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Assessing the Role of Digital Platforms in Strengthening Agricultural Extension Services: Advisory to Empowerment

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HIGHLIGHTS

- The use of digital platforms among small farmers in Uttar Pradesh has increased their knowledge, adoption capacity, and yield.
- Taking into account socio-economic factors, the empowerment score of farmers using digital platforms is 13% higher than that of non-users.
- Hybrid digital-traditional extension systems are required for inclusive empowerment and equity of farmers.

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ABSTRACT

The study conducted during 2025 explores the contribution of digital platforms in strengthening agricultural extension services and empowering farmers in Uttar Pradesh, India. Using a cross-sectional survey of 400 farmer households selected by stratified random sampling, the study compares digital platform users and non-users in terms of knowledge, empowerment, technology adoption, yield, and income. Validated multi-item scales and indices were used to measure perceived usefulness, digital use, and empowerment, which were supported by reliability and factor analysis. Group differences were tested with t-tests and chi-square statistics, while logistic regression assessed the probability of adopting at least three recommended practices, and a multiple regression modelled the determinants of empowerment. The results show that even after controlling for socio-economic and extension variables, digital platform users have significantly higher knowledge, empowerment scores, adoption indices, yield, and net farm income than non-users. Structural analysis shows that digital use influences empowerment both directly and indirectly through knowledge and information self-efficacy, underscoring the role of digital platforms as catalysts to drive the transition from consultation to empowerment.

INTRODUCTION

Smallholder farmers, who account for 86 per cent of agricultural land, face persistent challenges such as fragmented land, unstable markets, climate risks, and limited access to timely, reliable information (Mehmood, 2025). Traditional agricultural extension systems, operated primarily through government field staff, farmer field schools, and demonstration plots, are struggling to keep pace with these demands due to manpower shortages, geographical spread, and resource constraints (Nandi & Nedumaran, 2019). Agricultural extension coverage is inadequate in Uttar Pradesh, India's most populous state, and a major agricultural producing centre (Chaturvedi & Vatta, 2025). Here, the ratio of farmers to agricultural extension workers often exceeds 1,000:1, leading to uneven dissemination of knowledge and low adoption of productivity-enhancing practices (Satapathy et al., 2024). This gap has driven a

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significant shift towards comprehensive solutions such as digital platforms (Panda et al., 2017; Sondarva et al., 2023; Geethalaxmi et al., 2024), and agri-tech services to overcome information asymmetries and empower farmers (Dhamija & Bhide, 2011). Digitization has gained momentum since the launch of initiatives like Digital India, Kisan Suvidha, and Agri Stack Ecosystem. These initiatives aim to deliver personalized, real-time advice on weather, pests, markets, and input optimization directly to farmers' smartphones. By 2025, smartphone penetration in rural India reached approximately 70%, supported by affordable data plans and connectivity expansion led by Jio, creating an enabling environment for information and communications technology (ICT) based expansion. Platforms such as farmer call centres, m-Kisan portals, and private apps like Agrostar and Dehat are spreading rapidly, providing multilingual content and networks beyond official channels (Yashvardhan et al., 2022). Although these tools will guarantee increased access and efficacy, their revolutionary nature will be determined by whether they offer mere advisory knowledge or facilitate greater empowerment, which assists farmers in making choices independently and responding to uncertainties (Kumar et al., 2021). Empowerment within the agricultural extension field includes the transfer of information as well as self-reliance, activism of farmers, and building up of the collective bargaining power (Sindakis & Showkat, 2024). Theoretically, the use of theories such as empowerment theory and the Unified Theory of Acceptance and Use of Technology (UTAUT) which postulates that the adoption of information and communication technology (ICT) influences behavioural intentions with respect to the perceived usefulness, ease of use and trust and eventually develop outcomes such as innovation adoption and livelihood security (Ibrahim & El-Kassim, 2024; Godara et al., 2024; Mehla et al., 2025). However, in India, it has been demonstrated that digital technologies have both positive and negative impacts; the tools lead to a 10-20 per cent overall yield gain among users, although literacy and barriers to access tend to lock out older and marginalized farmers and women. The state Uttar Pradesh, where the majority are smallholder farmers, is endangered by climatic variability; policymakers must learn how digital communities can be used to change agricultural extension approaches to do less telling and more empowering. The findings generalize application of initial measures such as PM-Kisan, e-NAM, and state-level applications in agriculture to vow that digital transformation can ensure even-handed and climate-resilient farming (Chander & Rathod, 2020).

METHODOLOGY

The study involved cross-sectional survey based on quantitative approach, performed in Uttar Pradesh, India, selected owing to its agrarian significance, and increasing digital extension initiative of ingenuity (Balkrishna et al., 2023). It was performed on three districts that have middle-level, and backward agro-economic statuses, in terms of coverage of irrigation, cropping intensity, and digital connectivity measures. Four villages in each district, 12 in total, were randomly chosen with a sufficient network coverage and operational digital counselling channels with involvement of extension and panchayat offices (Rajkhowa & Qaim, 2021).

Target population consisted of all working agricultural households, split into two groups: users of digital platforms - people who visit digital consultations at least 3 times a year, and non-users. Sample size was determined using formula:

$$no = \frac{Z^2 pq}{e^2}$$

Where, Z = 1.96 (95% confidence),
p = q = 0.5 (maximum variance assumption), and e = 0.05

Where possible, there are limited population changes by providing mostly a sample of about 385 farmers. They stratified a random sample of 400 farmers at final stage to represent well various farm sizes and social categories. Finally, sample was distributed proportionally across district, villages, and user's level of sample.

Primary data was collected through structured personal interviews, which included socio-economic profiles, patterns of access, farm characteristics, and use of digital platforms (frequency, type, duration), decision-making autonomy, perceived quality of consultation, adoption of better practices, and outcome indicators such as yield and net farm income. Key concepts: trust in digital information, perceived usefulness, ease of use, and empowerment in decision making, were evaluated using a multi-item 5-point Likert scale (Lamm et al., 2021). Cronbach's alpha assessed scale of reliability.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{j=1}^{k}\sigma_j^2}{\sigma_T^2}\right)$$

All structures achieved β ≥0.81. Exploratory factor analysis confirmed dimensionality of scale through KMO value > 0.76; Bartlett test p < 0.001. A digital platform use index (DPUI) was constructed by aggregating standardized scores of frequencies, platform variety, and duration of use.

Descriptive statistics summarized respondents' profile and usage patterns. Independent t-tests and χ^2 tests were used for group comparisons. Logistic regression tested likelihood of adoption (Rajkhowa & Qaim, 2021).

$$\ln [P/(1-P)] = \beta_0 + \beta_1 DPUI_i + \beta_2 EC_i + \Sigma\beta_k X_{ki}$$

Empowerment determinants were modelled by multiple linear regression:

$$Y_i = \beta_0 + \beta_1 DPUI_i + \Sigma\beta_k X_{ki} + \varepsilon_i$$

SEM tested mediating pathways from digital use to empowerment through knowledge. Analyses were conducted using several appropriate software, including necessary diagnostics for model fit (R^2, CFI > 0.90, RMSEA < 0.05) (Douxchamps et al., 2017; Lazar et al., 2020).

RESULTS

In the primary investigation with the information acquired emphasizes over socio-economic profile of the 400 farmers sampled and establishes the contextual baseline against which the role of digital platforms in agricultural extension is interpreted. It reflects a situation where digital platforms have the potential for strong reach among smallholder farmers, but equity concerns remain important for extension planning (Balkrishna et al., 2023).

Table 1. Pattern of digital platform use among farmers

Indicator	Users (n = 240)	Non-users (n = 160)	Overall (N = 400)
Proportion of digital-platform users (%)	240 (60.0)	160 (40.0)*	–
Mean number of platforms used (± SD)	2.1 ± 0.8	0.3 ± 0.5	1.4 ± 1.1
Weekly frequency of digital advisory access	3.8 ± 1.6	0.4 ± 0.9	2.4 ± 2.1
% accessing mobile apps	62.5	8.1	39.0
% using WhatsApp groups	71.7	10.0	46.3
% using YouTube agri channels	54.6	6.3	34.5
% using IVR/Call centres	38.8	2.5	24.0
Average years of digital use	3.2 ± 1.4	0.5 ± 0.9	2.1 ± 1.8
% receiving advisory in local language	86.3	21.3	59.8

*Non-users refer to those not using any platform regularly; they may have incidental exposure.

The Table 1 describes the patterns of use of digital platforms, showing clear differences between users and non-users and showing how actively farmers engaged with digital advice channels. 60% of farmers are classified as users, showing that there is a majority in digital extension, yet 40% of farmers are largely deprived of regular digital consultation, which confirms that traditional methods are still important for inclusive extension. Users use, on average, more than two different platforms (2.1), while the diversity among non-users is almost negligible. This shows that once farmers enter the digital sphere, they start experimenting with multiple channels like apps, WhatsApp groups and YouTube. The frequency of weekly access to counseling (3.8 times for users vs. 0.4 times for non-users) reflects the difference between active, demand-based information-seeking behavior and sporadic, often incidental contact. The high proportion of users relying on WhatsApp groups (71.7%) and YouTube channels (54.6%) reflects the growing importance of peer-shared content and audio-visual learning in extended education, while mobile apps and IVR or call centers complement these as more formal or institutional channels. The average duration of digital use (about three years among users) shows that digital extension is not simply a new trend, but a mature component of the counseling setting, providing ample time for behavior change and adoption of practices. Importantly, more than 80% of users receive advice in local languages, underscoring the role of localization for usability and trust and providing a strong justification for investment in language-appropriate content by public and private providers. Table shows that digital platforms, particularly social and video-based platforms, are playing a central role in many farmers' information systems, while also highlighting a segment that is at risk of being left behind.

Results focus on the measurement quality of the key latent constructs in the study and confirm that the scales used to measure usefulness, ease of use, trust, empowerment, and use of digital platforms are psychometrically sound (Table 2). Cronbach alpha values for all constructs show high internal consistency between 0.81 and 0.90, suggesting that the items belonging to each scale reliably measure the same underlying concept. This is important when concluding intangible dimensions such as empowerment and trust, which cannot be directly observed and must be measured through multiple indicators. KMO values (0.76–0.86) and highly significant Bartlett tests support the suitability of the data for factor analysis, meaning that the correlation patterns between items are strong enough to justify the extraction of latent factors. Eigenvalues and percentage of explained variance show that each construct is dominated by a strong first factor (eigenvalues above 2.5 and approximately 49–53% of explained variance), which is consistent with theoretical expectations that these are essentially one-dimensional scales in an applied extension context. The Cronbach alpha of the empowerment scale is 0.90, and approximately half the variance is explained by the main factor, making it particularly strong. This allows the empowerment scores in the study to be confidently used as outcome variables in subsequent regression and structural models. Similarly, the reliability of the DPUI index supports its role as a central explanatory variable representing the intensity and prevalence of digital engagement. These results ensure that the quantitative analysis is based on well-established and validated constructs, thereby reducing measurement error and increasing the credibility of the observed relationships between digital platforms, empowerment, and performance.

The result compares key outcome indicators between digital platform users and non-users and presents the first direct evidence linking digital engagement to extension outcomes (Table 3). Across all variables, users significantly outperformed non-users, with large and statistically significant differences. Knowledge scores and empowerment scores among users are significantly higher, indicating that regular interaction with digital advisories not only increases information stores but also strengthens farmers' self-confidence and decision-making autonomy. The technology adoption index indicates

Table 2. Reliability and factor structure of key scales

Construct / Factor	No. of items	Cronbach's α	KMO	Bartlett's test (χ^2, p)	Eigenvalue	% Variance explained
Perceived usefulness of digital platforms	8	0.88	0.82	612.4, $p < 0.001$	3.95	49.3
Perceived ease of use	6	0.84	0.79	441.8, $p < 0.001$	3.10	51.6
Trust in digital information	5	0.81	0.76	328.6, $p < 0.001$	2.62	52.4
Empowerment in farm decision-making	9	0.90	0.86	735.7, $p < 0.001$	4.38	48.7
Digital platform utilization index (DPUI)	7	0.87	0.80	589.3, $p < 0.001$	3.72	53.1

Table 3. Comparison of users and non-users of digital platforms

Variable	Users Mean ± SD	Non-users Mean ± SD	t-value	p-value
Knowledge score (0–30)	21.8 ± 4.2	17.3 ± 4.6	9.72	< 0.001
Empowerment score (0–45)	31.4 ± 6.1	25.8 ± 6.7	8.22	< 0.001
Technology adoption index (0–1)	0.64 ± 0.15	0.48 ± 0.17	9.03	< 0.001
Wheat yield (q/ha)	48.6 ± 6.8	43.1 ± 7.4	7.05	< 0.001
Net farm income (Rs./ha)	34,500 ± 8,200	28,400 ± 7,950	6.91	< 0.001
Extension contact score (0–20)	13.7 ± 3.9	11.2 ± 4.1	5.96	< 0.001
Risk management practices adopted (0–10)	6.2 ± 1.9	4.9 ± 2.0	6.41	< 0.001

that users have adopted a larger proportion of recommended practices, which is consistent with the idea that frequent, timely, and customized information reduces the uncertainty and transaction costs associated with adopting an innovation. The yield difference between users (about 5.5 quintals per hectare in wheat) and the increase in net farm income per hectare point to solid productivity and economic benefits, which are central to the theory of digital platforms moving extension from mere advisory functions to empowerment and livelihood enhancement. Although causality should be analysed more thoroughly in multivariate models, such clear mean differences indicate that digital use is at least strongly associated with better performance. Extension contact scores for users are also high, meaning that digital platforms often complement rather than replace traditional face-to-face extension; Digitally connected farmers may be more active overall in seeking out diverse information sources. Finally, risk management practices show that users implement more strategies such as crop diversification, weather-based decisions, and input planning, which supports the argument that digital advisories, especially advisories with real-time weather and market data, enable more informed risk management. Overall, the Table presents a consistent picture of digital platform users being better informed, more empowered, and economically better off, confirming the core proposition of the study.

Table 4 indicates a logistic regression model which examines the probability of farmers utilizing at minimum 3 suggested practices in view of utilizing at least one digital platform and choosing socio-economic and extension variables. The model (Odds Ratio, Nagelkerke R-squared 0.32 and the Hosmer-Lemeshow is non-significant) is analyzed to indicate that the model has reasonable explanatory power and fits the data. The most noteworthy finding is that there is a positive and highly significant coefficient of the DPUI score with odds ratio of about 1.30. This implies that, other factors held constant, every single unit of increase in the utilization of digital platforms will raise the likelihood of adoption of at least three suggested practices by about 30%. This explains the hunch that exists between digital engagement and the adoption of practice and goes beyond mere comparisons of groups. The positive significant effect of extension contact is also to be noted, therefore, the traditional extension remains relevant, as well as the digital tools are most effective when incorporated into a larger system of advising, rather than standing alone. The use of digital technologies is positively correlated with education, farm size and household income. This demonstrates that farmers who are better resourced and highly educated can much easier attempt and become acculturated to the suggested technologies. Though the effect of age is observed to be negative, it is not significant. This implies that younger farmers might be a bit more flexible in adopting digital technologies, but once the digital use and other aspects are put into consideration, age is not a good predictor of the probability of adoption. The negative sign of the constant shows that the probability of adoption at the base is rather low without the digital use and other conditions. On the whole, the Table highlights that despite consideration of socio-economic features and conventional extension contact, digital platforms play a crucial role in enhancing the likelihood of adoption of meaningful practices, which can reinforce their application as a transformative tool in the field of extension services delivery.

Table 5 contains the multiple regression analysis using the score of empowerments as the dependent variable and demonstrates the joint impact of the digital use and other variables on the sense of autonomy in the choices of farmers in agriculture. This model describes nearly fifty percent of the variance in empowerment (adjusted $R^2 = 0.47$) and this means that this model is a good overall fit to the social science context, and F-test supports the fact that the combination of predictors is significant. The standardized coefficient of DPUI has the most significant value ($\beta = 0.46$) and is significant, i.e., the most influential predictor of empowerment in the investigated variables. This is aligned with the notion that

Table 4. Logistic regression for adoption of at least three recommended practices (Y = 1 if adopted ≥3 practices)

Predictor	Coefficient (β)	Std. error	Wald χ²	Odds ratio (e^β)	p-value
Constant	-2.10	0.52	16.27	0.12	<0.001
DPUI score (0–10)	0.26	0.04	42.25	1.30	<0.001
Extension contact (0–20)	0.07	0.02	12.44	1.07	0.0004
Education (years)	0.05	0.02	6.89	1.05	0.0086
Farm size (ha)	0.11	0.04	7.48	1.12	0.0063
Age (years)	-0.01	0.01	1.84	0.99	0.1750
Household income (Rs. lakh/year)	0.09	0.04	5.25	1.09	0.0219

Model statistics: -2 Log likelihood = 412.7; Nagelkerke $R^2 = 0.32$; Hosmer–Lemeshow $\chi^2 = 6.18$ ($p = 0.63$).

Table 5. Multiple regression: determinants of empowerment score (0 - 45)

Predictor	Unstandardized β	Std. error	Standardized β	t-value	p-value
Constant	12.45	2.38	–	5.23	<0.001
DPUI score	1.14	0.15	0.46	7.79	<0.001
Knowledge score	0.32	0.07	0.24	4.57	<0.001
Extension contact score	0.28	0.09	0.18	3.11	0.0020
Education (years)	0.21	0.07	0.14	2.93	0.0036
Farm size (ha)	0.37	0.16	0.09	2.31	0.0214
Age (years)	-0.05	0.02	-0.11	-2.52	0.0120

Model diagnostics: $R = 0.69$; $R^2 = 0.48$; Adjusted $R^2 = 0.47$; $F (6,393) = 60.4$, $p < 0.001$.

through digital platforms, farmers are able to access, to evaluate and to take action on information more independently, and therefore, their autonomy to make decisions is fortified. The knowledge scores also play a significant role in the field of empowerment, implying that the route between the digital advice and the empowerment is partly laid through the increments in technical and market knowledge levels; Better-informed farmers feel more confident negotiating, innovating and making calculated risks. The beneficial impact of extension contact is maintained which enhances the complementary nature of digital and tangible extension contact. There are small positive impacts that education and the size of the farms have, which imply that human capital and resource base continue to play a significant role in perceptions of empowerment even though not as much as the use of digital. The age factor has a small negative impact, which means that younger farmers are more empowered to exploit digital information as compared to the older ones, perhaps because of higher levels of digital literacy and receptivity to change. In general, Table 6 proves the underlying value that, when incorporated into an enabling atmosphere of extension, digital platforms can change farmers into active and empowered decision makers, rather than passively receiving advice.

Findings give a more detailed view of empowerment by sub-classifying the items of empowerment by using exploratory factor analysis into three latent factors. The first one, which is called decision autonomy, aggregates the items concerning the independent choice of crops, inputs, time of work, and marketing decision and reflects the greatest amount of variance meaning that the ability to make the major agricultural decisions is the most important dimension of empowerment, in this case. Information self-efficacy is the second factor and is represented by the confidence of the farmers in seeking, confirming, and utilising digital information which directly depend on the experience with the digital platforms; This factor underlines that empowerment does not only concern the availability of information, but also the perceived capability to use it. The third reason is collective voice and activism which represents the involvement of farmers in the groups, bargaining power with the buyers and interaction with the authorities indicating that the idea of empowerment has social and institutional aspect connected with collective action and representation. The overall variance (approximately 65 per cent) and the pattern of explainable factors suggest that the concept of empowerment in the paper is multidimensional and coherent, and each dimension has the definite practical consequences with respect to the extension strategies. Online platforms can change these aspects in various ways, such as directly enhancing information self-efficacy and indirectly affect decision autonomy and collective voice via knowledge and network effects. This factor structure therefore offers a conceptual basis to the further analysis of SEM and means that extension planners can focus on particular areas of empowerment with the help of tailored digital interventions.

Results from the Table 7 summarize the goodness-of-fit indices for the structural equation model linking digital platform use, knowledge, and empowerment, and show that the proposed theoretical model is statistically acceptable. The χ^2/df ratio is less than 2, and the CFI and TLI values are greater than 0.90, indicating that the hypothesized relationships between the latent variables and their indicators, as well as between the latent variables themselves, fairly accurately reproduce the observed covariance structure. The RMSEA and SRMR values are less than 0.05, which generally falls within the goodness-of-fit range and suggests that discrepancies between the model-based and observed covariance

Table 7. Goodness of fit indices for the SEM model of digital platforms, knowledge, and empowerment

Fit index	Value	Acceptable threshold (reference)
χ^2/df	1.94	< 3.0
Comparative Fit Index (CFI)	0.95	≥ 0.90
Tucker–Lewis Index (TLI)	0.93	≥ 0.90
Root Mean Square Error of Approximation (RMSEA)	0.049	≤ 0.08
Standardized Root Mean Square Residual (SRMR)	0.041	≤ 0.08

Table 6. Summary of exploratory factor analysis for empowerment-related items

Factor label	Key high-loading items (loading ≥ 0.50)	Eigenvalue	% Variance explained
F1: Decision autonomy	Choice of crop, input purchase, timing of operations, marketing choice	3.10	34.4
F2: Information self-efficacy	Ability to search, verify, and apply digital advice	1.62	18.0
F3: Collective voice and agency	Participation in groups, negotiation with buyers, dealing with officials	1.12	12.5

Total variance explained = 64.9%; rotation method = Varimax.

matrices are small. These indices collectively show that conceptualizing digital platform use as an exogenous indirect factor influencing knowledge and empowerment, with potential mediating pathways, is supported by the data. Although detailed path coefficients are not shown here, satisfactory matching provides confidence in partitioning the total effects using SEM outputs into direct effects of digital use on empowerment and indirect effects through mediating factors such as knowledge and information self-efficacy. This is important for extension research and practice because it shows that digital platforms empower farmers directly by increasing their sense of control and indirectly by increasing their knowledge and confidence in information management. Therefore, good model matching validates the study's broader theoretical framework, which suggests that "from advice to empowerment" is not a simple linear outcome of providing information, but rather a mediated process shaped by digital engagement, learning, and evolving farmer capabilities.

DISCUSSION

The results are strong evidence that digital platforms help a great deal to improve the agricultural extension services and empower farmers among the Uttar Pradesh smallholders but the benefits of using digital platforms are moderated by the complementary variables and access equity. Users of digital-platforms all exhibited higher results than non-users on all assessed outcomes, in part knowledge (21.8 vs 17.3), empowerment (31.4 vs 25.8), technology adoption (0.64 vs 0.48), wheat yields (48.6 vs 43.1 q/ha) and net farm incomes (Rs. 34,500 vs Rs. 28,400/ha) which all showed significant practical effects. Even when the socio-economic traits and traditional extension contact were held constant in multivariate analyses, these disparities remained established which substantiates the fact that digital engagement is a unique advantage in addition to selection implications. The odds ratio of 1.30 of DPUI implies that every unit change in digital utilization increases the likelihood of the adoption of ≥ 3 recommended practices by 30 percent and the empowerment regression implies that 46 percent of the standardized variance is explained by digital utilization, which is why digital utilization is the most significant predictor. The findings are consistent with UTAUT models, in which familiar usefulness and ease of use are the factors that influence technology acceptance and behavioral intentions. The fact that WhatsApp groups (71.7%), YouTube (54.6%), and other applications that involve dialogic and peer-mediated content and visual information are more frequently used by farmers implies that social learning is an effective tool in increasing the coverage of digital extension to farmers. Greater success in adoption (86.3) is also attributed to high local-language delivery, because culturally relevant content can foster trust and understanding in low-literacy farmers. The factor analysis yielding the three dimensions of empowerment, including decision autonomy, information self-efficacy, and collective voice, provides conceptual clarity, where digital platforms empower the agency of individual-level (crop/input choices) and empower the action of networked collectives (collective voice). Digital and traditional extension complements one another, which is of particular interest. The positive effect of extension contact on the adoption (β = 0.07) and empowerment (β = 0.28) suggests that hybrid systems can be employed in which digital tools extend frequency/personalization, and human agents can be used to build contextual trust. This disputes the digital first solutions, upholding blended approaches in successful Indian programs such as mKisan and Kisan Call Centres (Maulika et al., 2024). These equity issues are still urgent. The non-users (40%), which are concentrated among the marginal farmers who lack smartphones (20%), as well as the internet (12.5%), may widen the divides unless measures are taken by using collective devices, village kiosk, and literacy programs. The negative impact of age as an empowering factor implies that young farmers gain more than older, whereas the education/farm size gradients do not disappear with the digital leveling potential. Although it is not described in this paper, gender disaggregation is a promising subject worth examining in the future due to women being underrepresented in digital space. The implications of the policy are evident: Multilingual, video/social media content should be scaled, whereas the frontline extension should be enhanced to interpret digital cues. The Digital Agriculture Mission of Uttar Pradesh must focus on the last-mile connectivity, trainings to farmers, and collaboration with the private sector in order to be inclusive. Limitations such as not being a causal study due to cross-sectional design and self-reported outcomes would be enhanced by longitudinal studies with objective yield/market data. Effects of interventions should be tested in future, and women/youth sub-groups should be studied.

All in all, extension on the digital platform sparks the transition of dissemination of information to empowerment, yet implementation requires a conscious effort to integrate with human systems and equity protection (Guntukougula et al., 2023). This makes Uttar Pradesh a policy to emulate with smallholder digital transformation in India, with a balance between scale, inclusion and sustainability.

CONCLUSION

It has been empirically found that farmers with high levels of digital use, including mobile applications, WhatsApp groups, YouTube channels, and call centres, tend to have a higher knowledge level, adopt recommended practices, better yields, and better net farm income compared to non-users. The findings further suggest that empowerment is a multidimensional concept, which is comprised of decision-making autonomy, informational self-efficacy, and collective expression, and digital platforms affect these dimensions directly and indirectly via enhanced knowledge and confidence in information management. Nonetheless, the fact that non-users are usually poor and less connected in large numbers demonstrates that digitalization can be a source of an enlarged difference when mismanaged. This paper thus states that the proposed extension efforts in the future ought to foster the hybrid approaches in which digital platforms increase reach and personalization, whereas human extension agents are used to guarantee inclusion, contextualization, and trust building.

DECLARATIONS

Ethics approval and informed consent: Informed consent was sought from the respondents regarding the study during the course of the data collection.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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