binary value between 0 and 1, where 1 indicates that the farmer has adopted Napier and 0 indicates non-adoption. The probit model, which is the initial stage of PSM, is defined explicitly as

$$\text{Napier adoption} = \alpha_0 + \alpha_1 M_1 + \alpha_2 M_2 + \alpha_3 M_3 + \dots + \alpha_n M_n + \varnothing_i \quad (1)$$

where Napier adoption is the dependent variable, α_0 is the intercept, and $\alpha_1, \alpha_2, \alpha_3 \dots \alpha_n$ are the coefficient of predictor variables $M_1, M_2, M_3, \dots M_n$, respectively, while $\varnothing_i$ is the error term. The predictor variables used in the investigation are illustrated in Table 1. These variables are identified contextually while considering earlier empirical research, such as Ashley [40] and co-authors, Kassie [41,42] and his team, Murage [43] and co-authors, Ndiritu [44] and his team, Tadesse and team [45], and Teklewold [46] and his team.

Table 1. Details of variables and measurement.

Variable	Type	Definition and Measurement
Treatment variable		
Adoption of Napier cultivation	Dummy	If the household adopted Napier on or before 2021 and is still continuing = 1. Never cultivated Napier = 0
Outcome variables		
Average milk production (L/day/cow)	Continuous	Amount of milk produced by each cow (non-exotic breed) daily
Total milk production per household per year (L)	Continuous	Overall milk production (considering only non-exotic cows) in a year
Time dedicated to feeding the livestock (minutes/livestock)	Continuous	Time dedicated to feeding each livestock
Women's hours dedicated to feeding the livestock (minutes/livestock)	Continuous	Time dedicated (by women) to feeding each livestock
Net monthly income (Rs/cow/month)	Continuous	(Average monthly milk yield by a cow $\times$ Average price of milk per liter $\times$ No. of milk-producing cows)—amount spent for feeding each cow per month
Per capita milk consumption (ml/day/person)	Continuous	Amount of milk retained for consumption / No. of family members who consumed milk daily
Livestock health	Dummy	If the farmer feels the cow's health remains good throughout the year = 1; otherwise = 0
Veterinary doctor visit (per cow per year)	Continuous	No. of times the veterinary doctor visits a cow for a medical emergency
Independent variables		
Age	Continuous	Age of household head in years
Gender	Dummy	Male headed = 1; female headed = 0
Education	Continuous	Number of years in formal education
Household size	Continuous	Number of family members (>12 years) take food together
Farm experience	Continuous	Family head involved in farming (in years)
Livestock units	Continuous	Number of tropical livestock(s) in the household
Assured irrigation	Dummy	Having irrigation facility = 1; otherwise = 0
Member of farmers' organization	Dummy	Having membership in farmers' organization/group = 1; otherwise = 0
Institutional credit access	Dummy	Taken institutional credit in last three years = 1; otherwise = 0
Agricultural extension	Dummy	Meet with agriculture extension persons/experts = 1; otherwise = 0
Training	Dummy	Received training about Napier farming = 1; otherwise = 0
Off-farm income	Dummy	Household having income from off-farm sources = 1; otherwise = 0
Farm size (acre)	Continuous	Agricultural field area

Comparing the observable outcomes of Napier adopters and non-adopters is the objective of the PSM approach. Furthermore, the PSM method does not depend on assumptions about the distribution and functional form of the error terms. Past studies used the PSM approach to address the issue of self-selection bias and calculate the average treatment effect (ATE) of technology adoption [47]. Similarly, the PSM method can be utilized to determine the impact of producing/adopting Napier, provided that the requirements of conditional independence (where unobserved factors do not influence the adoption) and common support (where there is a substantial overlap in propensity scores between adopters and non-adopters) are satisfied [48]. The primary concept behind the PSM technique is to identify persons within a group of farmers who possess comparable observable characteristics to adopters before any condition (here, Napier production) is applied. This entails identifying a control group with similar traits to the adopted individuals. It is assumed that, by considering all pre-adoption observable characteristics relevant to adopting Napier and the outcome variables, farmers who have adopted will have similar average results as non-adopters would have had if they had adopted. The variations in results observed between the control and treated groups are ascribed to the adoption of Napier. The steps involved in the PSM approach are presented in Figure 4.

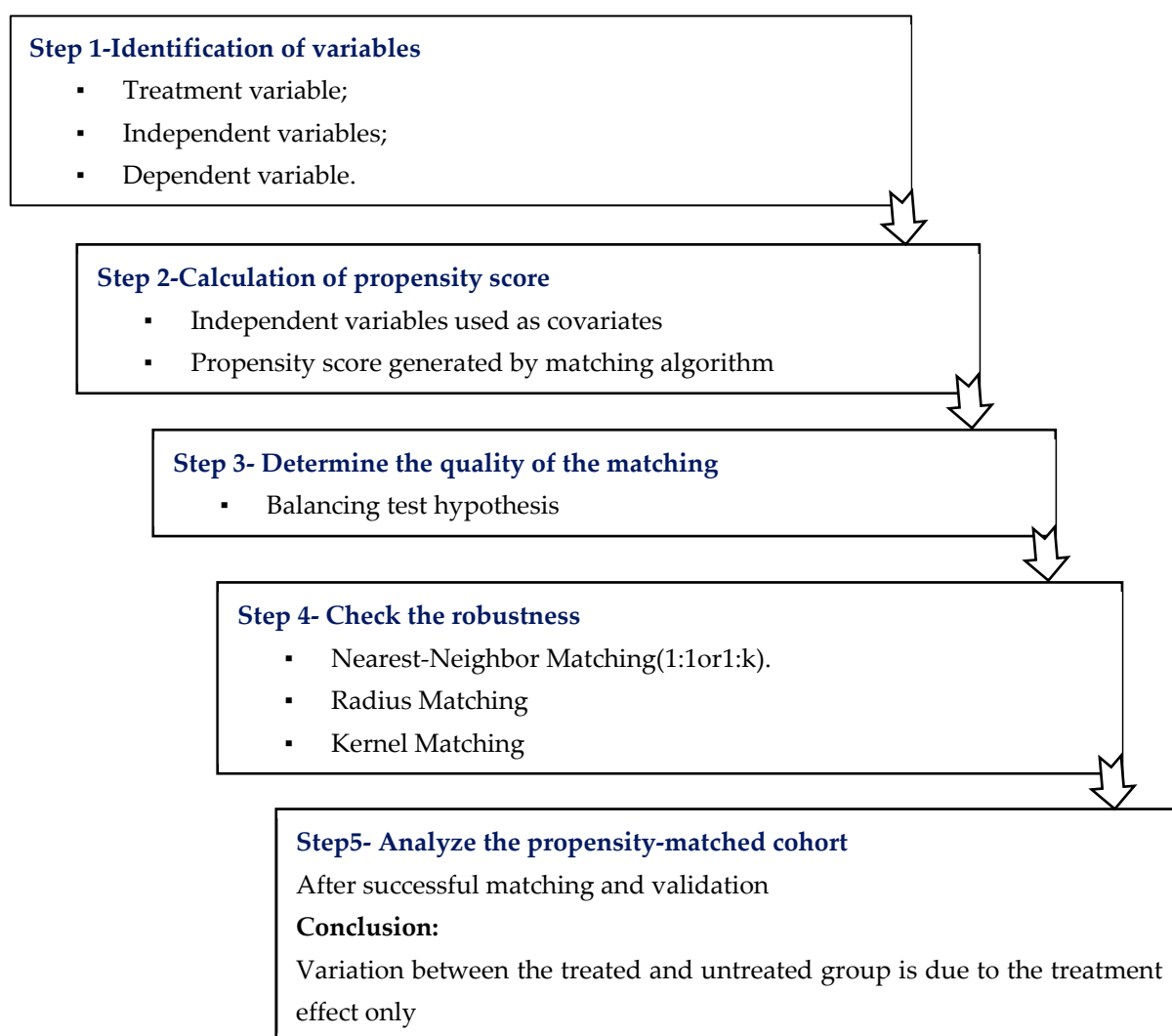


Figure 4. Steps involved in propensity score matching approach used in this study.

The best-matching estimator matches the estimated propensity scores in the second phase. Matching methods are statistical techniques employed to estimate the causal effect

of a treatment or intervention. The process entails comparing treated units with analogous untreated units to mitigate confounding factors. As per the existing literature, the matching algorithms that are most frequently employed are Nearest Neighbor Matching (NNM), Kernel-Based Matching (KBM), and Radius Matching (RM). NNM is straightforward to implement and comprehend; however, if the nearest neighbor is not an appropriate match, it may result in biased estimates. KBM facilitates nuanced matching by assigning weights to potential matches according to their similarity to the treated unit; however, it may be computationally demanding, particularly with large datasets. RM is straightforward to implement; however, the selection of the radius can greatly influence the outcomes. A suitable matching algorithm is chosen for the present investigation while considering its ability to match many insignificant variables, produce a small pseudo- R^2 after matching, and minimize the mean standardized bias [49]. The matching process is limited to a condition where the treated and control groups shared support. Propensity score matching estimates the average treatment effect on the treated (ATT) by finding control units with similar observable characteristics to treated units, effectively creating a counterfactual group. The ATT is measured (Equation (2)) as

$$ATT = H(Z_1 - Z_0 \mid I = 1) = H(Z_1 \mid I = 1) - H(Z_0 \mid I = 1) \quad (2)$$

Given the unobserved nature of the counterfactual outcome $H(Z_0 \mid I = 0)$ for a particular household, the ATT can be approximated using $H(Z_0 \mid I = 1)$. Nonetheless, this strategy could result in a biased ATT. The characteristics of non-adopters and adopters might have varied before the adoption process. Hence, the anticipated variations in the final result might not be solely attributable to adoption.

The PSM approach is predicated on conditional independence and common support assumptions, which are anticipated to possess conditions comparable to randomized experiments [50]. Conditional independence, also known as the strong ignorability assumption, assumes that, given a set of observed covariates, the potential outcomes are independent of treatment assignment. As we factor in the conditional independence, the propensity score is calculated (Equation (3)) as

$$\rho(K) = \text{pr}(I = 1 \mid K) = H(I \mid K) \quad (3)$$

where $I = 1$ or 0 is a dichotomous decision for Napier adoption and non-adoption. K is a vector of farmers' socioeconomic attributes; therefore, the conditional distribution of K , denoted by $\rho(K)$, remains consistent across both the adopters and non-adopters.

Consequently, the propensity score estimation attempts to balance the observed distribution of the covariates between the two groups under this assumption [51].

The following constitutes the assumption of common support (Equation (4)):

$$0 < \text{pr}(I = 1 \mid K) < 1 \quad (4)$$

This postulation guarantees that each farmer has a favorable likelihood of adopting Napier.

Using the two assumptions stated in (Equations (3) and (4)), the ATT can be calculated as in Equation (5):

$$ATT = H[H\{Z_1 \mid I = 1, \rho(K)\} - H\{Z_0 \mid I = 0, \rho(K)\} \mid I = 1] \quad (5)$$

2.2. Study Area and Sampling

Livestock farming is a substantial method of sustenance for rural households inhabiting the semi-arid areas of India. However, in AP, there has been a substantial decline in the population of milk-producing livestock, which serve as a primary source of milk for

the state, since 2016–2017. We employed a multistage sampling method to choose participants for a questionnaire survey. Since 2020, Dr. Reddy’s Foundation has been promoting Napier cultivation in 24 mandals of the Srikakulam and Vizianagaram districts. Nearly 6500 farmers adopted Napier cultivation in these two districts until 2023–2024. Hence, these were the purposefully selected districts for primary data collection where farmers of both groups, i.e., non-adopters (grow their livestock on normal fodder) and adopters (feeding livestock with Napier), were available for sampling. Collecting data from these districts is crucial in regard to overcoming the selection bias and presenting the counterfactuals. We used Yamane’s [52] formula to measure the adequate sample size (Equation (6)):

$$n = \frac{N}{1 + N(e^2)}, n = \frac{6500}{1 + 6500(0.06^2)}, n = 267 \quad (6)$$

Here, n is the size of the sample households, N is the size of the population, and e is the precision. However, 267 households were sufficient for this analysis. We selected 309 farmers for the questionnaire survey.

3. Results and Discussions

3.1. Socioeconomic Characteristics and Impact of Napier Adoption

The study presents specific socioeconomic characteristics of livestock farmers in the Srikakulam and Vizianagaram districts of Andhra Pradesh, India, in Table 2. The results show that the families are headed by male members (96–98% of households) aged between 42 and 46.5 years. Additionally, Napier adopters have an impressive 31 years of experience in dairy farming, while counterparts have only 27 years in their kitty. Our data further reveal that 33% of the farmers in the region earn income from off-farm activities due to smaller land holdings. Farmers with large farms and bigger livestock units are able to mechanize certain aspects of Napier grass cultivation and harvesting, reducing labor costs. Interestingly, we observed that older farmers have well-established networks with other farmers, extension agents, and input suppliers. These networks can provide valuable information, support, and access to resources that can facilitate the adoption of new technologies.

Table 2. Descriptive statistics of farmers’ socioeconomic and demographic characteristics.

Explanatory Variables	Napier Adopters		Napier Non-Adopters		Mean Difference Test
	Mean	SD	Mean	SD	
Age	46.36	10.46	42.3	9.81	0.076
Education	7.19	2.18	5.54	1.83	0.043
Gender	0.96	0.14	0.98	0.16	0.246
Household size	4.75	1.15	4.79	1.32	0.441
Membership in farmers organization	0.48	0.08	0.35	0.06	0.037
Farm experience	31.32	8.33	27.18	7.11	0.062
Off-farm income	0.32	0.08	0.33	0.06	0.283
Farm size	2.97	0.46	2.63	0.42	0.037
Assured irrigation	0.76	0.15	0.73	0.11	0.242
Livestock units	3.08	0.32	2.77	0.26	0.019
Institutional credit access	0.56	0.18	0.55	0.22	0.423
Agricultural extension	0.98	0.16	0.86	0.2	0.056
Training	0.89	0.13	0.82	0.15	0.239

We measured the impact of Napier adoption using the PSM approach and presented the results in Table 3. We have analyzed the impact of adopting Napier grass on milk production, time-saving, income, per capita consumption, and livestock health. Our results

state that incorporating Napier grass into feeding regimes can increase daily milk production by 24.6%. Cows fed with Napier grass using climate-smart push–pull technologies produced 1.16–1.26 L more milk per day compared to those not fed with Napier grass. Previous studies have shown that feeding livestock with climate-smart fodder can result in a 15–40% increase in milk [53]. Additionally, annual milk production per household can increase by 1244 L (61.2%) as a result of adopting Napier grass. Napier grass is rich in nutrients, particularly protein and energy, which are essential for milk production. This can lead to improved milk yield and quality [54]. It is important to note that the specific performance of each forage can vary depending on factors such as management practices, fertilization, and irrigation, but Napier, compared with Bermudagrass, Ryegrass, Alfalfa, and Sorghum-Sudan Grass, has a high cost efficiency and milk yield [55]. Furthermore, Napier production ensures a continuous supply of fodder for the livestock throughout the year. A continuous food supply not only ensures improved milk production but also enhances the milk productive period for the livestock by 21–30 days (on average, based on three matching algorithms). Moreover, with food sufficiency, farmers become confident in cultivating more lactating livestock than non-Napier farmers. All these elements result in an improved annual milk yield per household for Napier producers compared to non-adopters.

The results indicate that farmers who have adopted Napier spent significantly less time on livestock rearing (28–30 min per cow) compared to non-adopters. These findings are consistent with a study [56] which found that the use of advanced forage technology led to a notable decrease in time spent on feeding. The time saved through Napier grass adoption can present significant opportunities for farmers. This additional time can be utilized in various ways, directly impacting their livelihoods and overall well-being. More time can be spent on tasks like cleaning livestock sheds, providing supplementary feeds, monitoring animal health, or attending training programs, workshops, or seminars to enhance their knowledge and skills. If farmers have access to markets and infrastructure, they may use the saved time to transport and sell their products, increasing their income.

Furthermore, our results show that women's involvement in livestock farming in Napier-adopting households has improved significantly compared to non-Napier-adopting farmers. This suggests that having dedicated land for Napier near the livestock farm makes livestock farming less laborious and time-consuming. Therefore, with Napier adoption, livestock rearing becomes a more women-intensive activity than with non-Napier adoption. Increased women's participation in livestock farming not only contributes to women's empowerment but also saves man-days. Napier grass cultivation can provide women with a source of income, either through the sale of surplus fodder or livestock products. This can lead to increased financial autonomy and decision-making power. Furthermore, as the benefits of Napier grass become evident, it can lead to a more equitable distribution of labor within the household. Men may become more involved in livestock care, particularly during the dry seasons when Napier grass provides a reliable feed source. The Napier adoption redefines the gender roles, as women working in typically male-dominated agricultural fields can defy gender conventions and show that they can contribute equally to the economy. In addition, successful women in Napier cultivation can inspire others in their community, fostering a cultural shift toward recognizing women's capabilities in diverse sectors. However, it is important to note that the impact of Napier grass adoption on household dynamics, gender equity, and economic empowerment can vary depending on factors such as cultural norms, local market conditions, and government policies. Our inferences from this study can help policymakers and development organizations to re-design interventions that maximize the positive impacts of Napier grass adoption for women and their communities.

Table 3. Impact of Napier on various outcome variables.

Outcome Variables	NNM							KM					RM				
	Napier Adopters	Napier Non-Adopters	ATT	SE	Critical Level of Hidden Bias	Napier Adopters	Napier Non-Adopters	ATT	SE	Critical Level of Hidden Bias	Napier Adopters	Napier Non-Adopters	ATT	SE	Critical Level of Hidden Bias		
Average milk production (L/day/cow)	ATT	6.09	4.83	1.26 ***	0.57	2.15–2.20	6.04	4.88	1.16 ***	0.53	2.20–2.25	6.11	4.93	1.18 ***	0.61	2.15–2.20	
Total milk production per household per year (L)	ATT	3351.6	2071.1	1280.5 ***	143.8	2.85–2.90	3286.4	2028.6	1257.8 ***	149.1	2.80–2.85	3186.9	1994.2	1192.7 ***	133.6	2.70–2.75	
Time dedicated to feeding the livestock (minutes/livestock)	ATT	128	156	−28 ***	10.83	1.85–1.90	122	153	−31 ***	11.84	1.75–1.80	123	154	−31 ***	11.06	1.95–2.00	
Women’s hour dedicated to feeding the livestock (minutes/livestock)	ATT	92	68	24 ***	6.17	2.20–2.25	97	75	22 ***	7.02	2.10–2.15	89	63	26 **	5.46	2.35–2.40	
Net monthly income (Rs/cow/month)	ATT	4734.16	2686.87	2047.29 ***	169.1	2.35–2.40	4689.18	2144	2545.18 ***	2122.3	2.20–2.25	4716	2161	2555 ***	2110	2.20–2.25	
Per capita milk consumption (ml/day/person)	ATT	383.18	240.17	143.01 ***	5.54	2.15–2.20	395.6	243.7	151.9 ***	6.03	2.35–2.40	388.6	237.6	151 ***	5.3	2.20–2.25	
Livestock health	ATT	0.86	0.65	0.21 ***	0.17	2.05–2.10	0.83	0.61	0.22 ***	0.14	2.25–2.30	0.84	0.69	0.15 ***	0.15	2.25–2.30	
Veterinary doctor visit (per cow per year)	ATT	3.56	4.76	−1.2 ***	0.21	2.55–2.60	3.45	4.61	−1.16 ***	0.23	2.45–2.50	3.51	4.73	−1.22 ***	0.24	2.50–2.55	

*** = Significant at 1%. ** = Significant at 5%.

Napier adopters earn Rs 2047–2555/cow/month more than non-Napier farmers, according to our analysis. Napier adopters receive a better price for their milk since it has 1.86% more fat than non-Napier farmers. Furthermore, non-Napier feeder cows consume 14% more feed than Napier feeder cows, causing more expenses for non-Napier farmers than Napier farmers. The higher milk yield with low feed consumption translates to higher incomes for Napier adopters. Napier grass can enhance agricultural incomes across households and farm sizes. Smallholder farmers can gain fodder, better livestock health, livelihood stability, profit margins, a competitive edge, as well as additional income sources. Medium-sized farms can boost agri-production, diversify incomes, and cut feed preparation and distribution costs. Large-scale farmers profit from economies of scale, feed quality, and market prospects. Napier producers earn more and consume more milk per person than non-adopters, rising from 143 to 152 mL (based on several matching techniques). Additional milk consumption (4.4 L/month/person and 54 L/year/person) keeps family members healthy, minimizes medical costs, and assures food security. In addition, Napier consumption safeguards farmers and cattle health. Results show that 84% of Napier producers say their livestock stays healthy with Napier, while 65% of non-Napier farmers say their livestock stays healthy with grass. The study also found that Napier-consuming cattle need 1.2 fewer veterinarian visits per year. These findings are similar to the findings by Do Valle [57] and colleagues, which state that Napier grass is a rich source of essential nutrients, including protein, carbohydrates, and minerals, and is highly digestible. This balanced nutrient profile supports optimal growth, reproduction, and milk production in livestock, and its high fiber content promotes healthy gut microbiota through short-chain fatty acids [58]. In addition, Napier grass contains antioxidants that can help neutralize harmful free radicals, boosting the immune system and protecting livestock from diseases.

The results presented in Table 3 indicate that each ATT value is linked to a specific τ -bound value, representing a gamma level that could support the causal inference of Napier adoption. For instance, the gamma value for per capita milk consumption falls within the range of 2.35–2.40, implying that, if households with similar baseline covariates have a 135–140% difference in their likelihood of adopting Napier, the positive impact of Napier adoption on per capita milk consumption may be called into question. This suggests that there must be a high enough hidden bias to potentially influence the findings in Table 3. The elevated gamma values associated with the dependent variables indicate that most external factors are considered baseline covariates that could influence the treatment and dependent variables.

3.2. Determinants of Napier Grass Adoption

Since the outcome for Napier technology adoption is categorical variable with two possible values (e.g., adopted or not adopted), we used a probit analysis for analyzing binary dependent variables. We present the outcomes of the probit model analysis in Table 4. Furthermore, we performed a chi-square test to assess the overall goodness-of-fit of the model. It helped us to determine whether the observed data significantly differ from the data provided by the model. The chi-square probability estimated is higher than the specified value ($\text{prob} > \text{Chi}^2 = 0.316$) at a significance level of 1% (Table 4). Based on the results, we cannot reject the null hypothesis and establish that the error terms follow a normal distribution, indicating the suitability of the probit model in this case. We present the Variance Inflation Factor (VIF) as a statistical metric to assess the multicollinearity among the independent predicted variables, implying no statistically significant correlation between the predictor variables (Table 5). We also analyzed the effects of the adopter's age, livestock, farmer or social organization membership, formal education, and farm size on Napier technology adoption and presented them in Table 6.

Table 4. Jarque–Bera test of normality of the error terms.

Skewness-Kurtosis Test (Jarque–Bera)	
Ho: Normal Distribution	
Chi ² (2) = 1.391	
Prob > Ch ² = 0.316	

Table 5. The Variance Inflation Factor is used to evaluate multicollinearity.

Explanatory Variables	VIF	Tolerance
Age	1.43	0.70
Education	1.27	0.79
Gender	1.19	0.84
Household size	1.33	0.75
Membership in farmers organization	1.26	0.79
Farm experience	1.18	0.85
Off-farm income	1.12	0.89
Farm size	1.26	0.79
Assured irrigation	1.22	0.82
Livestock units	1.36	0.74
Institutional credit access	1.45	0.69
Agricultural extension	1.41	0.71
Training	1.2	0.83

Table 6. Determinants of Napier adoption.

Explanatory Variables	Coefficient	Standard Error	Marginal Effects
Age	0.112 **	0.051	0.061
Education	0.161 ***	0.043	0.092
Gender	0.008	0.003	0.002
Household size	0.005	0.002	0.001
Membership in farmers organization	0.103 **	0.003	0.069
Farm experience	0.159 **	0.003	0.083
Off-farm income	0.023	0.016	0.009
Farm size	0.186 ***	0.014	0.119
Assured irrigation	0.126	0.091	0.008
Livestock units	0.166 ***	0.024	0.103
Institutional credit access	0.082	0.055	0.047
Agricultural extension	0.094 **	0.003	0.024
Training	0.139	0.086	0.176

** = significant at 5%; *** = significant at 1%.

Our analysis shows that the unit increase in livestock farmer age from the mean improves Napier grass adoption by 6.1%, indicating that more experience increases the possibility of adopting new agricultural technology [59]. We found that younger farmers engage in innovative approaches with higher turnovers. This supports the idea that younger farmers require time and experience to foresee the benefits of nutrient-rich feed. However, elderly farmers favor the adoption as a long-term investment and patiently await rewards [60]. In addition, we also observed that, due to a growing need for animal feed, households with more livestock prefer using Napier grass. [61]. In line with earlier reported data, we observed that Napier adoption increases by 10.3% for households with more livestock units than the average [62]. Napier grass adoption also increases with farmer or social organization memberships. A 1% increase in farmers' organization/group memberships boosts Napier production adoption by 6.9%. As per our analysis, 38% of Napier adopters are members of farmers' organizations, whereas only 35% of non-adopters belong to this group. Furthermore, farmers can share knowledge in the farmer-to-farmer knowledge transfer model with social group membership [61]. In addition, social organizations provide informal crisis relief to farmers. Extension services are additional tools that further catalyze Napier production among farmers. Our results agree with earlier findings, suggesting that village extension agent visits and farmer interactions are crucial to promoting interventions [61]. Extension programs help producers learn about new

technologies. Farmers can also see possible benefits through demonstrations and meet agricultural experts and early adopters through extension services. The study demonstrates that education strongly influences Napier adoption. With more schooling, Napier adoption rose by 9.2%. This suggests that formal education helps farmers see technology's long-term benefits. Furthermore, our data reveal that there is a 11.9% Napier adoption rise with a 1% farm-size increase. This suggests that large-scale farmers are more likely to use Napier as a forage crop.

3.3. Quality of Matching Through the Covariate Balancing Test

We also present the results for the covariate balancing test performed to further validate the impact of Napier adoption. In this analysis, we tried to ensure that the outcome variables are similar between those who adopt Napier and those who do not. Table 7 shows the results for covariate balancing. A significant reduction in overall bias is established through the propensity score matching (PSM) analysis while using any matching algorithms. The standardized mean difference for all covariates is reduced by 47.8–48.1%. Additionally, the likelihood ratio test results (p -values) show that the combined significance of covariates is not rejected before matching but is rejected after matching. Post-matching, the pseudo- R^2 values for all three matching algorithms (NNM, KBM and RM) decrease significantly. Statistically insignificant p -values obtained from the likelihood ratio test, low pseudo- R^2 , and low mean standardized bias indicate that the propensity score successfully equalizes the distribution of covariates between both groups.

Table 7. PSM quality indicators before and after matching.

Matching Algorithm		Pseudo- R^2 Before Matching	Pseudo- R^2 After Matching	$\rho > \chi^2$ Before Matching	$\rho > \chi^2$ After Matching	Mean Standardized Bias Before Matching	Mean Standardized Bias After Matching	(Total)% Bias Reduction
Napier grass adoption	NNM	0.193	0.032	0.003	0.397	28.23	14.66	48.06
	RM	0.177	0.026	0.017	0.517	29.81	15.47	48.10
	KBM	0.183	0.033	0.020	0.773	27.06	14.12	47.82

Source: Author's calculations using the survey data. NNM = Nearest Neighbor Matching; RM = Radius Matching; KBM = Kernel-Based Matching.

4. Conclusions

Restricted grazing, insufficient land area, and erratic climatic conditions constrain fodder alternatives for dairy producers in India's peninsular agroecological zones. This study examines the influence of socioeconomic factors on the adoption of Napier grass, milk yield, feed sufficiency, and farmer welfare. The adoption of Napier grass enhanced milk production, feed sufficiency, animal health, household income, and per capita milk consumption. Our work underscores the necessity of comprehensive methods to advance new agricultural technologies and highlights the importance of prioritizing social interactions to enhance information accessibility. Moreover, research indicates that enhancing farmer competencies and providing on-farm training would facilitate technology adoption. Enhancements are necessary for service providers assisting farmers with market access and inputs. In addition, our research indicates that the adoption of Napier grass is influenced by farm size and the educational attainment of farmers. Extensive land ownership and enhanced educational attainment promote the adoption of climate-smart forages such as Napier grass. Policymakers ought to allocate resources to enhance extension services, equipping farmers with technical expertise and information. Incorporating Napier grass with additional climate-smart initiatives can improve resilience and sustainability. Formulating techniques to engage youth in agriculture, including value-added goods and social media, can be beneficial. Enhancing infrastructure and market accessibility can promote

the sale of Napier grass and dairy products. The findings of our study can significantly affect the understanding of how fodder production influences the income and well-being of smallholder farmers in Peninsular India. Nonetheless, the study's constraints, including spatial specificity and reliance on self-reported data, indicate that future research should investigate the long-term effects of Napier grass uptake. Future research should focus on exploring the potential of Napier grass to be integrated into various climate-smart agricultural practices like reducing heat stress in livestock. It can also be explored further for socioeconomic benefits, such as an alternative source of income generation, poverty reduction, and gender equity. The research may involve field experiments, modeling, economic analysis, and participation from farmers and local communities. By addressing these research questions, Napier grass can be harnessed as a climate-smart agricultural practice, contributing to sustainable agriculture and food security. In addition to these, Napier grass faces challenges in regions with limited water resources, particularly in arid and semi-arid regions. Smallholder farmers often lack reliable irrigation systems, making them vulnerable to water scarcity. In addition, insufficient extension services in rural areas and limited technical knowledge also hinder the adoption and optimal utilization of Napier grass. Our survey showed that more than 30% of farmers expressed concerns regarding these constraints. We suggest policy interventions to address water management constraints in Napier cultivation through promoting water-efficient irrigation techniques, strengthening extension services, developing drought-tolerant varieties, and promoting community-based approaches.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su17020495/s1>, Figure S1: Year-wise per-capita milk availability; Figure S2: Year-wise milk productivity; Table S1: District-wise data for milch and non-milch animals in AP; Table S2: Milk producing buffalo number; Table S3: Average milk production; Table S4: Per capita milk availability.

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