CLIMATE TRENDS

Water and Heat Stress in the Hills: How Climate Change is Reshaping Agricultural Practices in Uttarakhand

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Executive Summary

Agriculture, the backbone of Uttarakhand's rural economy, is under mounting pressure from climate change. Rising temperatures, erratic rainfall, and extreme weather events are disrupting farming practices. A decade-long assessment by Climate Trends reveals a 27.2% decline in agricultural area and a 15.2% drop in yields in the hill districts of the state. The plain areas, on the other hand, witnessed a 15% increase in crop yield for a 2.5% rise in area under cultivation. Cereals like wheat, rice, and millets have witnessed sharp declines in the hills, while climate-resilient crops such as maize, pulses, and spices have shown encouraging growth. Native pulses like pigeon pea and horse gram, along with spices like turmeric and chillies, are gaining prominence in the state due to their adaptability and market value. The findings underscore the need for a strategic shift towards climate-resilient, diversified farming practices, revival of traditional systems like *Barahnaja*, and supportive policies to safeguard food security and rural livelihoods in Uttarakhand's vulnerable hill regions.

1.Background

Agriculture constitutes the backbone of Uttarakhand's rural economy. Nearly 80 percent of the state's population live in the mountains and depend on rainfed farming, practised on terraced hill slopes. Majority of the farmers of the state belong to the small and marginal category and produce nearly half of the total grains. Over 55 percent of the cultivated area of Uttarakhand is rainfed. With 92 percent of its landscape covered by rugged mountains, the state is highly prone to climate extremes. The impacts of climate change in the form of heat and moisture stress on crops are disrupting yields, altering farming practices, and affecting rural livelihoods. Agriculture's share in the state's Gross State Domestic Product (GSDP) has also declined from 11.5 percent in 2011–12 to just 8.8 percent in 2021–22. Despite these changes, agriculture continues to sustain nearly half of the state's population, underscoring the urgent need to address the vulnerabilities of hill farming under a changing climate.

The current analysis attempts to capture the changing agricultural landscape in Uttarakhand through an assessment of the yields and area under cultivation of some of its major cereals, pulses, oilseeds and potato between 2012 to 2021.

- **Methodology**

For this study, the Compound annual growth rates (CAGR) for all the crops were computed for the study period 2012-2021.The empirical formula for CAGR is given as:
CAGR = (Final value/Initial value) 1/t -1
Where t=Time in years, (for this study, t=10)
The Compound Annual Growth Rate (CAGR) measures the annualized rate of growth of a value over a specified period, assuming consistent growth, while minimizing the impact of short-term variations. Agricultural yields can vary widely each year due to weather, pests, policy changes, or market dynamics. CAGR smooths out these annual ups and downs to give you the average rate of consistent growth or decline. It helps identify underlying growth patterns by focusing on the long-term trajectory rather than short-term volatility. Unlike simple averages, the CAGR accounts for the compounding effect—how changes build upon previous years' values and aids in comparing growth rates across different crops and time periods.

2.The Agricultural Landscape of Uttarakhand

Uttarakhand consists of thirteen districts mostly concentrated on the hills with Udham Singh Nagar, Hardiwar and parts of Dehradun spanning the plains and foothills. These areas are characterized by hot and moist subtropical climate.

The hilly districts constitute Chamoli, Pauri Garhwal, Rudra Prayag, Tehri Garhwal, Uttarkashi and upper reaches of Dehradun in the Garhwal sector and Almora, Bageswar, Champawat, Pithoragarh and the higher altitudes of Nainital districts in the Kumaon sector.

The major crops grown in the state are cereals and pulses with productivity as low as 1.2 to 1.4 tons/hectare (ha), far below national averages, but with a considerable range of varieties.

Uttarakhand Hills

- Cereals comprised a total area of ***354661 hectares covering 86% of the total area under cultivation in the hills*** with a total production of ***588460 metric tonnes*** in 2021. They constituted ***91%*** of the total crop production in the hills of Uttarakhand in 2021.

- In terms of both areas under production and yield, cereals like wheat, paddy, finger millet (*mandwa*), barnyard millet (*sanwa*), barley and maize topped the list in 2021 *(Appendix 1)***.** Amaranth or ramdana, although not widely cultivated in the hills, also belong to the family of cereals.

- **Pulses** (horse gram, black gram, kidney beans, oilseeds, red lentil, pigeon pea, yellow split pea and chickpea) and **oil seeds** (soyabean, black soyabean, lahi-sarson-toriya, sesame, groundnut) together constituted an area of ***58340 hectares*** and a yield of ***56820 metric tonnes comprising 14% area under cultivation and 9% of*** total agricultural production[1] in the hills in 2021.

- Total area under agricultural cultivation and agricultural yield in the hills of Uttarakhand show a linear decline of 27.2% and 15.2% respectively between 2012 and 2021.

Table 1: Decline in Agricultural Production in the Hills of Uttarakhand

	2012	2021	% Decline
Total Area under Agriculture in Hills in Hectares	567312	412981	-27.2
Total Agricultural Yield in the Hills in MT Tonnes	760606	645280	-15.2
Note: Agricultural Production here includes only cereals, pulses, oilseeds			

Source: The table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

Uttarakhand Plains

- Wheat, paddy, mustard and rapeseed were the most widely cultivated food crops in the plains of Uttarakhand, whereas, finger millet, barnyard millet and barley were the least grown crops in 2021 *(Appendix 2)*.

- Unlike the hilly districts, the plains have witnessed a ***15 percent increase*** in crop yield for only a ***2.5 percent rise*** in area under cultivation between 2012 and 2021.

[1] Agriculture production in this analysis includes cereals, pulses and oilseeds only

- Cereals comprised a total area of ***322006 hectares covering 94 percent of the total area under cultivation in the plains*** with a total production of ***1162937 metric tonnes*** in 2021. They constituted ***98%*** of the total agricultural production in the plains of Uttarakhand in 2021.

- **Pulses** (primarily yellow split pea, black gram, chickpea, red lentil) and **oil seeds** (soyabean, black soyabean, lahi-sarson-toriya, sesame, groundnut) together constituted an area of ***21676 hectares*** and a yield of ***25581 metric tonnes comprising 6% area under cultivation and 2%*** of the total agricultural production in the plains in 2021.

Table 2: Trend in Agricultural Production in the Plains of Uttarakhand

	2012	2021	% Change
Total Area under Agriculture in Plains in Hectares	335258	343682	2.5
Total Agricultural Yield in the Plains in MT Tonnes	1034070	1188518	15
Note: Agricultural Production here includes only cereals, pulses and oilseeds			

Source: The table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

3. Trends in the Cultivation of Major Crops in Uttarakhand

This section highlights the trends in area under cultivation and yields of cereals, pulses, oilseeds and potato in the hill and plain districts of Uttarakhand between 2012 and 2021.

Cereals

- **Plains**

Table 3: Rate of change in Area under Cultivation and Yield of Cereals

Sl No	Crop	% Change in Area between 2012-2021	% Change in Yield between 2012-2021
1	Wheat	0.18	1.22
2	Paddy	0.57	2.07
3	Finger Millet (Mandwa)	-12.34	-9.23
4	Barnyard Millet (Sanwa)	-22.04	-20.94
5	Barley	-12.43	-7.91
6	Maize	-4.95	-3.69
7	Amaranth (Ramdana)	Not cultivated	Not cultivated

Source: The table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

Wheat and **paddy** are the major cereals cultivated in the plains. They exhibit positive trends in cultivation over the years. In 2021, the areas under wheat and paddy cultivation were 173622 and 143537 hectares with corresponding yields of 660203 Mt tonnes and 490780 Mt tonnes respectively.

Millets and **barley** are sparsely cultivated crops in the plains and have recorded the maximum decline in yield and area under cultivation between 2012 and 2021.

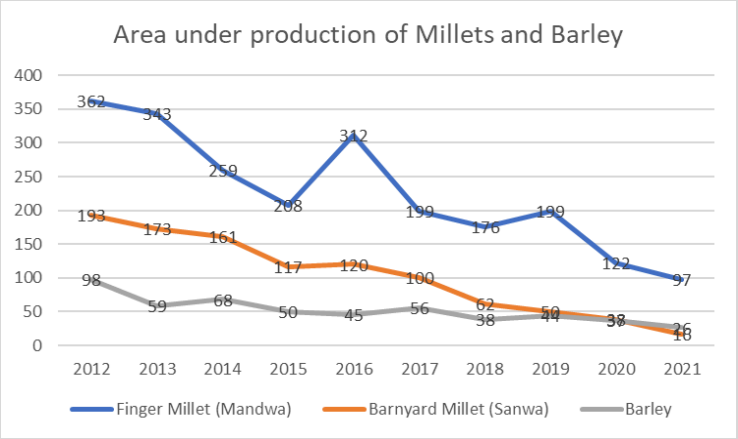


Figure 1: Trends in the Area under Production of Millets and Barley

Source: Department of Agriculture, Government of Uttarakhand

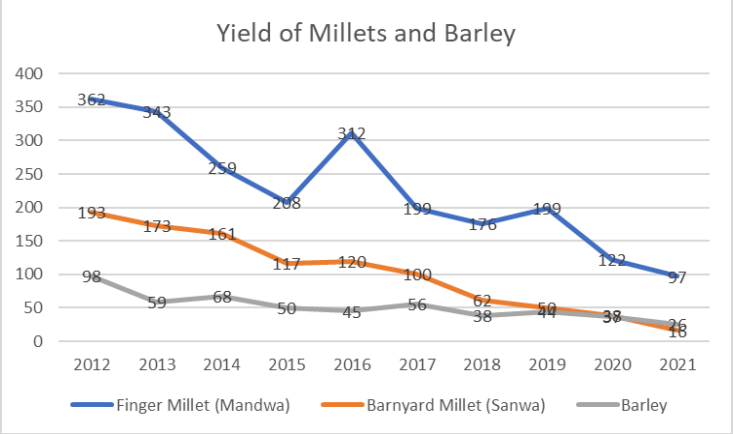


Figure 2: Trends in the Yields of Millets and Barley

Source: Department of Agriculture, Government of Uttarakhand

Maize on the other hand, showed a steady decline in yield and area under production between 2012 and 2021.

Table 4: Maize Cultivation in the Plains

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**

Area under Production (in Hectares)	7824	7249	6273	5438	5224	5057	5076	4677	4211	4708
Yield in (Mt Tonnes)	17079	13005	14907	11282	10609	11807	10495	10692	11048	11729

Source: Department of Agriculture, State of Uttarakhand

- **Hills**

All major cereals show a negative trend in both areas under cultivation and yield between 2012 and 2021 except maize and amaranth. Despite fall in area under cultivation these two crops have recorded 5.9 and 5.6 percent increases in yield.

Table 5: Rate of change in Area under Cultivation and Yield of Cereals

Sl No	Crop	% Change in Area between 2012-2021	% Change in Yield between 2012-2021
1	Wheat	-4.63	-2.85
2	Paddy	-2.83	-1.33
3	Finger Millet (Mandwa)	-3.65	-3.09
4	Barnyard Millet (Sanwa)	-4.03	-2.2
5	Barley	-1.63	-1.08
6	Maize	-1.72	5.9
7	Amaranth (Ramdana)	-2.2	5.6

Source: Table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

Table 6: Wheat Cultivation in the Hills

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Area Under Cultivation (in hectares)	179061	170883	169453	166399	163034	151332	132219	125678	119478	111458
Yield (in Mt Tonnes)	269044	259076	206183	171144	222837	235890	245491	234770	182443	201452

Source: Department of Agriculture, Government of Uttarakhand

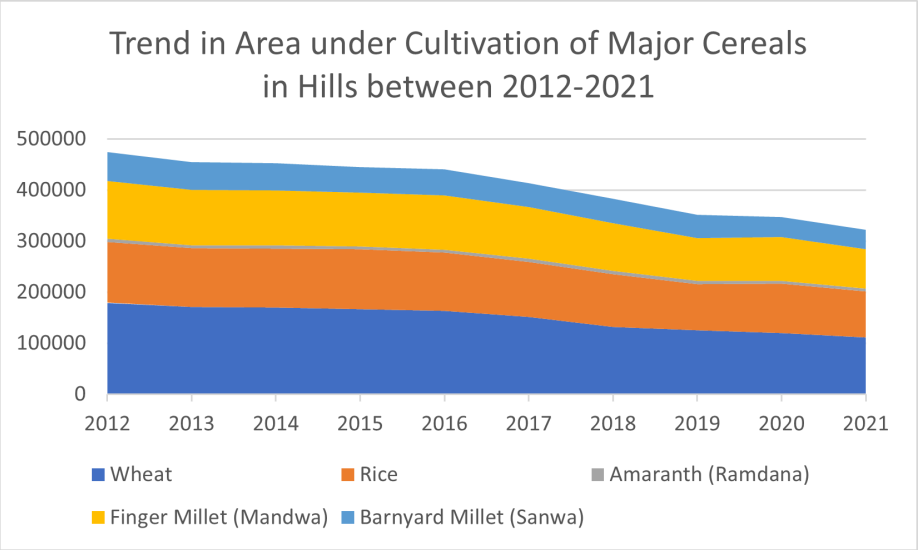
Table 7: Paddy Cultivation in the Hills

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Area Under Cultivation (in hectares)	119405	114676	115779	117129	113897	107853	103169	89995	97248	89651

Yield (in Mt Tonnes)	161344	160349	157985	164560	163023	155393	141730	131219	159169	141166

Source: Department of Agriculture, Government of Uttarakhand

- Wheat (-4.63%) has shown the maximum decline in area under cultivation followed by barnyard millet (-4.03%), finger millet (-3.65%), paddy (-2.83%), ramdana (-2.2%), maize (-1.72%) and barley (-1.63%). Finger millet (-3.09%) has witnessed the maximum decline in yield among cereals followed by wheat (-2.85%), paddy (-1.33%) and barley (-1.08%). Maize (5.9%) showed the maximum increase in yield followed by ramdana (5.6%).
- In case of wheat, paddy, barnyard millet, finger millet and amaranth, the rate of decline in area under cultivation is more drastic between 2017 and 2021 as compared to the first half of the decade i.e. 2012-2016. Barley and maize do not follow a similar trend.
- However, all cereals reached their lowest decadal area under cultivation in 2021. Their yields however do not follow such a linear trend.



Figures 3: Trend in Area under Cultivation of Major Cereals in Hills

Source: Department of Agriculture, State of Uttarakhand

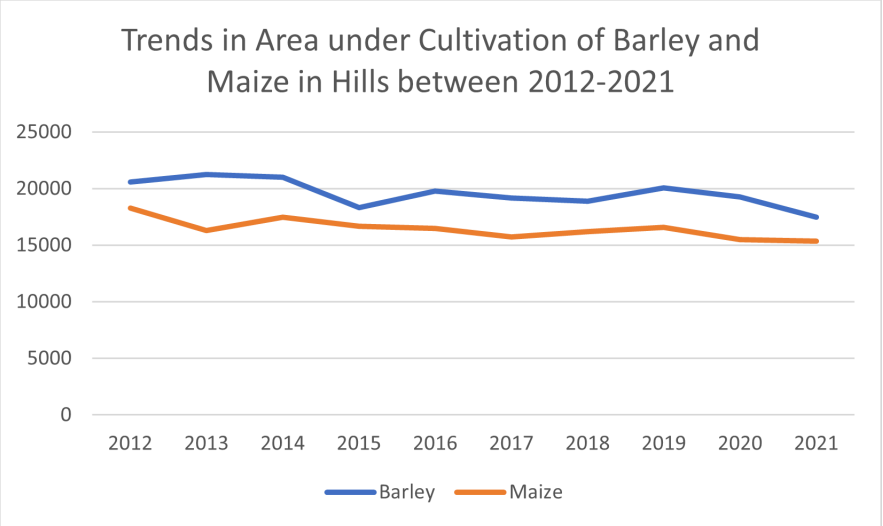


Figure 4: Trends in Area under Cultivation of Barley and Maize in Hills

Source: Department of Agriculture, Government of Uttarakhand

Pulses

- **Plains:**

In terms of cultivation area and yield, yellow split pea (matar) and black gram (urad) have moderate cultivation in the plains. Chickpea, red lentil, black soyabean and horse gram are sparsely cultivated. Pigeon pea and kidney beans are negligible.

Table 8: Rate of Change in the area under cultivation and yield of Pulses in Plains

Sl No	Pulses	% Change in area between 2012-2021	% Change in yield between 2012-2021
1	Yellow Splitpea (Matar)	-1.47	-2.18
2	Black gram (urad)	8.66	15.87
3	Chickpea (chana)	1.48	1.34
4	Red Lentil (masoor)	-6.62	-0.36

Source: The table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

Yellow splitpea (matar) and red lentil show negative trends whereas black gram (urad) exhibits the maximum increase in area and yield among all crops under analysis.

- **Hills:**

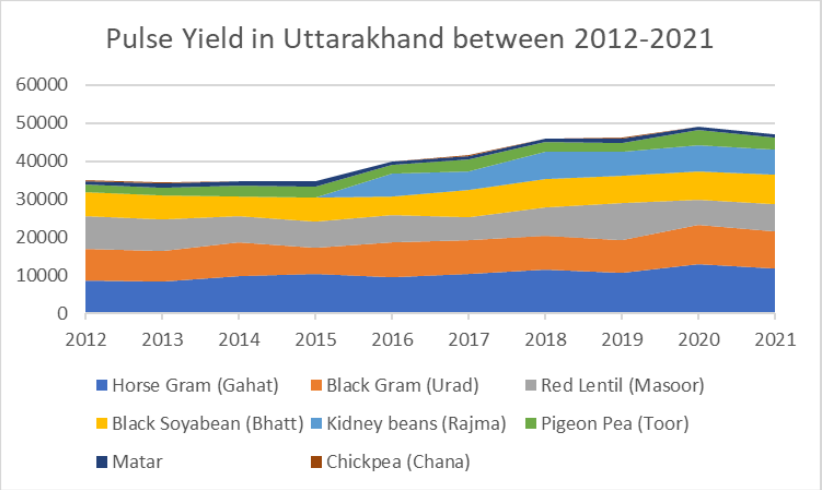
Among pulses, horse gram (gahat) has the highest area under cultivation and yield followed by black gram (urad) and red lentil (masoor), black soyabean (bhatt), kidney beans (rajma), pigeon pea (toor), matar and chana.

Table 9: Rate of Change in the area under cultivation and yield of Pulses in Hills

Sl No	Pulses	% Change in area between 2012-2021	% Change in yield between 2012-2021
1	Horse Gram (Gahat)	0.35	3.12
2	Black Gram (Urad)	-1.6	1.72
3	Red Lentil (Masoor)	-2.26	-2
4	Black Soyabean (Bhatt)	0.66	2.05
4	Kidney beans (Rajma)	0.11	1.22
5	Pigeon Pea (Toor)	1.21	4.5
6	Matar	-2.07	-2.68
7	Chickpea (Chana)	18.51	2.78

Source: Table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

- Pigeon pea, horse gram, chick pea, black soyabean and kidney beans have recorded an increase in area and yield.
- Pigeon pea and Horse gram recorded the highest increase in yield among pulses in the hills despite minimal increase in area under cultivation.
- Black gram (Urad) witnessed a rise in yield (1.72%) despite a fall in area under cultivation.
- Red lentil (masoor) and split pea (matar) recorded declines in both areas and yields.
- Although data for kidney beans was available only for the second half of the decade (2016-2021). In these 6 years, it has witnessed 1.22 percent increase in yield.
- Chickpea has shown a remarkable linear increase in area under cultivation, the highest among all crops in the hills from 120 hectares under cultivation in 2012 to 656 hectares in 2021. However, the increase in yield has not been proportionate. It has increased from 92 MT tonnes in 2012 to 121 MT tonnes in 2021.
- Horse gram, black soyabean and pigeon pea saw an increase in yield in the second half of the decade and reached all-time high in 2020, Black gram (urad) reached decadal lowest area in 2021, while split pea saw lower yields and area under cultivation in the second half of the decade.



Figures 5: Trends in Pulse Yield in Hills

Source: Department of Agriculture, State of Uttarakhand

Oilseeds

Plains:

Rapeseed and mustard constitute the highest growing crops in the plains after wheat and paddy. It is closely followed by soybean which has witnessed a sharp decline over the last decade. Sesame and groundnut are sparsely cultivated with the latter showing significant decline in area and yield between 2012 and 2021.

Table 10: Rate of Change in Area under Cultivation and Yield of Oilseeds in Plains

Sl No	Oilseeds	% Change in area between 2012-2021	% Change in yield between 2012-2021
1	Rapeseed and mustard	3.27	1.7
2	Soyabean	-4.32	-10.01
4	Sesame	1.31	1.62
5	Groundnut	-8.44	-6.08

Source: The table has been compiled based on data from the Department of Agriculture, Government of Uttarakhand

Table 11: Soybean Cultivation in the Plains

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Area under Production (in Hectares)	5250	5791	6726	6960	6655	5703	4811	3541	3534	3376

Yield in (Mt Tonnes)	14948	10510	10702	10681	9073	7945	5218	3649	4211	5204

Source: Department of Agriculture, Government of Uttarakhand

Hills:

Table 12: Rate of Change in Area under Cultivation and Yield of Oilseeds in Hills

Sl No	Oilseeds	% Change in area between 2012-2021	% Change in yield between 2012-2021
1	Lahi-sarson-toriya	1.65	2.3
2	Soyabean	-0.08	0.71
4	Sesame	0.27	-0.12
5	Groundnut	-7.15	-3.15

Source: Department of Agriculture, Government of Uttarakhand

- Oilseeds do not rank among the most cultivated crops in the hills of Uttarakhand. Among them, lahi-sarson-toriya (mustard-rapeseed) and soyabean still have moderately high yields and area under cultivation. Sesame and groundnut lie at the bottom of the chart.
- Lahi-sarson-toriya (mustard-rapeseed) displays increase in both area and yield. Soyabean registered 0.71% increase in yield despite marginal fall in area. Despite an increase in area under cultivation, sesame lost 0.12 percent yield between 2012 and 2021.
- Lahi-sarson-toriya (mustard-rapeseed) showed an increase in yield and area under cultivation in the second half of the decade. Til also displayed an increasing trend in the second half of the decade reaching highest in 2019. Soyabean saw an increase in yield in the second half of the decade without any discernible trend in area under cultivation.
- For all oilseeds, the yield is not commensurate with the area under cultivation. Despite substantial areas being allotted to their cultivation, the yield is not proportionately high.
- Sugarcane and Groundnut is the least grown crop in the hills of Uttarakhand and both have shown the highest declines in area and yield in the last decade.

Potato

The most important vegetable of Uttarakhand is potato, predominantly grown in hilly areas. Among all the vegetables cultivated in Uttarakhand, potato had the highest area under cultivation and yield. In the past 5 years the crop has seen a drastic decline in yield by 70.82% from 367309 Mt Tonnes of yield in 2020-21 to 107150 Mt Tonnes in 2023-24 across the state. The area under cultivation has shrunk from 26867.46 Hectares in 2020-21 to 17083.04 Hectares between 2020-21 to 2022-23 recording a yearly decline of 36.4 percent.

Table 13: Yield and Area under Cultivation of Potato in Uttarakhand

	2016-17	2017-18	2018-19	2019-20	2020-21	2022-23	2023-24
Yield	360370.5	362174.7	363797.6	368641.4	367309	183921.5	107150.0
Area Under Cultivation	26038.19	26311.34	26448.52	26769.38	26867.46	17083.02	N/A

Source: Department of Agriculture, State of Uttarakhand and Agricultural & Processed Food Products Export Development Authority (APEDA)

District Level Trend Analysis for Major Crops

Paddy: All the hill districts have recorded decline in area under paddy production to varying degrees. Districts with the maximum fall in the area under cultivation and yield of paddy include Pauri Garhwal, Almora and Champawat. Haridwar experienced the maximum increase in paddy yield followed by Udham Singh Nagar and Dehradun.

Wheat: In terms of wheat cultivation, the districts reveal a mixed trend. Districts recording the maximum decline in area under wheat cultivation include Bageswar, Almora, Tehri Garhwal and Pauri Garhwal. Districts experiencing the maximum decline in wheat yield include Pauri Garhwal, Almora and Rudraprayag. Rudraprayag experienced a decline in yield despite 3.17% increase in area under wheat production.

Some districts saw increases in area under wheat cultivation which include Rudraprayag, Uttarakashi, Champawat. However, Uttarkashi saw a small decline in yield. In the plain areas, Dehradun recorded a decline in wheat cultivation, Haridwar and Udham Singh Nagar saw increases in both yield and area under production.

Finger Millets (Mandwa): The districts with the highest decline in area and yield under finger millet production include Pauri Garhwal, Tehri Garhwal and Champawat.

Barnyard Millets (Sanwa): The districts with the highest decline in area and yield under barnyard millet production include Pauri Garhwal, Bageswar , Pithoragarh.

Maize: Rudraprayag has witnessed the highest increase in area under cultivation and yield of maize. Chamoli, Pauri Garhwal, Uttarkashi, Champawat saw increases in yield. Bageswar saw declines in area and yield between 2012 and 2021. Dehradun and Haridwar have witnessed declines in area under cultivation.

Pulses:

- **Toor daal** has seen remarkable growth in Almora, followed by Rudra Prayaga and Tehri Garhwal.
- **Horse Gram (Gahat)-** Bageswar witnessed declines in area and yield, Tehri Garhwal, Uttarkashi and Almora saw increases in area. Uttarkashi and Almora saw increases in yield, Champawat saw increase in yield despite decline in area.

- **Masoor:** Pauri Garhwal witnessed decline in area and yield, Uttarakashi and Almora saw increases in area and yield.
- **Matar:** Pauri Garhwal, Rudra Prayag and Champawat saw increases in area and yield.
- **Urad:** Uttarkashi saw increase in area, Bageswar saw decline in area, Champawat, Tehri Garhwal, Uttarkashi, Almora, Pithoragarh witnessed increase in yield.
- **Rajma:** Pauri Garhwal, Rudra Prayag and Bageswar saw increases in area and yield.
- **Chana:** Not a widely grown crop in Almora but has seen tremendous growth in area and yield in the district followed by Champawat and Pithoragarh.

Potato: Almora saw the highest decline in yield between 2020 and 2022, followed by Rudraprayag, Pithoragarh, Pauri and Tehri. In terms of decline in area, Almora topped the list followed by Dehradun, Bageswar, Pauri Garhwal, Tehri Garhwal and Pithoragarh. Chamoli saw an increase in area but decline in yield.

Summary

Total area under agricultural production and agricultural yield in the hills of Uttarakhand show a linear decline of 27.2% and 15.2% respectively between 2012 and 2021. Unlike the hilly districts, the plains have witnessed a 15 percent increase in crop yield for only a 2.5 percent rise in area under cultivation in the same period.

Cereal cultivation still occupies an important place in both the hills and plains of Uttarakhand with the highest yields and areas under cultivation. However, between 2012-2021 all cereals have seen declines in yields and areas under cultivation to varying degrees in the hills. While rice and wheat exhibit positive trends in cultivation in the plains, maize, barley and millets have seen drastic declines. Pulses and oilseeds, however, majorly show increasing trends in area and yield in the hills. Although their share in hill cultivation is smaller than that of cereals. Greater variations in yield and area were noted in the second half of the decade with all cereals reaching their decadal lows between 2020 and 2021. Districts which have witnessed declines in major cereals have seen increases in the cultivation of pulses.

- While **Almora** saw declines in paddy and wheat production, it witnessed maximum increase in pigeon pea (toor) daal and increases in horse gram (gahat), masoor, urad and chana.
- **Pauri Garhwal** saw declines in paddy, wheat and millets but increases in maize, matar, rajma.
- **Champawat** witnessed declines in paddy, millets, but increase in wheat, maize, horse gram, matar, urad and chana
- While **Bageswar** saw declines in most crops including wheat, millets, maize, horse gram, urad but increase in rajma.
- Despite decline in paddy and wheat production, **Rudra Prayag** saw a dramatic rise in maize production along with matar and rajma, toor daal.
- While **Tehri Garhwal** witnessed declines in finger millets and wheat but rise in pigeon pea (toor) and urad daal.

4. Climate Change in Uttarakhand

The changing patterns of agricultural production in the state of Uttarakhand can be partially attributed to its rapidly warming climate in addition to socio-economic constraints, cultural preferences and market fluctuations etc. However, further research is needed to strengthen such correlations.

Temperature Rise

Uttarakhand is climatologically sensitive, ecologically fragile and highly vulnerable to natural disasters. Research by Climate Trends estimates that the state has recorded approximately 1.5-degree Celsius warming between 1970 and 2022 with higher elevations experiencing amplified rates of warming. Average temperature in Uttarakhand increased at an annual rate of 0.02 degrees Celsius over the same period. Warming has induced changes in rainfall patterns and intensified climate extremes. Higher altitudes are experiencing more rapid and acute temperature shifts as compared to lower-lying areas. Research indicates that temperatures in hill districts, such as Uttarkashi, Chamoli, Rudraprayag, and Pithoragarh have increased more substantially than in Haridwar, Dehradun, and Pauri Garhwal.

Changing Rainfall Patterns and Drought

Over the last century, there has been significant fall and variability in average annual rainfall in Uttarakhand with hill districts becoming drier. However, high-intensity rainfall extremes of shorter duration continue to loom large. Rainfall patterns have shown considerable interannual variability over the past century, with a reduction in the number of rainy days since the 1990s, particularly in the hilly regions of the state. While the total rainfall has not decreased significantly, the frequency of extreme rainfall events has increased. A study conducted by the Council on Energy, Environment and Water reveals that several tehsils in the state have seen a decline in rainfall during the initial monsoon months of June and July in the past 40 years. The analysis also highlights a decline in October-November-December rainfall in the states of Uttarakhand with approximately 86 percent of tehsils in Uttarakhand experiencing a reduction in the northeast monsoon. Another study on the distribution of rainfall in the upper Kumaon region between 1950-2018 shows that rainfall has been decreasing with the highest rate of 3.88 mm/year in Bageshwar followed by Almora (3.33 mm/year) and Pithoragarh (2.06 mm/year) whereas Champawat has increasing trend rate of 0.149 mm/year due to the heavy rainfall in recent past. In the past 20 years, winter temperatures at high elevations of the state have increased at the rate of 0.12◦C/decade. Precipitation has fallen by 11.2 mm per decade, potentially affecting rabi crops. Annual rainfall is high (1,523 mm) but more than 90 percent is received during the July-September monsoon months, which together with steep slopes, means rapid and large runoff, resulting in soil loss of 40 tons/ha/year. At the same time, there has been an overall reduction in the discharge rate of stream and spring water sources, critical for year-round water supply both for agriculture and the domestic needs of villagers in the state.

Extreme weather Events

Uttarakhand has been in the eye of recurring disasters ranging from extreme rainfall events, flooding, hailstorms and landslides resulting in significant damages to agricultural fields and

standing crops. According to India's Atlas on Weather Disasters, in 2022 the state witnessed 57 days of extreme weather conditions. The number rose to 94 in 2023 when 44,882 hectares of farm lands were lost to extreme weather events. Dwindling agricultural prospects have also led to widespread out migration from the hills to the plains which could also explain the shrinking area under agricultural production in the last decade.

5. Climate Impacts on Crop Production in Uttarakhand

Research indicates that the yield of paddy has decreased due to insufficient rainfall at the time of transplantation while warmer winters and reduced winter rainfall have affected wheat production. Extreme rainfall events erode topsoil productivity and damage standing crops. Rising air temperatures increase crop evapotranspiration, thus increasing water demand for crop production to maintain optimal yield. Crops like potatoes are highly susceptible to warm weather conditions. Highly sensitive to temperature and drought, a moderate level of water stress can also cause reductions in tuber yield.

The state was once home to a rich repository of agrobiodiversity with over 40 indigenous millets and coarse cereals, many of which are nearing extinction. Repeated crop failures from erratic monsoons and lighter snowfall are discouraging farmers from investing in the cultivation of local millet varieties like foxtail millet and flaxseed. Barnyard and finger millets are also declining in production across the state. They have witnessed an average 4% decline in area under cultivation in hills. Although sparsely cultivated in the plains, they have encountered nearly 22% (barnyard millet) and 12% (finger millets) shrinkage in areas under cultivation in the plains.

Potatoes in India thrive in cool weather, with optimal temperatures ranging from 15 to 25°C (59 to 77°F) for overall growth and 17-20°C (63-68°F) specifically for tuber development. The vegetative growth of the plant is best at a temperature of 24°C while tuber development is favoured at 20°C. Hence, potato is grown as a summer crop in the hills and as a winter crop in the tropical and subtropical regions. Higher day temperatures can make some areas unsuitable for potato production due to lower tuber yields and quality. Drought, salinity, frost, flooding, and erratic unseasonal weather will negatively impact potato production. It has the potential to reduce seed tuber production. Potatoes are typically grown as a winter crop in the plains and as a summer crop in the hills. The rising temperatures and water stress in the hills could be attributed to declining potato yields. Potatoes need adequate and consistent soil moisture for germination and tuber formation. They are extremely sensitive to drought particularly at tuber initiation which leads to substantial loss in tuber yield. Optimal water supply is essential for potatoes, because of its shallow root system. Studies indicate that the winter and post monsoon seasons are likely to be more affected by warming. Increasing drought due to reduction in winter precipitation and unpredictable and unseasonal rains and frost can significantly reduce potato yield.

> *"Potatoes are a heavy feeder crop that requires high amounts of nutrients. In the hills, farmers largely practice organic farming by default, relying mainly on cow dung manure. However, this alone cannot meet the high nutrient demands of*

potatoes—particularly for phosphorus, potash, and other micronutrients—leading to declining yields. Most farmers neither use chemical fertilizers nor have efficient composting methods, further contributing to low productivity. Climate change is also a significant factor. Potatoes in the hills are entirely rain-fed, and rainfall has become increasingly erratic. Typically, potatoes are planted in early March and harvested by May–June in the hills, while in the plains, they are planted in October–November and harvested by January. Earlier, there used to be 2-3 spells of snow falls between October to December. Now the lack of timely rain, reduced snowfall between October and January, rising temperatures, and occurrences of hail have all negatively impacted potato cultivation," explained **Dr Anil Kumar, Vegetable Scientist, Krishi Vigyan Kendra, Udham Singh Nagar.**

"Potato cultivation in the hills is suffering because of lack of soil moisture. The land has become dry, water retention of soil has reduced, evapotranspiration rates are high due to heat. All these affect the yield. Moreover, farmers are struggling to protect their fields from the attacks from wild boars at night who dig the soil and uproot the plants," said **Yogendra Bisht, President, Lok Chetna Manch, Uttarakhand.**

On the other hand, maize has shown a remarkable growth in the hills but a nearly decline in the plains. Cultivated in semi-arid conditions, it thrives in warm climates with temperatures between 25°C and 30°C and approximately 50-100 cm of rainfall. Its cultivation is less water intensive than that of paddy's. Increasing temperatures and water stress in the hills could have favoured its growth.

6.The Path to Resilience

Crop Diversification and Multicropping

Dwindling agricultural prospects, crop losses due to erratic weather, and mass outmigration have cast a shadow over hill cultivation in Uttarakhand. Climate resilient agriculture practices have been a part of Uttarakhand's cultural tradition in the hills. The now obsolete Barahnaja system of multicropping was a hallmark of sustainable farming practice in the state. Rooted in the agricultural wisdom of the Himalayan region, Barahnaja—meaning "twelve seeds" in Garhwali-was a diverse, climate-resilient mixed cropping system involving grains, pulses, millets, oilseeds, vegetables, and medicinal herbs grown together in a single field. This method not only enhances soil fertility and biodiversity but also ensures food security and ecological balance. Under this system failures of one or two crops are often compensated by proper yields and incomes from the rest. However, scattered and fragmented landholdings in contemporary times have led to its extinction at present. However, despite dependence on paddy-wheat monocropping systems farmers continue to practice multicropping with one or two pulses and millets sowed in the same field.

Pulses: Climate Resilient Alternatives to Paddy and Wheat

Despite the decline in cereal yields, the rise in production and recognition of native GI-tagged pulses like *pahari toor daal*, *gahat* (horse gram), and *bhatt* (black soybean), urad and millets like amaranth (ramdana) signals a shift toward more climate-resilient farming aimed at coping with the heat and water stress in the hills. Incorporating pulses into cropping systems and agroforestry enhances adaptation by improving soil health, conserving water, and diversifying incomes while ensuring nutrition security. Multiple cropping systems, such as intercropping or crop rotations with pulses, have a higher soil carbon sequestration potential than monocrop systems. Their low water footprint, drought tolerance, and ability to grow in poor soils make pulses a cornerstone of sustainable hill agriculture in a warming world. Conversations with Krishi Vigyan Kendras in Bageswar and Uttarkashi revealed that they have introduced drought tolerant varieties of pigeon pea to deal with prolonged dry spells. Pulse crops are good for areas with less rainfall, short duration crops like moong and urad are promoted among farmers to cope with delayed monsoons.The 6-year "Mission for Aatmanirbharta in Pulses" focusing on the procurement of Tur, Urad and Masoor from farmers as announced in the Central budget in 2025 could further incentivize their cultivation in the state.

> *"Water stress is a huge concern in the hills of Uttarakhand. Erratic rainfall patterns are significantly impacting the cultivation of paddy and wheat. Soil quality has degraded and its productivity has gone down over the years. Lack of adequate winter rainfall is particularly affecting rabi crops. There is not enough water available to cultivate paddy or wheat. Hence farmers are seeking alternatives. Although the baranaja system is no longer prevalent due to scattered landholdings, farmers are practising multi cropping with millets and pulses. Pulses are giving them good economic returns. Cash crops, particularly spices like turmeric and chilli are also gaining currency in the hills. They are also immune to animal attacks. Other adaptation practices include rain water harvesting, mulching, income diversification through poultry farming and livestock rearing."* **mentioned Yogendra Bisht, President, Lok Chetna Manch, Uttarakhand.**

Spices are Gaining Currency in Uttarakhand

Area under spice cultivation in the state of Uttarakhand as a whole has increased by 50% and yield has increased by 10.5% between 2016 and 2022. Field interviews indicate that among spices turmeric and chillies have seen tremendous growth due to their market returns and immunity to animal attacks. Areas under turmeric and chilli cultivation show linear growths of nearly 112% and 35% respectively. Their corresponding increase in yields are 122.5% for turmeric which showed a dramatic spike in 2022 following a consistent growth between 2016 and 2020. Chilli yields increased by 21% between 2016 and 2022.

Both chilli and turmeric require warm humid conditions but are adaptable to soil varieties and wide temperature ranges. In fact, a Study conducted in north east India found that under mid-hill conditions, yield and quality attributes of turmeric will not be affected significantly by rise in temperature due to global warming.

Table 14: Increase in Spice Cultivation in Uttarakhand

	2016	2017	2018	2019	2020	2022
Area Under Cultivation (in hectares)	12700.66	13674.53	14120.42	14536.07	14280.79	18030.86
Yield (in Mt Tonnes)	87617	91177.6	93624.96	96282.04	95999.39	96849.83

Source: Department of Horticulture, State of Uttarakhand

Table 15: Increase in Turmeric Cultivation in Uttarakhand

	2016	2017	2018	2019	2020	2022
Area Under Cultivation (in hectares)	1482.48	1570.44	1722.42	1769.01	1790.81	3145.43
Yield (in Mt Tonnes)	12652.73	13928.17	14181.6	14748.65	15195.59	28161.23

Source: Department of Horticulture, State of Uttarakhand

Table 16: Increase in Chilli Cultivation in Uttarakhand

	2016	2017	2018	2019	2020	2022
Area Under Cultivation (in hectares)	2754.52	2762.08	2802.53	2874.76	2751.03	3723.87
Yield (in Mt Tonnes)	8857.49	9158.16	9473.69	9632.02	9333.48	10744.51

Source: Department of Horticulture, State of Uttarakhand

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Appendix 1

Crop Production in Uttarakhand Hills

Sl No	Crop	Area in Hectares in 2021	% Change in Area between 2012-2021	Yield in M Tonnes in 2021	% Change in Yield between 2012-2021
1	Wheat	111458	-4.63	201452	-2.85
2	Paddy	89651	-2.83	141166	-1.33
3	Finger Millet (Mandwa)	77830	-3.65	114977	-3.09
4	Barnyard Millet (Sanwa)	37578	-4.03	60542	-2.2
5	Barley	17488	-1.63	25206	-1.08
6	Maize	15355	-1.72	38368	5.9
7	Horse Gram (black chana)	11258	0.35	11829	3.12
8	Black Gram (Urad)	8888	-1.6	9710	1.72
9	Red Lentil (Masoor)	8084	-2.26	7021	-2
10	Lahi-Sarson-Toriya (mustard-rapeseed)	7505	1.65	4544	2.3
11	Black Soyabean (Bhatt)	6680	0.66	7772	2.05
12	Kidney beans (Rajma)	5679	0.11	6711	1.22
13	Ramdana	5301	-2.2	6749	5.6
14	Soyabean	3788	-0.08	4796	0.71
15	Pigeon Pea (Toor)	2820	1.21	3012	4.5
16	Sesame (Til)	1561	0.27	412	-0.12
17	Matar	1361	-2.07	831	-2.68
18	Chickpea (Chana)	656	18.51	121	2.78
19	Groundnut (Moongfali)	40	-7.15	61	-3.15
20	Sugarcane	4	-7.79	334	-4.69

Appendix 2

Crop Production in Uttarakhand Plains

Sl No	Crop	Area in Hectares in 2021	% change in area between 2012- 2021	yields in metric tonnes in 2021	% change in yield between 2012-2021
1	Wheat	173622	0.18	660203	1.22
2	Rice	143537	0.57	490780	2.07
3	Sugarcane	93258	-1.08	8437528	2.89
4	Lahi-Sarson-Toriya	9469	3.27	10029	1.7
5	Maize	4708	-4.95	11729	-3.69
6	Matar	3830	-1.47	3952	-2.18
7	Soyabean	3376	-4.32	5204	-10.01
8	Black Gram (Urad)	3037	8.66	4476	15.87
9	Chickpea (Chana)	555	1.48	473	1.34
10	Red Lentil (Masoor)	460	-6.62	434	-0.36
11	Groundnut (Moongfali)	407	-8.44	615	-6.08
12	Sesame (Til)	295	1.31	81	1.62

13	Black Soyabean (Bhatt)	135	0	216	0
14	Horse Gram (Gahat)	103	0	90	0
15	Finger Millet (Mandwa)	97	-12.34	148	-9.23
16	Barley	26	-12.43	50	-7.91
17	Barnyard Millet (Sanwa)	16	-22.04	27	-20.94
18	Pigeon Pea (Toor)	8	-12.67	10	-9.46
19	Kidney beans (Rajma)	1	NA	1	0
20	Amaranth (Ramdana)	0	0	0	0

Source: Department of Agriculture, State of Uttarakhand