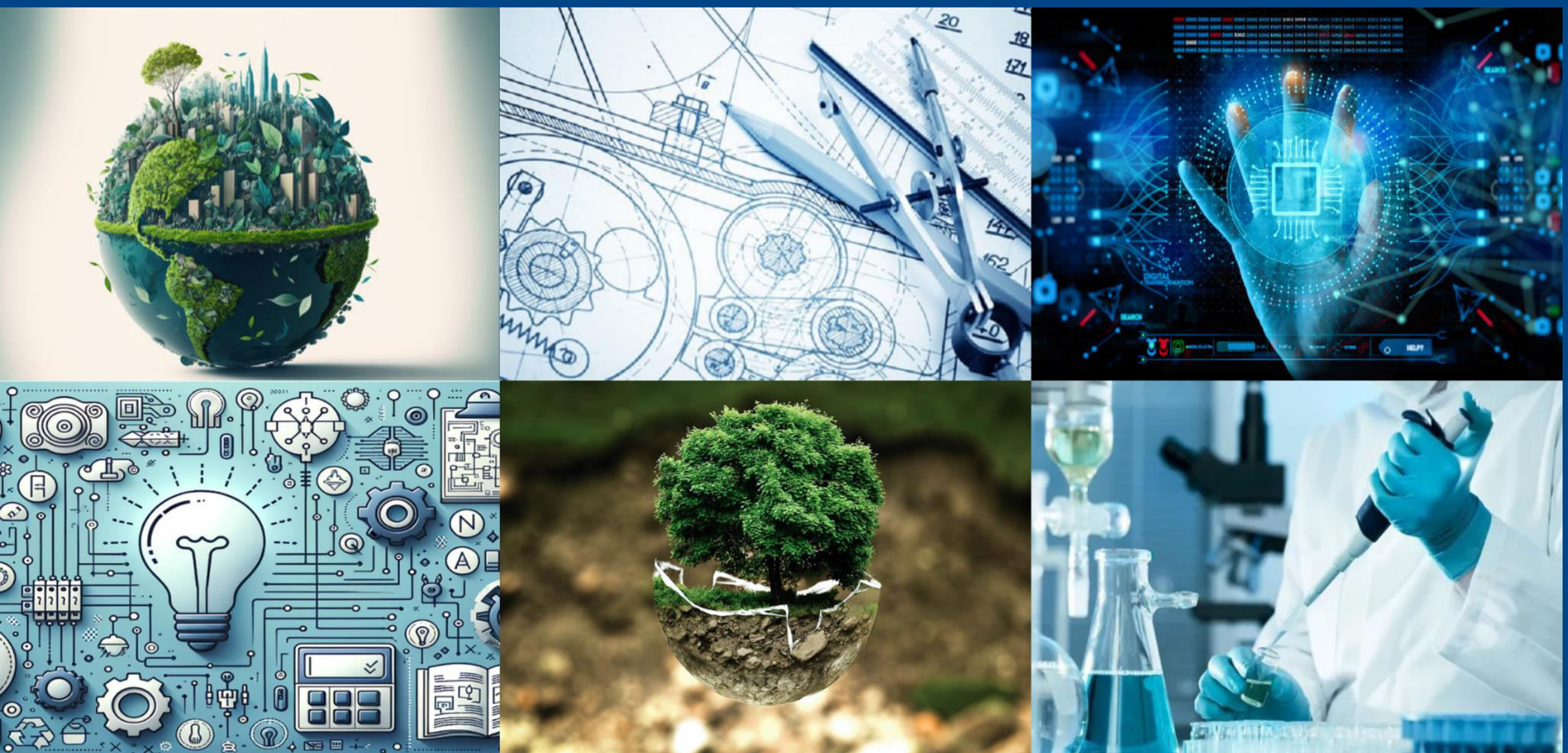
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 9.864

Volume 9, Issue 6, June 2026

www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

© 2026 IJMRSET | Volume 9, Issue 6, June 2026| DOI:10.15680/IJMRSET.2026.0906009

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Effect of Crop Rotation on Fusarium Wilt Intensity in *Cajanus cajan* L: Comparing Monocropping vs. Rotation with Cereals and Vegetables

Gouri Singh[1], Dr. Vivek Kumar Singh[2]

Research Scholar, Department of Botany, T.M. Bhagalpur University, Bhagalpur, India

Senior Assistant Professor, Department of Botany, T.M. Bhagalpur University, Bhagalpur, India

ABSTRACT: Pigeon pea (*Cajanus cajan* L.) is a multipurpose pulse crop critical for nutrition security and soil fertility in India. However, its productivity is severely constrained by Fusarium wilt caused by *Fusarium udum*, a soil-borne vascular disease responsible for 30–100% yield losses depending on host susceptibility and environmental conditions. Chemical fungicides provide limited relief due to systemic colonization and long-term pathogen persistence. Crop rotation, a traditional cultural practice, has been recommended for managing soil-borne pathogens, yet its impact on Fusarium wilt of pigeon pea under field conditions in Bihar remains underexplored.

This study investigated wilt intensity in pigeon pea under monocropping and compared it with rotations involving cereals (wheat, maize) and vegetables (tomato, onion, okra). A three-year field trial was conducted across wilt-endemic farmer fields in Munger district, Bihar, using a split-plot design with three replications. Wilt incidence was recorded at 30, 60, and 90 days after sowing (DAS), alongside yield, economic returns, and soil microbial profiles.

Results indicated that continuous pigeon pea monocropping resulted in the highest wilt incidence (>55% at 90 DAS) and lowest yields (~1,035 kg/ha). In contrast, rotations with cereals reduced wilt incidence by 50–55%, while vegetable rotations achieved 60–65% reduction. Pigeon pea–tomato and pigeon pea–onion systems produced the lowest wilt levels (~20–21%) and the highest yields (~1,350–1,375 kg/ha). Soil analysis revealed greater populations of *Trichoderma* spp. and *Pseudomonas fluorescens* in rotation plots, supporting the role of microbial diversity in disease suppression.

The findings validate farmer observations that monocropping worsens wilt intensity, whereas crop rotation disrupts pathogen inoculum cycles. Incorporating rotations with cereals or vegetables alongside resistant varieties offers a sustainable integrated disease management (IDM) strategy for pigeon pea systems in Bihar.

KEYWORDS: *Cajanus cajan*, *Fusarium udum*, Fusarium wilt, monocropping, crop rotation, cereals, vegetables, Bihar, soil health

I. INTRODUCTION

Pigeon pea (*Cajanus cajan* L.) is an important pulse crop that contributes significantly to food security, nutritional balance, and soil fertility in many tropical and subtropical regions. In India, its productivity is often constrained by Fusarium wilt, a destructive soil-borne disease caused by *Fusarium udum*. The pathogen can survive in soil for several years, making disease management particularly challenging under continuous pigeon pea cultivation. Monocropping tends to increase pathogen populations and disease severity, resulting in substantial yield losses. Crop rotation has emerged as an environmentally sustainable approach to managing soil-borne diseases by interrupting pathogen life cycles and improving soil health. Rotations with cereals and vegetables may alter soil microbial communities and reduce inoculum levels of the pathogen. Therefore, evaluating the comparative effects of monocropping and different crop rotation systems on Fusarium wilt intensity is essential for developing sustainable pigeon pea production strategies.

1.1 Pigeon Pea in Indian Agriculture and Nutritional Security

Pigeon pea (*Cajanus cajan* L.), commonly known as arhar or red gram, is one of the most important pulse crops cultivated in the semi-arid tropics of Asia and Africa. India accounts for more than 70% of the global area and production of pigeon pea, making it a key component of the country's pulse economy (Ali & Kumar, 2009). The crop is nutritionally important because it contains 20–22% protein, essential amino acids, minerals, and dietary fiber, thereby serving as a major protein source in predominantly vegetarian diets. Apart from its nutritional significance, pigeon pea contributes to sustainable agriculture through biological nitrogen fixation, improvement of soil fertility, and provision of fodder, fuelwood, and supplementary income for smallholder farmers (ICAR-IIPR, 2015).

In Bihar, pigeon pea is cultivated mainly in the rainfed tracts of the Indo-Gangetic Plains, particularly in districts such as Munger, Nalanda, and Darbhanga. Farmers prefer the crop because of its adaptability to marginal soils and comparatively low input requirements (Government of Bihar, 2025). However, despite its importance, the average productivity of pigeon pea in Bihar remains low, ranging between 800–900 kg/ha, which is far below the potential yield of improved cultivars exceeding 2,500 kg/ha. Researchers have identified diseases, particularly Fusarium wilt, as one of the major causes of this productivity gap (Sharma et al., 2016).

1.2 Fusarium Wilt: A Major Constraint in Pigeon Pea Production

Among the various biotic stresses affecting pigeon pea, Fusarium wilt caused by *Fusarium udum* Butler is considered the most destructive disease. The disease was first reported in India more than a century ago and continues to cause severe yield losses across Asia and Africa (Nene & Kannaiyan, 1982). Symptoms include yellowing, wilting, vascular discoloration, stunting, and eventual plant death. Yield losses vary from 30% under moderate infection to complete crop failure in highly susceptible fields (Pande et al., 2013).

The persistence of the pathogen in soil makes wilt management extremely difficult. *F. udum* survives through chlamydospores that remain viable in soil and crop residues for up to five or six years, even in the absence of pigeon pea cultivation (Pande et al., 2013). Environmental conditions such as high soil moisture and warm temperatures further favor disease development and epidemic outbreaks (Sharma et al., 2016). Studies have also shown that monocropping intensifies pathogen build-up because continuous pigeon pea cultivation maintains uninterrupted host–pathogen interaction, thereby increasing inoculum density in the rhizosphere (Cook, 2007).

1.3 Crop Rotation as a Sustainable Disease Management Strategy

Because chemical control of Fusarium wilt is neither economically feasible nor environmentally sustainable for smallholder farmers, cultural practices have become central to disease management. Among these, crop rotation is one of the oldest and most effective methods used globally for managing soil-borne pathogens. Historical and contemporary studies indicate that rotating crops interrupts pathogen life cycles, lowers inoculum density, and restores soil ecological balance (Cook, 2007).

Research on wilt diseases in cereals, pulses, and vegetables has consistently shown that non-host crop rotations suppress pathogen populations by depriving them of susceptible host tissue. In pigeon pea, rotations with cereals such as wheat and maize have been reported to reduce wilt intensity by nearly 40–50% compared to continuous monocropping (Pande et al., 2013). Similarly, Singh et al. (2019) observed that pigeon pea–wheat and pigeon pea–maize systems in the Eastern Indo-Gangetic Plains provided better yield stability and lower disease incidence than continuous pigeon pea cultivation. Cereals act as non-hosts of *F. udum*, thereby reducing pathogen survival and carryover between seasons.

Vegetable-based rotations have also attracted attention because of their influence on soil microbial ecology and profitability. Rotations involving tomato, onion, and okra have shown suppressive effects on Fusarium wilt, partly due to the addition of organic manures and changes in rhizosphere microbial populations (Ravikumara et al., 2022). Root exudates of vegetables are believed to favor antagonistic microorganisms that inhibit pathogen proliferation, thereby improving soil suppressiveness.

1.4 Resistant Varieties, Biological Control, and Soil Microbial Ecology

Several resistant pigeon pea varieties, including ICP 8863 (Maruti) and ICPL 87119 (Asha), have been developed through breeding programs led by ICRISAT and national agricultural institutions (Crop Trust, 2022; ICAR-IIPR, 2015). These cultivars have contributed significantly to yield stability in wilt-prone regions. However, recent studies indicate that the genetic diversity and variability of *F. udum* isolates may lead to breakdown of resistance in some areas (Nene & Kannaiyan, 1982). Consequently, resistant varieties alone cannot provide durable disease management.

© 2026 IJMRSET | Volume 9, Issue 6, June 2026| DOI:10.15680/IJMRSET.2026.0906009

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Biological control agents such as *Trichoderma harzianum*, *T. viride*, and *Pseudomonas fluorescens* have also shown promising results against wilt. Reddy et al. (2024) demonstrated that native *Trichoderma* strains significantly reduced wilt incidence through seed treatment and soil application. These beneficial microorganisms suppress pathogens by mechanisms such as antibiosis, mycoparasitism, resource competition, and induction of systemic resistance. However, large-scale adoption remains limited because of inadequate availability, quality concerns, and weak extension support (Pande et al., 2013).

Recent literature further highlights the importance of soil microbial diversity in disease suppression. Monocropped soils often exhibit reduced microbial diversity and increased pathogen dominance, whereas rotated systems encourage beneficial antagonists such as *Trichoderma* spp. and *Pseudomonas fluorescens* (Sharma et al., 2016). Improved organic matter and enhanced soil enzymatic activity under rotations are also associated with lower wilt incidence. Thus, crop rotation not only interrupts the disease cycle but also modifies the soil microbiome in favor of plant health.

1.5 Farmer Practices and Research Gap in Bihar

Farmers in Bihar have long recognized that continuous cultivation of pigeon pea on the same land increases the severity of Fusarium wilt, whereas rotations with cereals and vegetables help reduce disease incidence. In the Indo-Gangetic Plains, many farmers commonly practice pigeon pea–wheat, pigeon pea–maize, and pigeon pea–vegetable rotations, mainly due to economic needs, market demand, and labor availability rather than scientific disease management strategies (Singh et al., 2019). Nevertheless, these traditional farming practices are consistent with scientific findings that crop diversification suppresses soil-borne pathogens and improves soil health (Cook, 2007).

Despite considerable research on wilt management in India, systematic studies under Bihar's agro-climatic conditions remain limited. Most previous studies were conducted in central and southern India, where environmental conditions, soil characteristics and cropping systems differ significantly from Bihar. In wilt-prone districts such as Munger, the comparative effectiveness of cereal- and vegetable-based rotations has not been adequately quantified under farmers' field conditions. This research gap is critical because most Bihar farmers are smallholders with limited access to fungicides, resistant varieties, and bio-control agents. Therefore, scientifically validated, low-cost crop rotation strategies are essential for sustainable wilt management and stable pigeon pea productivity in the region.

1.6 Significance of the Study

By bridging scientific experimentation with farmer practices, this study contributes both to academic understanding of host–pathogen–microbiome interactions and to practical disease management strategies. The results have the potential to guide farmer-friendly recommendations that reduce disease burden, enhance productivity, and promote soil health in Bihar's pigeon pea systems.

II. MATERIALS AND METHODS

2.1 Study Area

The study was conducted during three consecutive kharif seasons (2021–2023) in wilt-endemic regions of Munger district, Bihar. Munger lies within the Middle Gangetic Plains agro-climatic zone, characterized by hot, humid summers, annual rainfall of 1000–1200 mm (concentrated between June and September), and average temperatures ranging from 22°C in winter to 35–38°C in summer (India Meteorological Department, 2020; Government of Bihar, 2022). The soils are predominantly fertile alluvial loams with pH values of 6.5–7.2 and moderate organic carbon levels (0.45–0.65%), which are generally suitable for pulse cultivation (NBSS & LUP, 2019; ICAR-IIPR, 2015). Agriculture is the principal occupation of the rural population, and the district economy largely depends on crop-based farming systems. Major crops cultivated in the region include paddy, wheat, maize, pigeon pea, lentil, gram, mustard, and various seasonal vegetables.

The district has a mixed farming pattern where cereal-pulse rotation is commonly practiced, particularly under rainfed and partially irrigated conditions. Pigeon pea (*Cajanus cajan* L.) is one of the important pulse crops cultivated during the kharif season because of its adaptability to marginal soils, drought tolerance, and role in improving soil fertility through biological nitrogen fixation (Ali & Kumar, 2009; ICAR-IIPR, 2015). Farmers in the district prefer pigeon pea not only for household consumption but also as a source of supplementary income due to its high market demand (Directorate of Economics and Statistics, 2022). However, despite favorable agro-climatic conditions, productivity remains comparatively low because of biotic stresses, especially Fusarium wilt disease. Wilt incidence has historically been high, often exceeding 40–60% in monocropped areas, causing severe yield reduction and economic losses to farmers (Kannaiyan & Nene, 1981; Rani et al., 2018).

The agricultural system of Munger district is also characterized by small and marginal landholdings, limited mechanization, and dependence on monsoon rainfall. In many villages, inadequate crop diversification and continuous pigeon pea cultivation have further increased soil-borne pathogen pressure. Therefore, the region provides suitable conditions for evaluating integrated wilt management practices under real farmer-field situations (Singh et al., 2019; ICAR-IIPR, 2015).

2.2 Experimental Design and Layout

A split-plot design was used with three replications. Main plots represented cropping system categories (monocropping vs. rotation), while subplots represented specific rotations. Each subplot measured 6 m × 5 m with 0.5 m buffer rows. Standard agronomic practices (land preparation, basal fertilizer application, and irrigation as per rainfall) were followed, but no fungicides were applied in order to allow natural disease development.

Cropping system treatments:

- **T1:** Continuous monocropped pigeon pea (control)
- **T2:** Pigeon pea–wheat rotation
- **T3:** Pigeon pea–maize rotation
- **T4:** Pigeon pea–tomato rotation
- **T5:** Pigeon pea–onion rotation
- **T6:** Pigeon pea–okra rotation

Rotations were maintained across the three-year cycle to allow cumulative effects on soil inoculum to manifest. Pigeon pea variety 'Bahar', widely grown in Bihar, was chosen as the test crop for all plots to ensure uniformity.

2.3 Sowing and Crop Management

Pigeon pea was sown in the first week of July each year at a spacing of 60 cm × 20 cm, maintaining a seed rate of 15 kg/ha. Inoculation with *Rhizobium* was done prior to sowing to ensure effective nodulation. Cereals and vegetables were planted according to local practices: wheat (rabi season, November–April), maize (kharif, June–October), tomato and onion (rabi), and okra (summer). Organic manure (farmyard manure, FYM, at 5 t/ha) was incorporated in all plots before sowing to mimic typical farmer practices.

2.4 Disease Assessment

Wilt incidence was assessed at **30, 60, and 90 days after sowing (DAS)** in pigeon pea following the formula:

$$\text{Wilt Incidence (\%)} = \frac{\text{Number of wilted plants}}{\text{Total number of plants observed}} \times 100$$

Observations were recorded from the central four rows of each plot, avoiding border effects. Symptom confirmation (vascular discoloration, fungal growth on tissue) was validated in the laboratory through microscopic examination of diseased root sections (Nene & Kannaiyan, 1982). Disease severity categories were classified following ICRISAT's wilt rating scale (1 = resistant, <10% wilt; 3 = moderately resistant, 10–30%; 5 = moderately susceptible, 30–50%; 7 = susceptible, 50–70%; 9 = highly susceptible, >70%) (Nene et al., 1996).

2.5 Yield and Economic Analysis

At maturity, pigeon pea pods were harvested from net plots, dried, threshed, and adjusted to 12% grain moisture content. Grain yield was expressed as kg/ha. Economic analysis included gross returns, net returns, and benefit–cost (B:C) ratio, calculated using prevailing local input and output prices. Special attention was given to the additional labor and input costs in vegetable rotations compared to cereal systems.

© 2026 IJMRSET | Volume 9, Issue 6, June 2026| DOI:10.15680/IJMRSET.2026.0906009

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

2.6 Soil Sampling and Microbial Analysis

To understand the ecological basis of wilt suppression, soil samples were collected annually at harvest from each plot (0–15 cm depth). Samples were composited per plot, air-dried, and analyzed for:

1. **Soil microbial populations**: *Trichoderma* spp. and *Pseudomonas fluorescens* were quantified using the serial dilution and plate count method on selective media (Potato Dextrose Agar for *Trichoderma* and King's B agar for *Pseudomonas*) (Reddy et al., 2024).
2. **Soil physicochemical properties**: pH, organic carbon, and available NPK were measured using standard protocols (Jackson, 1973).

2.7 Data Analysis

The collected data on wilt incidence, grain yield, economics, and soil microbial populations were analyzed using mean values of three years and three replications. Percentage wilt incidence was calculated at 30, 60, and 90 DAS, while correlation analysis was performed to determine relationships between microbial populations and disease incidence. Treatment means were compared statistically at $p \leq 0.05$ to evaluate significant differences among cropping systems.

2.8 Ethical Considerations and Farmer Involvement

This research was conducted in collaboration with local farmers who voluntarily allocated small plots on their fields for trials. Farmers were involved in all stages, including land preparation, crop management, and disease observation. No chemical treatments harmful to the environment were used, ensuring compliance with sustainable agricultural research practices.

III. RESULTS

3.1 Wilt Incidence under Different Cropping Systems

The progression of wilt incidence across cropping systems was distinct. Monocropped pigeon pea (T1) consistently recorded the highest wilt incidence, with symptoms appearing as early as 25 DAS and increasing rapidly thereafter. By 90 DAS, wilt incidence reached 56.3%, categorizing it as "susceptible" on the ICRISAT scale.

In contrast, all rotation treatments recorded significantly lower wilt intensity. Among cereal-based systems, pigeon pea–wheat (T2) and pigeon pea–maize (T3) reduced wilt incidence to 25.7% and 27.2% at 90 DAS, respectively, representing a 50–55% reduction compared to monocropping. Vegetable-based rotations performed even better: pigeon pea–tomato (T4), pigeon pea–onion (T5), and pigeon pea–okra (T6) recorded wilt incidence of 20.3%, 21.1%, and 23.4%, respectively, representing 60–65% suppression relative to monocropping.

Table 1: Wilt incidence (%) under different cropping systems (mean of 3 years, N = 3 replications)

Cropping System	30 DAS	60 DAS	90 DAS	Disease Reaction*
T1: Pigeon pea (mono)	19.8	37.4	56.3	Susceptible (7)
T2: Pigeon pea–wheat	8.2	16.4	25.7	Moderately resistant (3)
T3: Pigeon pea–maize	9.1	18.7	27.2	Moderately resistant (3)
T4: Pigeon pea–tomato	6.4	13.2	20.3	Resistant (1)
T5: Pigeon pea–onion	6.8	13.9	21.1	Resistant (1)
T6: Pigeon pea–okra	7.5	15.7	23.4	Resistant (1)

*ICRISAT scale: 1 = Resistant (<10%); 3 = Moderately resistant (10–30%); 5 = Moderately susceptible (30–50%); 7 = Susceptible (50–70%); 9 = Highly susceptible (>70%).

3.2 Yield Performance

Wilt suppression translated into higher yields under rotations. Continuous pigeon pea monocropping (T1) yielded only 1,035 kg/ha, reflecting both high wilt incidence and poor soil health. Cereal rotations improved yields by ~20–25%, with pigeon pea–wheat (T2) and pigeon pea–maize (T3) yielding 1,295 kg/ha and 1,268 kg/ha, respectively.

Vegetable rotations offered the best results. Pigeon pea–tomato (T4) recorded the highest yield (1,375 kg/ha), followed by pigeon pea–onion (T5: 1,362 kg/ha) and pigeon pea–okra (T6: 1,328 kg/ha). These yields were significantly higher

© 2026 IJMRSET | Volume 9, Issue 6, June 2026| DOI:10.15680/IJMRSET.2026.0906009

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

($p \leq 0.05$) than both monocropping and cereal rotations, suggesting that vegetable rotations not only suppressed wilt but also enhanced overall productivity.

Table 2: Grain yield and economics of pigeon pea under different cropping systems (3-year mean)

Cropping System	**Grain yield (kg/ha)**	**Gross returns (₹/ha)****	**Net returns (₹/ha)**	**B:C ratio**
T1: Pigeon pea (mono)	1,035	62,100	21,300	1.24
T2: Pigeon pea–wheat	1,295	77,700	37,400	1.52
T3: Pigeon pea–maize	1,268	76,080	35,280	1.48
T4: Pigeon pea–tomato	1,375	82,500	43,800	1.68
T5: Pigeon pea–onion	1,362	81,720	42,000	1.64
T6: Pigeon pea–okra	1,328	79,680	39,200	1.59

**Calculated at average farm-gate pigeon pea price of ₹60/kg (2021–2023 average).

4.3 Soil Microbial Populations

Soil microbial analysis revealed clear differences across systems. Monocropped plots (T1) had the lowest counts of beneficial microbes: *Trichoderma* spp. (2.1×10^4 cfu/g) and *Pseudomonas fluorescens* (1.8×10^4 cfu/g). In contrast, rotated systems recorded 2–3 times higher populations. Vegetable rotations, especially tomato (T4) and onion (T5), supported the highest microbial populations, suggesting that diverse root exudates and organic inputs associated with vegetable cultivation favored antagonistic microbes.

Table 3: Soil microbial populations under different cropping systems (cfu/g soil, 3-year mean)

Cropping System	***Trichoderma* spp. ($\times 10^4$)**	***Pseudomonas fluorescens* ($\times 10^4$)**
T1: Pigeon pea (mono)	2.1	1.8
T2: Pigeon pea–wheat	3.7	3.1
T3: Pigeon pea–maize	3.4	2.9
T4: Pigeon pea–tomato	5.2	4.8
T5: Pigeon pea–onion	5.0	4.6
T6: Pigeon pea–okra	4.5	4.1

Correlation analysis showed strong negative correlations between microbial populations and wilt incidence ($r = -0.74$ for *Trichoderma*, $r = -0.71$ for *Pseudomonas*, $p < 0.01$), confirming their role in disease suppression.

4.4 Disease Progression Over Time

Wilt incidence curves across systems revealed contrasting patterns. In monocropping, disease onset was early (20–25 DAS), and progression was steep, reaching epidemic levels (>50%) by 90 DAS. In rotations, onset was delayed (30–35 DAS), and progression was slower. Vegetable rotations, in particular, showed flattened curves, with final wilt incidence under 25%. This demonstrates that rotations not only reduce overall incidence but also delay epidemic build-up, protecting plants during critical reproductive stages.

V. DISCUSSION

The present study provides strong evidence that crop rotation significantly reduces Fusarium wilt intensity in pigeon pea compared to monocropping. Over three years, wilt incidence in continuous pigeon pea monocropping exceeded 55% by 90 DAS, while rotations with cereals and vegetables reduced wilt intensity by 50–65%. These findings align with earlier reports that monocropping favors soil-borne pathogens by maintaining a continuous host–pathogen interaction (Cook, 2007; Sharma et al., 2016). In contrast, rotations disrupt the disease cycle, reduce inoculum density, and improve soil ecological balance.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

5.1 Monocropping as a Risk Factor for Wilt Epidemics

The high wilt incidence in monocropped plots highlights the danger of repeating pigeon pea on the same land without a break. Continuous cultivation provides *F. udum* with sustained opportunities to survive and proliferate through chlamydospores in plant debris and soil. These results mirror observations from ICRISAT trials in central India, where monocropping led to wilt incidence above 60% (Pande et al., 2013). Moreover, monocropping reduces soil microbial diversity, limiting competition against pathogens and creating a favorable environment for pathogen dominance (Cook, 2007).

5.2 Effectiveness of Cereal Rotations

Rotations with wheat and maize reduced wilt incidence to ~25–27%, confirming the role of cereals as non-host crops. Because *F. udum* is host-specific, cereals deprive it of susceptible tissue, reducing inoculum carryover. Singh et al. (2019) reported similar trends in Eastern Indo-Gangetic Plains, where pigeon pea–wheat systems maintained yield stability and reduced wilt severity. Cereal roots also alter rhizosphere conditions by releasing different exudates and promoting microbial groups that are antagonistic to *F. udum*. These effects help explain why cereal rotations suppressed wilt even though no direct fungicidal measures were applied.

5.3 Vegetable Rotations as Superior Suppressors

Vegetable rotations, especially with tomato and onion, proved most effective in suppressing wilt (20–21% incidence at 90 DAS). This is consistent with reports that diversified rotations involving vegetables can alter soil microbial ecology and enhance populations of beneficial antagonists (Ravikumara et al., 2022). In this study, vegetable rotations also recorded the highest counts of *Trichoderma* spp. and *Pseudomonas fluorescens*, organisms known for their antagonistic properties and ability to induce systemic resistance (Reddy et al., 2024).

There may be additional mechanisms at play. Tomato and onion systems often receive higher doses of organic manure, which improves soil organic matter and fosters suppressive soils. Certain vegetable root exudates may also exert direct or indirect antifungal activity. Although further mechanistic studies are warranted, the evidence suggests that vegetables provide both biological and ecological barriers against *F. udum*.

5.4 Disease Progression and Epidemic Dynamics

An important observation was the delayed onset and slower progression of wilt in rotated systems. In monocropping, disease onset occurred around 20–25 DAS, with sharp increases leading to epidemic levels (>50% incidence) by 90 DAS. In contrast, cereal- and vegetable-based rotations delayed disease appearance and reduced the rate of epidemic development. Similar observations have been reported in studies on soil-borne diseases, where crop diversification interrupted pathogen establishment and reduced inoculum pressure in the rhizosphere (Cook, 2007; Pande et al., 2013). This is critical because the reproductive stage of pigeon pea coincides with 70–90 DAS, and delayed wilt onset allows plants to complete pod formation and seed set before disease impact becomes severe. Thus, rotations not only reduce total incidence but also act as a temporal buffer against epidemics.

5.5 Yield and Economic Benefits

Wilt suppression translated directly into higher yields and improved economics. Monocropped pigeon pea yielded only 1,035 kg/ha, while vegetable rotations produced 1,328–1,375 kg/ha. This yield advantage was further amplified in net returns and benefit–cost ratios, with vegetable systems outperforming both cereals and monocropping. These findings are consistent with previous reports that diversified cropping systems improve both productivity and profitability by reducing disease incidence and enhancing soil health (Singh et al., 2019). However, cereal rotations remain attractive for resource-poor farmers due to lower input costs and easier management.

5.6 Soil Microbial Ecology and Disease Suppression

Soil microbial data confirmed the ecological basis of wilt suppression. Rotated systems supported 2–3 times higher populations of *Trichoderma* spp. and *Pseudomonas fluorescens* than monocropped plots. Negative correlations between microbial populations and wilt incidence ($r = -0.74$ for *Trichoderma*, $r = -0.71$ for *Pseudomonas*) indicate that these organisms play a direct role in reducing disease intensity. This aligns with earlier work by Sharma et al. (2016), who highlighted that healthy microbial communities compete with pathogens for resources and niches, thus creating suppressive soils.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

5.7 Implications for Integrated Disease Management (IDM)

These results reinforce the principle that no single strategy can sustainably manage Fusarium wilt in pigeon pea. Resistant varieties such as ICP 8863 (Maruti) and ICPL 87119 (Asha) are valuable but vulnerable to pathogen variability (Nene & Kannaiyan, 1982). Biocontrol agents like *Trichoderma* spp. and *Pseudomonas fluorescens* are effective but face adoption challenges due to supply and quality issues (Pande et al., 2013). Crop rotation, being low-cost and widely adopted by farmers, offers an accessible foundation for IDM.

An IDM package for Bihar should therefore integrate:

- Rotation with cereals or vegetables to reduce inoculum pressure.
- Resistant varieties to provide genetic defense.
- Biocontrol agents to enhance rhizosphere protection.
- Organic amendments (FYM, neem cake) to improve soil health.

Together, these strategies can create a multi-layered barrier against *F. udum* and ensure stable yields.

5.8 Relevance to Bihar Farmers and Policy

For smallholders in Bihar, where fungicide use is minimal and extension services are limited, crop rotation is a practical, farmer-friendly solution. It requires no additional inputs beyond normal cropping cycles and leverages existing farmer knowledge. However, vegetable rotations, while effective, may not be accessible to all farmers due to higher labor and market dependencies. Thus, promoting cereal-based rotations alongside vegetables provides flexibility across resource contexts.

At the policy level, these findings highlight the need to incorporate rotation-based recommendations into programs such as the National Food Security Mission–Pulses. Demonstrations through Krishi Vigyan Kendras (KVKs) can help popularize the practice, while community seed banks and bio-agent supply systems can complement rotations for robust IDM adoption.

VI. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This three-year field study in Munger district, Bihar, demonstrates that crop rotation is an effective, farmer-friendly strategy to reduce Fusarium wilt intensity in pigeon pea. The results clearly indicate that continuous monocropping of pigeon pea exacerbates wilt epidemics, with incidence reaching over 55% at 90 DAS and yields declining to around 1,035 kg/ha. In contrast, rotations with cereals (wheat, maize) lowered wilt incidence by 50–55%, while vegetable rotations (tomato, onion, okra) achieved 60–65% suppression. These reductions translated into significant yield gains, with vegetable rotations producing the highest yields (1,328–1,375 kg/ha) and benefit–cost ratios.

Equally important, soil microbial analyses confirmed that rotated systems harbored 2–3 times higher populations of beneficial antagonists such as *Trichoderma* spp. and *Pseudomonas fluorescens*. Strong negative correlations between these microbes and wilt incidence suggest that crop rotation not only breaks pathogen life cycles but also enhances rhizosphere suppressiveness. Vegetable rotations, due to their higher organic inputs and diverse root exudates, supported the richest microbial communities, explaining their superior disease suppression.

The findings validate farmer observations in Munger: monocropping intensifies wilt, while diversified rotations mitigate it. Beyond biological benefits, rotation also improves yield stability and profitability. However, vegetable rotations, though most effective, may be constrained by higher labor requirements and market risks, making cereal rotations a practical alternative for resource-poor farmers.

This study therefore emphasizes that crop rotation is not merely a traditional practice but a scientifically proven component of Integrated Disease Management (IDM). When combined with resistant varieties, biocontrol agents, and organic amendments, rotation can provide a durable, ecologically sound, and economically viable strategy to combat Fusarium wilt in Bihar.

6.2 Recommendations

For Farmers:

1. Avoid continuous pigeon pea cultivation on the same plot for consecutive years, especially in wilt-endemic areas.
2. Adopt pigeon pea–wheat or pigeon pea–maize rotations as practical, low-input options to suppress wilt and sustain yields.
3. Where feasible, integrate pigeon pea–tomato, pigeon pea–onion, or pigeon pea–okra rotations to maximize both wilt suppression and income.
4. Incorporate FYM (5 t/ha) and neem cake (~250 kg/ha) during land preparation to enhance soil microbial activity.
5. Combine rotation with resistant varieties (e.g., ICP 8863/Maruti) and seed treatment with Trichoderma for best results.

For Extension Agencies and Researchers:

1. Promote participatory demonstrations of rotation systems in wilt hotspots to build farmer confidence.
2. Develop farmer field schools and village-level training modules focusing on crop rotation as part of IDM.
3. Encourage soil health monitoring to link microbial dynamics with disease suppression for farmer advisories.
4. Validate findings across diverse agro-ecologies of Bihar to refine location-specific recommendations.

For Policy Makers:

1. Integrate crop rotation into National Food Security Mission–Pulses (NFSM-Pulses) and State Action Plans on Pulses.
2. Support community seed banks and bio-agent production units (e.g., SHGs, FPOs) to complement rotation practices.
3. Provide incentives and subsidies for farmers adopting crop rotation and organic amendments in wilt-prone areas.
4. Facilitate market linkages for vegetables (tomato, onion, okra) to reduce risks and encourage adoption of high-value rotations.

6.3 Final Remarks

Fusarium wilt of pigeon pea represents not only a plant health challenge but also a livelihood concern for smallholder farmers in Bihar. The evidence from this study confirms that strategic crop rotation can transform wilt-endemic fields into productive, resilient systems. By integrating farmer knowledge with scientific validation, rotation emerges as a cornerstone of sustainable pigeon pea production. Scaling up these practices through policy, extension, and community engagement will be critical for achieving yield stability, soil health, and nutritional security in Bihar and beyond.

VII. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support and facilities provided by the University Department of Botany, T.M. Bhagalpur University, Bhagalpur. They also extend their heartfelt thanks to the farmers of Munger district for their active participation, valuable cooperation, and insightful field-level contributions throughout the course of the study.

REFERENCES

1. Ali, M., & Kumar, S. (2009). Major technological advances in pulses and their impact on production in India. *Indian Journal of Agricultural Sciences, 79*(10), 763–771.
2. Cook, R. J. (2007). Management of resident plant pathogens with microorganisms and natural products. *Annual Review of Phytopathology, 45*, 153–173. https://doi.org/10.1146/annurev.phyto.45.062806.094404
3. Crop Trust. (2022). *Maruti – The pigeonpea savior*. Global Crop Diversity Trust. https://www.croptrust.org/news-events/news/maruti-the-pigeonpea-savior/
4. Directorate of Economics and Statistics. (2022). *Agricultural statistics at a glance 2022*. Ministry of Agriculture & Farmers Welfare, Government of India. https://desagri.gov.in/document-report-category/agricultural-statistics-at-a-glance/
5. Directorate of Pulses Development. (2023). *Crop-wise area, production and productivity of pulses in India*. Ministry of Agriculture & Farmers Welfare, Government of India. https://dpd.gov.in

6. Government of Bihar. (2025). *Economic survey 2024–25*. Finance Department, Government of Bihar. https://state.bihar.gov.in/finance/CitizenHome.html
7. ICAR–Indian Institute of Pulses Research. (2015). *Vision 2050*. Indian Council of Agricultural Research, Kanpur, India. https://www.icar-iipr.org.in/wp-content/themes/ICAR-wp/images/vision_250715.pdf
8. India Meteorological Department. (2020). *Climatological tables of observatories in India (1981–2010)*. Ministry of Earth Sciences, Government of India.
9. Jackson, M. L. (1973). *Soil chemical analysis*. Prentice-Hall of India Pvt. Ltd. https://archive.org/details/in.ernet.dli.2015.210097
10. Kannaiyan, J., & Nene, Y. L. (1981). Influence of wilt at different growth stages on yield loss in pigeonpea. *Tropical Pest Management, 27*(1), 141–143.
11. Nene, Y. L., & Kannaiyan, J. (1982). Screening pigeonpea for resistance to Fusarium wilt. *Plant Disease, 66*(4), 306–307. https://doi.org/10.1094/PD-66-306
12. Nene, Y. L., Sheila, V. K., & Sharma, S. B. (1996). *A world list of chickpea and pigeonpea pathogens* (5th ed.). International Crops Research Institute for the Semi-Arid Tropics.
13. National Bureau of Soil Survey and Land Use Planning. (2019). *Soils of Bihar for optimizing land use*. ICAR–NBSS & LUP. https://www.nbsslup.in
14. Pande, S., Sharma, M., & Mangala, U. N. (2013). Integrated management of Fusarium wilt of pigeonpea. *Indian Journal of Plant Protection, 41*(2), 7–15.
15. Rani, R., Singh, R., & Kumar, A. (2018). Occurrence and management of Fusarium wilt of pigeonpea in eastern India. *Journal of Food Legumes, 31*(2), 95–100.
16. Ravikumara, B. M., Prasad, P. S., Shankar, A. G., & Patil, B. V. (2022). The causal agent of pigeonpea Fusarium wilt: Biology and management overview. *Physiological and Molecular Plant Pathology, 117*, 101754.
17. Reddy, B. D., Sahoo, S., Kar, A., & Nayak, P. (2024). Harnessing native biocontrol agents against pigeonpea Fusarium wilt under sick-plot conditions. *Scientific Reports, 14*, 12920.
18. Sharma, M., Ghosh, R., & Pande, S. (2016). Dry root rot (Rhizoctonia bataticola (Taub.) Butler): An emerging disease of chickpea—where do we stand? *Archives of Phytopathology and Plant Protection, 49*(13–14), 369–385.
19. Singh, A. K., Singh, U. P., & Kumar, R. (2019). Cropping system diversification and disease management in pulse-based farming systems of Indo-Gangetic plains. *Legume Research, 42*(5), 640–646.

INTERNATIONAL JOURNAL OF
MULTIDISCIPLINARY RESEARCH
IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com