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INFLUENCE OF INTEGRATED CROP MANAGEMENT TECHNOLOGY ON POTATO PRODUCTIVITY, PROFITABILITY, ENERGY DYNAMICS AND CARBON FOOTPRINTS IN NORTH-WESTERN HIMALAYAS

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ABSTRACT: An '*on-farm*' adaptive research study was conducted during 2006-2011 in wet-temperate north-western Himalayas to evaluate the effects of integrated crop management (ICM) technology on potato tuber productivity, profitability, energy dynamics and carbon footprints. This '*On-farm*' field study revealed that the ICM technology imbedded with improved potato varieties like Kufri Shailja and Kufri Giriraj along with balanced nutrition (120:80:60 kg NPK/ha & 20 t FYM/ha) and proper crop management and plant protection measures manures, led to higher productivity (27.8%), net returns (34.5%) and bio-energy production (58.1%) compared to farmers' practice (FP). The ICM resulted in slightly higher carbon footprints (0.08 kg CE kg^{-1} fresh potato tuber yield) compared to FP (0.069 kg CE kg^{-1} fresh potato tuber yield) due to better crop management and higher input-use. However, the total carbon output under ICM was ~31.3% higher over FP, indicating that ICM may prove as a viable mitigation strategy to climate-change. Overall, ICM is a better option over FP w.r.t. potato productivity, profitability, net-income gains, bio-energy and carbon output in wet-temperate north-western Himalayas.

KEYWORDS: Bioenergy, crop management, carbon footprints, Himalayas, potato, tuber productivity.

INTRODUCTION

India is the 2nd largest producer of potato (*Solanum tuberosum*) in the world after China, accounting for ~12% of global potato production (CPRI, 2019-20). Total area under potato in India is ~2.16 million ha (m ha) with the production of 51.3 million tonnes (mt) and average productivity of 23.8 t ha^{-1} far behind China (FAOSTAT, 2021). During last 3 decades, India has achieved a cumulative annual growth rate (CAGR) of ~4.57%; however, our potato productivity could achieve a CAGR of merely ~1.39%. Since, potato is an important food and industrial crop in India, playing a vital role in national food and nutritional security besides backing-up industrial applications. Hence, we have to sincerely focus on its yield enhancement through improved cultivars, improved crop management technology and its horizontal expansion in the conventional and non-conventional areas. In India, potato is grown throughout the nation with comparatively higher yield in Indian plains due to better technology dissemination and adoption compared to hill and mountain ecosystems, where it is mostly grown as summer/*Kharif* crop with comparatively low yields. Thus, we need to focus equally on enhancing the potato productivity in these hill and mountain ecosystems through appropriate technology development and its dissemination for higher adoption rates in order to boost to national potato production as a whole.

Potato assumes greater importance in Indian Himalayas especially north-western

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Himalayas (NWH) where hill farmers grow it in mid and high-hills (Choudhary *et al*., 2010; 2013), but poor edaphic factors coupled with poor crop management lead to low potato yields (17.4 t ha^{-1}) compared to national averages (Paul *et al*., 2016). Most of the arable area under potato in NWH is rainfed, where high rainfall in *Kharif* potato season leads to nutrient run–off losses and soil organic matter (SOM) depletion in hilly topography which lead to low crop productivity and unhealthy soils (Choudhary *et al*., 2013; Paul *et al*., 2016). Furthermore, non-adoption of improved cultivars, balanced plant nutrition, improved crop management technology, are some of the major factors which result in poor potato productivity in NWH (Choudhary *et al*., 2013). As, potato requires higher doses of plant nutrition due to its high yield potential in a shorter cycle, thus, sustaining the potato productivity and soil health is again a challenging task for resource-poor small-holder hill farmers who already lack awareness about advanced farm technology (Paul *et al*., 2016). Thus, the development and dissemination of site-specific integrated crop management (ICM) technology imbedded with improved potato cultivars, balanced plant nutrition, improved crop and water management, pest and disease management is highly essential to boost the potato productivity in NWH and collateral agro-ecosystems. Thus,'on-*farm*' experimentation was undertaken to assess the comparative performance of some potato cultivars under proven integrated crop management (ICM) technology in wet temperate region of Himachal Pradesh w.r.t. potato productivity, profitability and water-use efficiency besides its energy and carbon footprint estimation for its long-term sustainability in wet-temperate NW Himalayas. In addition, an intensive technology transfer programme was also aimed at higher technology adoption for improved potato productivity and income gains in NWH.

MATERIALS AND METHODS

Study area and climate

Current study comprising technology gap analysis, '*on-farm*' experimentation, technology adoption and its impact assessment, was conducted during *Kharif* 2006-2011 in Himachal Pradesh, India. The Mandi district of Himachal Pradesh geographically located centrally in the state [31°13`20`` to 32°04`30``N latitude; 76°37'20" to 77°23'15" E longitude; 700 to 4000 m altitude], was selected as the study district with high-hill wet-temperate region of this district as the study area covering its Sundernagar, Sadar, Darang, Karsog, Gohar and Seraj Blocks. First of all, the gap analysis by employing PRA technique was done during 2006-2008 on the adoption of improved potato production technology in the high-hill wet-temperate region of this district (Sundernagar, Sadar, Darang, Karsog, Gohar and Seraj Blocks) (Table 1). Thereafter, one representative block Seraj in Mandi district was selected randomly for the current '*on-farm*' experimentation in Reyara village (Janjehli) of Seraj block by the CSK HPKV, Farm Science Centre, Mandi (HP). The soil of experimental site was silty-clay loam in texture, acidic in reaction (pH 5.4) with soil organic carbon 9.6 g kg^{-1} soil besides available nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) to the tune of 241.8, 12.2 and 393.9 kg ha^{-1}, respectively. Rainfall and temperature data was recorded at '*Agro-Meteorological Observatory*' of CSK HPAU, Farm Science Centre, Sundernagar, India (Fig. 1). The study area receives an average annual rainfall of 1700 mm ~75% of which is received during July–Sept., and the rest is received during Dec.–Feb. The hottest months are May to July with mean daily

Table 1. Gap in adoption of improved potato production technology in high hill wet temperate zone (Under rainfed situation).

S. No.	Technology package	Integrated crop management technology	Existing farmers' practice	Gap in adoption (F/P/N)*
1.	Sowing time	March-April	March-April	N
2.	Sowing method	In furrows (50 cm 20 cm)	In furrows (50 cm 20 cm)	N
3.	Varieties	Kufri Jyoti, Kufri Giriraj	Kufri Jyoti	N
4.	Seed rate/ha	25 q/ha	20 q/ha	P
5.	Tuber treatment	Indofil M-45 @ 0.05%	Not done	F
6.	FYM (t/ha)	20 t/ha	10 t/ha	P
7.	Fertilizers (kg/ha) ($N:P_2O_5:K_2O$)	120:80:60	60:60:30	P
8.	Fertilizer placement	In furrows	In furrows	N
9.	Chemical weed management	Isoproturon 75WP @ 1.0 kg a.i./ha or Oxiflorofen (Goal 23.5 EC) @ 0.5 kg a.i./ha	Not done	F
10.	Manual weed management	One hand-weeding + earthing-up at 30 DAP One hand-weeding + earthing-up at 50 DAP	When plants attains a height of 15-20 cm	P
11.	Pest management (White grub)	Furadan 3 G @ 2.5 kg/ha	Not done	F
12.	Disease management (Late blight)	Two sprays of Redomil MZ -72 WP or Metamyl 0.25% at 15 days interval followed by 4 sprays of Indofil M-45 @ 0.25% at weekly interval	Use of non recommended fungicides 2 sprays)	F

*F-Full gap; P-Partial gap; N-No gap

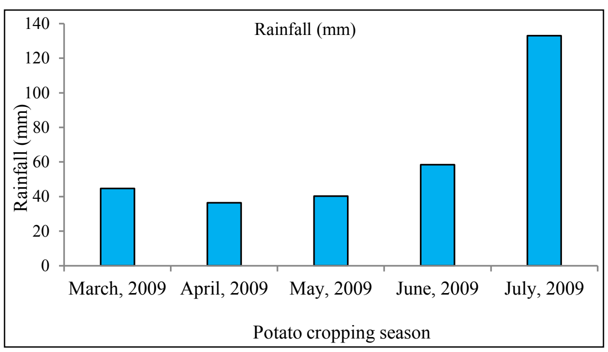

Fig. 1. Average monthly rainfall (mm) during potato growing period.

maximum temperature ranging between 32–35^{0}C, whereas December to February are the coldest months, with mean daily minimum temperature ranging between 2.6–3^{0}C.

Experimental and treatment details

On the basis of the gap analysis, the integrated crop production technology for potato was standardized by the CSK HPKV, Farm Science Centre, Sundernagar, Mandi (HP) during 2007-2008 at its Research farm. Thereafter '*on-farm*' experimentation was conducted during summer (March–July) seasons of 2009 under two crop management scenarios' *viz*. integrated crop management (ICM) technology and farmers' practice (FP) using improved potato cultivars *viz*. Kufri Himalini, Kufri Giriraj, Kufri Shailja alongwith Kufri Jyoti (as check) in Reyara village (Janjehli) of Seraj block, Himachal Pradesh in randomized block design replicated five times with the plot size of 2.5 m 3.2 m (8 m^2) each, for analysis of variance (ANOVA) following standard procedures (Rana *et al.*, 2014). Under ICM technology and the FP, the compete crop management schedule covering the entire field operations right from sowing of improved potato cultivars, balanced plant nutrition, improved crop and water management to pest and disease management till harvesting, is mentioned in Table 1.

Crop management

The potato crop was planted in 2nd week of March both in ICM and FP in respective plots/locations (Table 1), under rainfed conditions. On an average, the potato growing season during the study had 312.8 mm rainfall during March to July, 2009. The seed tubers weighing ~50 g each and having minimum two eyes were planted on raised–beds at 50 cm 20 cm spacing. Nutrient management was done strictly as per treatment plan and well-rotten FYM was added during land preparation in respective treatments on fresh weight basis (av. 35% moisture), which contained N, P, K to the tune of 0.86, 0.41 and 0.68% (on oven dry-weight basis), respectively. The half N and entire P and K were applied basally at planting time through urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively; while remaining half N was top dressed near potato rows in 2-equal splits at 1st and 2nd earthing-up operations. Weeds were controlled by using Oxiflorofen 23.5 EC @ 0.5 kg a.i. ha^{-1} as per treatment plan in ICM. Two hand-weeding (HW) followed by two earthing-up were done at 30 and 50 days after planting (DAP). Both ICM and FP plots, received plant protection practices as per treatment plan (Table 1), throughout the cropping season. Yield of net plot was recorded. Since, the experimental plot size was small; thus, crop was managed properly besides precise samplings' for maintaining the heterogeneity of low level in studied parameters.

Potato tuber yield and economics

The experimental observations on tuber yield were recorded following standard procedures (Rana *et al.*, 2014). The economic analysis was done using tuber yield, cost of cultivation incurred and prevailing market price of potato.

Energy calculations

Energy sources in farming systems include both direct (operational) and indirect (non-operational) energy sources (Kumar *et al.*, 2021). The direct energy sources directly release the energy *viz*. fuel, diesel, farm machinery, manual human labour and animal draft, etc. Indirect energy sources do not release energy directly but dissipate energy during conversion processes *viz*. seed, fertilizers, microbial inoculants, crop residues and manures, pesticides, etc. Energy for synthesis, manufacturing, transportation and distribution is considered as energy sequestered in these indirect energy sources. Both direct and indirect energy sources can again be classified as renewable and non-renewable energy sources. Direct energy sources like animate, solar, wind and water are classified as direct renewable energy sources. Diesel and electricity are classified as direct non-renewable energy sources. Indirect energy sources like manures are classified as indirect renewable energy sources. Fertilizer, chemical and machinery come under indirect non-renewable sources of energy. Hence, primary data on various farm inputs and potato management practices were used for computation of energy consumption using energy equivalents (Table 2). Energy output from the products (potato tuber and haulm yield) was calculated by multiplying the respective production levels with their respective energy equivalents (Table 2). According to the energy input and output, cost of cultivation and potato yield, the energy-use indices were calculated using standard procedures as given by Devasenapathy *et al.* (2008, 2009) and Kumar *et al.* (2021) as follows:

Energy input (MJ ha^{-1}) = A

Energy output (MJ ha^{-1}) = B

Net energy or energy return or energy balance (MJ ha^{-1}) = B – A

$$\text{Energy-use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Table 2. Energy equivalent of inputs and outputs in agricultural operations used in present study.

S. No.	Particulars	Units	Equivalent Energy (MJ)	Reference
A.	*Input*			
	Farm Machinery	kg	62.7	Devasenapathy *et al.* (2008, 2009); Paramesh *et al.* (2019)
	Knapsack sprayer	h	0.17	Kumar *et al.* (2021)
2.	Diesel	L	47.8	Pishgar-Komleh *et al.* (2012); Paramesh *et et al.* (2019)
3.	Human power	man-hour	1.96	Kumar *et al.* (2021)
5.	Fertilizers			
	Nitrogen (N)	kg	60.6	Devasenapathy *et al.* (2009)
	Phosphorus (P_2O_5)	kg	11.1	Devasenapathy *et al.* (2008
	Potassium (K_2O)	kg	6.7	Devasenapathy *et al.* (2008
	FYM	kg	0.30	Paramesh *et al.* (2019)
6.	Chemicals			
	Herbicides	kg	85	Pishgar-Komleh *et al.* (2012)
	Fungicide	kg	295	Pishgar-Komleh *et al.* (2012)
	Insecticides	kg	115	Pishgar-Komleh *et al.* (2012)
7.	Planting material			
	Potato tuber	kg	3.6	Pishgar-Komleh *et al.* (2012)
B.	*Output*			
1.	Potato tuber	kg	3.6	Pishgar-Komleh *et al.* (2012)

$$\text{Energy productivity (kg MJ}^{-1}\text{)} = \frac{\text{Economic yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy profitability} = \frac{\text{Net energy (MJ)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Specific energy} = \frac{\text{Energy input}}{\text{Potato tuber yield (kg/ha)}}$$

Carbon footprints and carbon budgeting

Carbon equivalents (CE) were estimated by multiplying the inputs (potato tubers, fuel, FYM, fertilizers, pesticides, etc.) with their respective carbon emission coefficients as given in Table 3. Emission coefficient for each herbicide/fungicide/pesticide is unavailable; so, it was assumed that emission during the processes of production, transportation, storage, and field application are same for all pesticides within a class (Lal, 2004). Total carbon input and output were calculated as sum of carbon equivalents of all inputs and outputs of potato crop.

Carbon output: Carbon output of potato crop was calculated as per methodologies given by Kumar *et al.* (2021) as given below:

Table 3. Estimates of equivalent carbon emissions for agricultural inputs used in presented study.

Input	Unit	Emission factors (kg CO_2-e/unit)	References
Human labour	man-h	0.70	Houshyar *et al.* (2015).
Machinery	h	3.32	Deng (1982); Yadav *et al.* (2018)
Diesel	litre	3.32	Deng (1982); Yadav *et al.* (2018)
Nitrogen (N)	kg	1.3	Kumar *et al.* (2021)
Phosphorus (P)	kg	0.2	Kumar *et al.* (2021)
Potassium (K)	kg	0.15	Kumar *et al.* (2021)
Farmyard manure (FYM)	kg	0.029 kg/kg	Bellarby *et al.* (2008)
Insecticide	kg a.i.	5.1	Lal (2004)
Herbicide	kg a.i.	6.3	Lal (2004)
Fungicide	kg a.i.	3.9	Lal (2004)

Carbon output (kg CE ha^{-1}) = Total biomass (grain yield + by-product yield) 0.44*

**Plant biomass contains on an average 44% carbon content as given by Lal (2004).*

Carbon efficiency: Carbon efficiency of potato crop was calculated as the ratio of total carbon output to carbon input: Carbon efficiency = Total carbon output/total carbon input

Carbon footprints: Carbon footprints of potato crop were calculated as per methodologies given by Kumar *et al.* (2021) hereunder:

Carbon footprints (kg CE/kg potato tuber) = Total carbon emission or input (kg CE/ha)/tuber yield (kg/ha).

Carbon sustainability index (CSI): The CSI of potato crop was estimated by computing the difference between total carbon output and total carbon input of potato crop and dividing it by the total carbon inputs of potato crop as given by Kumar *et al.* (2021) hereunder:

CSI = (Total carbon output – total carbon input)/total carbon input

Technology tranfer methodologies

In order to achieve the objectives of technology transfer on potato cultivation using ICM and improved varieties and its adoption in the study area in NWH, various technology transfer tools were used in current study during 2009-2010. Besides conductining '*On–farm*' experimentation, the farmers (n=68) of participating and sorrounding villages were also trained through hands-on training on potato cultivation using ICM through method demonstrations. Farmers' specialized trainings and field conventions for time-to-time technical back-up; were the technology-transfer efforts of CSK HPKV, FSC-Sundernagar (HP).

Knowledge upgradation, technology adoption and impact assessment

A thorough study was undertaken during 2009-2011 with well structured interview schedules (pre– & post–training) to assess the knowledge levels and knowledge upgradation of trainee farmers (n=68) in Seraj block of Mandi (HP). Extent of adoption of ICM under potato cultivation was assessed after one year of '*On-farm*' experimentation i.e. year 2010 while the net-income gains by the potato growers were assessed after two years i.e. year 2011 in the Seraj block of Mandi (HP) using participatory rural appraisal (PRA) technique, interview schedules and group dynamics method to have reliable and valid information (Choudhary *et al.*, 2013).

2.4. Statistical analysis

The experimental design was randomised block design (RBD) replicated five times and the statistical analysis was done by the standard procedure suggested by Gomez and Gomez (1984). Significance of differences among different treatments was tested using the standard F-test. Least significance difference (LSD) values at P = 0.05 were used to determine the significant differences between treatment means.

RESULTS AND DISCUSSION

Gap analysis on potato production technology in wet-temperate NW Himalayas

The data in Table 1 revealed that full gap was observed in potato seed tuber treatment, chemical weed management, pest management and disease management practices against the recommended practices in high-hill wet-temperate agro-ecological situations in the study area of Mandi district in NWH. Further, partial gap was observed in the practices like potato sowing method, seed rate, organic manure application and mechanical weed management. However, no gap was found in the time of planting and varieties grown by the farmers. It was revealed that Kufri Jyoti is the predominant variety grown by the potato farmers in high-hill wet-temperate NWH. Lack of awareness, technical know-how and non-availability of disease resistant (Late blight) variety planting material could be the possible reasons for the non-adoption of improved potato production technology in the region (Choudhary and Rahi, 2018). Hence, CSK HPKV, Farm Science Centre, Sundernagar, Mandi (HP) assessed the performance of new potato cultivars in Mandi district in high-hill wet-temperate NWH.

Potato tuber yield and economics

The results pertaining to the potato tuber yield and haulm yield differed significantly among the potato varieties with highest yield under Kufri Shailja with yield trend of Kufri Shailja > Kufri Giriraj > Kufri Jyoti> Kufri Himalini in current study (Fig. 2), indicating that the genetic yield potential of these varieties, differential tolerance to late blight of potato and their suitability to hill region of NWH led to this variation. Likewise, the integrated crop management (ICM) technology showed its superiority over the farmers' practice (FP) among all the varieties, due to balanced plant nutrition and crop management under ICM (Paul *et al.*, 2016; Varatharajan *et al.*, 2019a, 2019b). The integration of organic sources and chemical fertilizers alongwith proper crop management under ICM provided optimum and balanced nutrition; in addition, the supply of plant nutrients remained synchronised with the crop growth (Choudhary *et al.*, 2013); hence resulting in higher yields. The gross returns, net returns and B: C ratio also followed the similar trend as that of potato tuber yield where ICM showed its superiority among all the varieties following the trend of Kufri Shailja > Kufri Giriraj > Kufri Jyoti> Kufri Himalini at both the management levels (ICM and FP) in current study (Fig. 3). This may again be attributed to the yield variation under ICM technology and the farmers' practice (Choudhary and Rahi, 2018).

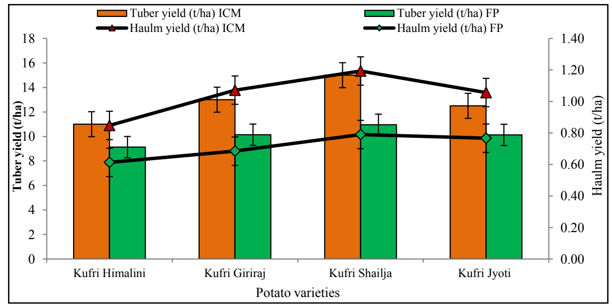

Fig. 2. Effect of ICM technology on tuber and haulm yield of potato cultivars in wet-temperate NW Himalayas. Vertical bars indicate LSD (P = 0.05).

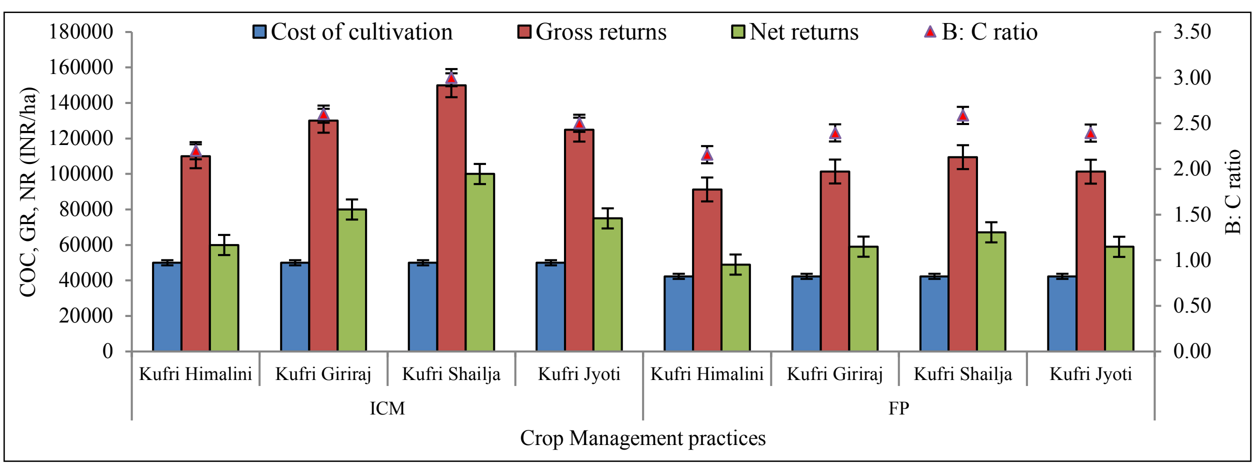

Fig. 3. *Effect of ICM technology on profitability of potato cultivars in wet-temperate NW Himalayas. Vertical bars indicate LSD (P = 0.05). (COC: Cost of cultivation, GR: Gross returns, NR: Net returns).*

Energy dynamics

The source- and operation-wise energy use pattern was computed for potato crop (Fig. 4 and 5). The mean total energy of 32538 and 20583 MJ ha^{-1} was consumed in this crop under ICM and FP, respectively (Fig. 4). Overall, the seed tubers contributed highest input energy followed by NPK fertilizers, FYM and then land preparation. Seed tubers and fertilizer application were the major contributors of total energy consumption in the crop. This may be attributed to high tuber rate @ 20 and 25 q/ha under ICM and FP, respectively. In ICM management, source-wise energy input pattern followed the trend of seed tubers>fertilizer>FYM>diesel>human>agro-chemicals>machinery>human power (Fig. 5). Under FP, source-wise energy input pattern followed the trend of seed tubers>fertilizer>diesel>FYM>human> machinery>agro-chemicals (Fig. 5). Seed tubers comprised higher amount of the total energy consumption mainly due to its huge quantity used and the respective energy equivalents (Pishgar-Komleh *et al.*, 2012). Furthermore, fertilizer application was the second major input both in ICM and FP plots. Source-wise energy input pattern also revealed that the share of indirect renewable was the highest over the indirect non-renewable, direct renewable and direct

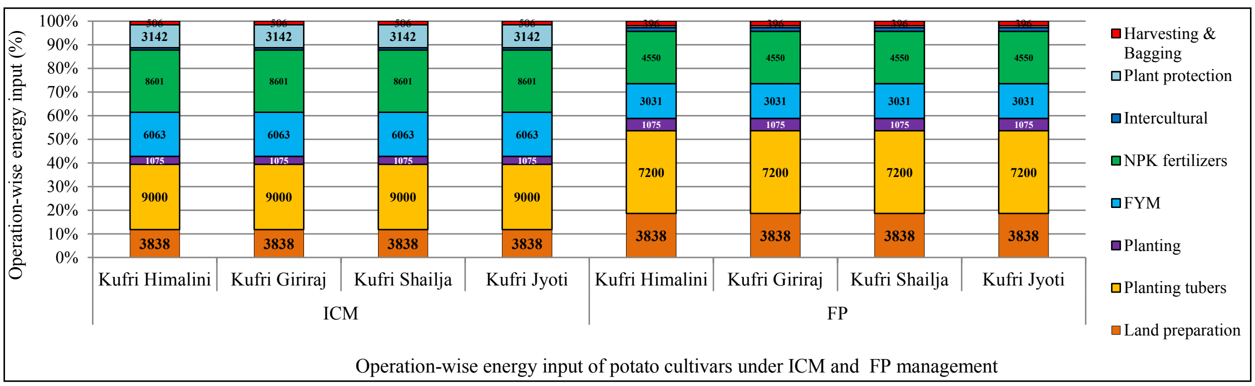

Fig. 4. *Operation-wise energy input (%, MJ/ha) of potato cultivars under ICM and FP management in wet temperate NW Himalayas.*

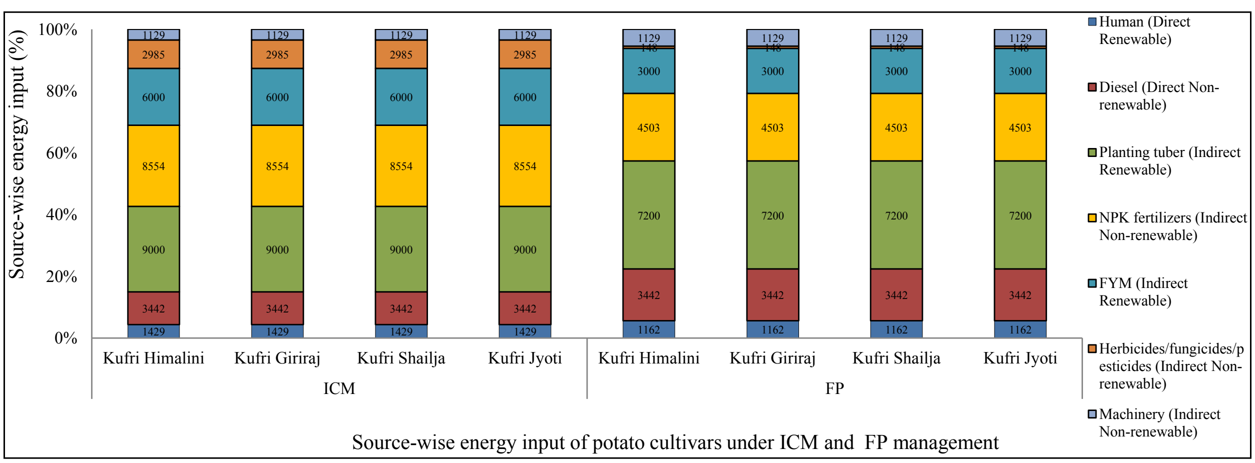

Fig. 5. *Source-wise energy input (%, MJ/ha) of potato cultivars under ICM and FP management in wet temperate NW Himalayas.*

non-renewable sources of energy both in ICM and FP (Fig. 5).

Energy-use indices

Total bio-energy output in potato crop under all the tested potato varieties ranged from 20583 to 32538 MJ/ha with highest magnitude under ICM compared to FP; while energy output varied from 46161–63235 MJ ha^{-1} under ICM and 37613–45534 MJ ha^{-1} under FP under different potato varieties (Table 4). On an average, proper crop management under ICM noticed higher net energy (21879 MJ/ha) and specific energy (2.56 MJ/kg) owing to higher productivity (Kumar *et al.*, 2021). However, the energy-use efficiency (2.03), energy productivity (0.49 kg/MJ) and energy profitability (1.03) were higher under FP, due to comparatively less energy consumption (Choudhary *et al.*, 2017).

Greenhouse gas emissions and carbon footprints

On an average, highest total greenhouse gas (GHG) emission equivalents from the inputs were observed under ICM (3738.1 CO_2-e kg ha^{-1}) compared to FP (2541.4 CO_2-e kg ha^{-1}) with respective field level emissions of 249.2–339.8 and 232.1–278.4 CO_2-e kg Mg^{-1} for fresh tuber yield, and 1298–1827 and 1149–1481 CO_2-e kg Mg^{-1} for tuber dry matter yield basis, respectively (Table 5). On an average, highest share of total emissions was computed for the seed tubers (34-40%) and the N_2O emissions from the farm (17-23%) both in ICM and FP (Fig. 6). This may be attributed to high seed rate and the high use of organics and N-fertilization (60-120 kg N/ha) in current study (Choudhary *et al.*, 2014; Rajpoot *et al.*, 2021).

On an average, highest total carbon input were observed with treatment ICM (1020 kg CE ha^{-1}) compared to FP which had the least total carbon input (693 kg CE ha^{-1}) in this study (Table 6). As, high use of chemical fertilizers, FYM and agro-chemicals was done under ICM compared to FP, thus, it led to higher GHG-emissions and total carbon input (Gan *et al.*, 2009; Goglio *et al.*, 2014). Under ICM, total carbon output varied between 1273 to 1792 kg CE ha^{-1} among different varieties with carbon footprints of 0.068–0.093 kg CE kg^{-1} of fresh tuber yield and 0.354–0.498 kg CE kg^{-1} of tuber dry matter yield among different

Table 4. Effect of crop management practices and potato cultivars on energy-use indices in potato crop.

Crop management practices	Potato cultivars	EI (MJ/ha)	EO (MJ/ha)	NE (MJ/ha)	EUE	EP (kg/MJ)	EPR	SE (MJ/kg)
ICM	Kufri Himalini	32538	46161	13623	1.42	0.34	0.42	2.96
	Kufri Giriraj	32538	55095	22557	1.69	0.40	0.69	2.50
	Kufri Shailja	32538	63235	30697	1.94	0.46	0.94	2.17
	Kufri Jyoti	32538	53177	20639	1.63	0.38	0.63	2.60
	Mean	32538	54417	21879	1.67	0.40	0.67	2.56
FP	Kufri Himalini	20583	37613	17030	1.83	0.44	0.83	2.25
	Kufri Giriraj	20583	41802	21219	2.03	0.49	1.03	2.03
	Kufri Shailja	20583	45534	24951	2.21	0.53	1.21	1.88
	Kufri Jyoti	20583	42384	21801	2.06	0.49	1.06	2.03
	Mean	20583	41833	21250	2.03	0.49	1.03	2.05

Note: EI-Energy input, EO-Energy output, NE-Net energy, EUE-Energy use efficiency, EP-Energy productivity, EI-Energy intensiveness, EPR-Energy profitability, SE-Specific energy.

Table 5. Effect of crop management practices and potato cultivars on carbon footprints of potato cultivation.

Crop management practices	Potato cultivars	GHG-emissions (CO_2-e kg ha^{-1})									CFy (CO_2-e kg Mg^{-1})	
		Machinery	Diesel	Human labour	Planting tubers	NPK fertilizers	FYM	Herbicides/ fungicides/ pesticides	N_2O from farm	Total	Fresh tuber yield basis	Dry tuber yield basis
ICM	Kufri Himalini	59.8	239	510.3	1275	580	181.0	51	842	3738.1	339.8	1827.0
	Kufri Giriraj	59.8	239	510.3	1275	580	181.0	51	842	3738.1	287.5	1445.0
	Kufri Shailja	59.8	239	510.3	1275	580	181.0	51	842	3738.1	249.2	1298.0
	Kufri Jyoti	59.8	239	510.3	1275	580	181.0	51	842	3738.1	299.0	1465.9
FP	Kufri Himalini	59.8	239	415.1	1020	290	94.5	2	421	2541.4	278.4	1480.6
	Kufri Giriraj	59.8	239	415.1	1020	290	94.5	2	421	2541.4	250.6	1326.1
	Kufri Shailja	59.8	239	415.1	1020	290	94.5	2	421	2541.4	232.1	1149.0
	Kufri Jyoti	59.8	239	415.1	1020	290	94.5	2	421	2541.4	251.0	1184.0

Table 6. Carbon budgeting and carbon footprints as influenced by crop management and potato cultivars.

Inputs	ICM					FP				
	Kufri Himalini	Kufri Giriraj	Kufri Shailja	Kufri Jyoti	Mean	Kufri Himalini	Kufri Giriraj	Kufri Shailja	Kufri Jyoti	Mean
Total carbon input (kg CE ha^{-1})	1020	1020	1020	1020	1020	693	693	693	693	693
Total carbon output (kg CE ha^{-1})	1273	1610	1792	1587	1566	1025	1144	1321	1282	1193
Carbon efficiency	1.25	1.58	1.76	1.56	1.54	1.48	1.65	1.91	1.85	1.72
Carbon sustainability index	0.25	0.58	0.76	0.56	0.54	0.48	0.65	0.91	0.85	0.72
Carbon footprint (kg CE kg^{-1} tuber dry matter yield)	0.498	0.394	0.354	0.400	0.412	0.404	0.362	0.313	0.323	0.350
Carbon footprint (kg CE kg^{-1} fresh tuber yield)	0.093	0.078	0.068	0.082	0.080	0.076	0.068	0.063	0.068	0.069

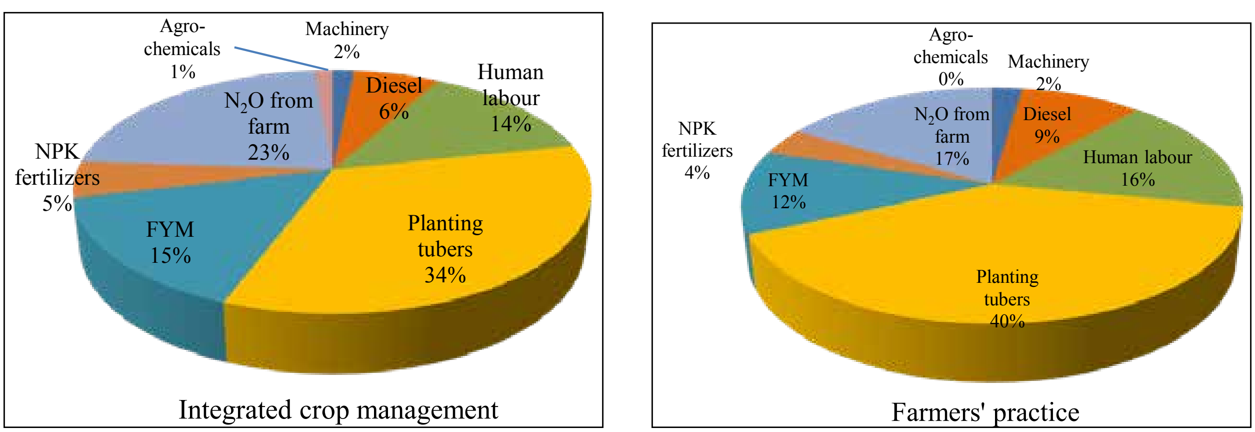

Fig. 6. Influence of integrated crop management technology on carbon footprints of potato cultivation in NW Himalayas.

potato varieties with least footprints under Kufri Shaija. On the other hand, FP exhibited carbon footprints of 0.063–0.076 kg CE kg^{-1} of fresh tuber yield and 0.313–0.404 kg CE kg^{-1} of tuber dry matter yield among different potato varieties with least footprints again under Kufri Shaija due to its higher productivity. On an average, FP observed higher carbon-efficiency (1.72) and carbon sustainability index (0.72) mainly due to lower carbon input used here (Choudhary *et al.,* 2017). However, ICM resulted in slightly higher carbon footprints (0.08 kg CE kg^{-1} fresh potato tuber yield) compared to FP (0.069 kg CE kg^{-1} fresh potato tuber yield) due to higher carbon inputs used in balanced plant nutrition, crop management and plant protection measures under ICM (Gan *et al.,* 2009; Goglio *et al.,* 2014; Choudhary *et al.,* 2017; Kumar *et al.,* 2021).

Pre- and post-training knowledge behaviour and impact assessment

Data presented in Table 7 on pre-training knowledge assessment of 68 farmers of Seraj block of Mandi district (Study area) revealed that their respective knowledge about potato crop management and improved varieties varied between 28–88 and 43–65%; whereas, the training interventions led to post-training knowledge enhancement of these farmers (n=68) by 89–100 and 92–97%, respectively. This pre-training assessment was done using well structured interview schedule using questionnaire as mentioned in Table 7.

The technology adoption rate after one year of study completion (year 2010) varied between 72–98% for different components of ICM in potato farming. Similarly, the technology adoption rate about improved potato cultivars varied between 71–83% (Table 7), due to regular technology transfer efforts (Choudhary *et al*., 2013).

The assessment of net income gains (NIGs) after two year of *'on-farm'* experimentation i.e. year 2011 in the study area revealed that by the adoption of ICM technology and improved potato cultivars, the average

Table 7. Assessment of knowledge upgradation (Av. values) and technology adoption (%) among trainee farmers (n=68) in Seraj block of Mandi district in Himachal Pradesh (Study area).

Technology component	Pre-training (%)	Post- Training (%)	Technology adoption rate after one year of study completion (%) (n=68)*
Potato crop management			
ICM in potato cultivation and its benefits	56	100	88
Potato tuber selection	58	95	86
Field preparation for tuber planting	78	95	91
Plant spacing	68	95	85
Integrated nutrient management	58	91	88
Weed management and plant protection measures	28	91	72
Intercultural operations	88	100	98
Haulm cutting	35	89	75
Harvesting time and methodology	84	100	91
Improved potato cultivars			
Knowledge & adoption of improved potato varieties	43	92	71
Knowledge about planting time	65	95	80
Knowledge about harvesting time	61	97	83

Note: *Technology adoption rate of 68 trained farmers after one year of study i.e. 2010.

Table 8. Net income gains by the adoption of ICM coupled with improved potato cultivars (n = 68) in wet-temperate region of Mandi district (study area).

Potato farming	Number of farmers (n=68*)	Net returns (INR/ha)		Percent (%) increase in NIGs
		Range	Average	
ICM coupled with improved potato cultivars	n = 68	58500–75800	66480	41.3%
FP using conventionally grown variety 'Kufri Jyoti'	n = 68	43780–57600	47065	–

*Note: n is the number of potato growers.

net income was INR 66480/ha with 41.3% higher net income gains (NIGs) among potato growers (n=68) over the conventionally grown variety 'Kufri Jyoti' under farmers' practice (Table 8).

CONCLUSION

This '*On-farm*' field study clearly demonstrated that the integrated crop management (ICM) technology imbedded with improved potato varieties like Kufri Shailja and Kufri Giriraj along with balanced nutrition (120:80: 60 kg NPK/ha & 20 t FYM/ha) as well as proper crop management and plant protection measures; may lead to higher potato productivity, profitability and bio-energy production. Since, the ICM resulted in slightly higher carbon footprints (0.08 kg CE kg^{-1} fresh potato tuber yield) compared to FP (0.069 kg CE kg^{-1} fresh potato tuber yield) due to better crop management and input-use. However, the total carbon output under ICM was ~31.3% higher over FP, indicating that ICM adoption may be a possible mitigation strategy to climate change. Overall, ICM is a better option over FP w.r.t. potato productivity, profitability, net-income gains, bio-energy and carbon output in diverse potato production systems of wet-temperate NW Himalayas and collateral agro-ecologies across the globe.

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