Total Degree of a Vertex in Cartesian Product and Composition of Some Intuitionistic Fuzzy Graphs

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Abstract. An intuitionistic fuzzy graph can be obtained from two given intuitionistic fuzzy graphs using Cartesian product and composition. In this paper, we discuss the total degree of a vertex in intuitionistic fuzzy graphs formed by these operations in terms of the degree of vertices in the given intuitionistic fuzzy graphs in some particular cases.

Keywords: Total degree of a vertex, Cartesian product and composition of two IFGs

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1. Introduction

Intuitionistic Fuzzy Graph theory was introduced by Atanassov in [1]. In [5], Karunambigai and Parvathi introduced intuitionistic fuzzy graph as a special case of Atanassov’s IFG. In [2], NagoorGani and Begum introduced degree, order and size in intuitionistic fuzzy graph. In [6] Radha and Vijaya introduced the total degree of a vertex in some fuzzy graphs. In[3] NagoorGani and Rahman introduced the total and middle intuitionistic fuzzy graph and they also introduced Total degree of a vertex in union and join of some intuitionistic fuzzy graphs in [4]. In this paper we discuss about Cartesian product and Composition operations of intuitionistic fuzzy graph and some properties of intuitionistic fuzzy graph are introduced.

2. Preliminaries

Definition 2.1. An intuitionistic fuzzy graph (IFG) is of the form \(G = (V, E)\) where

(i) \(V = \{v_1, v_2, ..., v_n\}\) such that \(\mu_1 : V \rightarrow [0,1]\) and \(\nu_1 : V \rightarrow [0,1]\) denotes the degree of membership and non-membership of the element \(v_i \in V\) respectively and \(0 \leq \mu_1(v_i) + \nu_1(v_i) \leq 1\), for every \(v_i \in V\).

(ii) \(E \subseteq V \times V\) where \(\mu_2 : V \times V \rightarrow [0,1]\) and \(\nu_2 : V \times V \rightarrow [0,1]\) such that

\[
\mu_2(v_i, v_j) = \min(\mu_1(v_i), \mu_1(v_j))
\]

\[
\nu_2(v_i, v_j) = \max(\nu_1(v_i), \nu_1(v_j))
\]

and \(0 \leq \mu_2(v_i, v_j) + \nu_2(v_i, v_j) \leq 1\), for every \((v_i, v_j) \in E\).
Here the triple \((v_i, \mu_{1i}, \nu_{1i})\) denotes the degree of membership and non-membership of the vertex \(v_i\). The triple \((e_{ij}, \mu_{2ij}, \nu_{2ij})\) denotes the degree of membership and non-membership of the edge relation \(e_{ij} = (v_i, v_j)\) on \(V \times V\).

**Definition 2.2.** Let \(G = (V, E)\) be an IFG. Then the degree of a vertex \(v\) is defined by \(d(v) = (d_{\mu}(v), d_{\nu}(v))\) where \(d_{\mu}(v) = \sum_{u \neq v} \mu_2(v, u)\) and \(d_{\nu}(v) = \sum_{u \neq v} \nu_2(v, u)\).

**Definition 2.3.** Let \(G = (V, E)\) be an IFG. If \((d_{\mu}(v), d_{\nu}(v)) = (k_1, k_2)\) for all \(v \in V\) that is if each vertex has same membership degree \(k_1\) and same nonmembership degree \(k_2\), then \(G\) is said to be a regular intuitionistic fuzzy graph.

**Definition 2.4.** Let \(G = (V, E)\) be an IFG. Then the total degree of a vertex \(u \in v\) is defined by
\[
\text{td}(u) = (\text{td}_{\mu}(u), \text{td}_{\nu}(u)) = (\sum_{u \neq v} \mu_2(u, v) + \mu_1(u), \sum_{u \neq v} \nu_2(u, v) + \nu_1(u))
\]
If each vertex of \(G\) has same membership total degree \(k_1\) and same nonmembership total degree \(k_2\), then said to be a total regular IFG.

**3. Total degree of a vertex in Cartesian product**

**Definition 3.1.** The Cartesian product of two intuitionistic fuzzy graphs \(G_1\) and \(G_2\) is defined as an intuitionistic fuzzy graph \(G = G_1 \times G_2 = (\mu, \nu, \mu_1, \nu_1)\) on \(G^* = (V, E)\) where \(V = V_1 \times V_2\) and
\[
E = \{(u_1, u_2)(v_1, v_2) : (u_1 = v_1, u_2 = v_2) \text{ or } (u_1, u_2) = (v_1, v_2) \}
\]

\[
(\mu_1 \times \mu_1)(u_1, u_2) = \mu_1(u_1) \land \mu_1(u_2), \forall (u_1, u_2) \in V_1 \times V_2
\]

\[
(\nu_1 \times \nu_1)(u_1, u_2) = \nu_1(u_1) \lor \nu_1(u_2), \forall (u_1, u_2) \in V_1 \times V_2
\]

**Definition 3.2.** By definition for any \((u_1, u_2) \in V_1 \times V_2\)
\[
\text{td}_{\mu}(G_1 \times G_2)(u_1, u_2) = \sum_{(u_1, u_2) \in V_1 \times V_2} ((\mu_1 \times \mu_2)(u_1, u_2)(v_1, v_2)) + (\mu_1 \times \mu_1)(u_1, u_2) = \sum_{u_2 = v_2, u_1v_1 \in E_1} \mu_1(u_1) \land \mu_2(u_2v_2)
\]

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\[ td_{v(G_1 \times G_2)}(u_1, u_2) = \sum_{(u_1, u_2) \in E} ((v_2 \times v_2')(u_1, u_2)(v_1, v_2)) + (v_1 \times v_1')(u_1, u_2) \]

Hence, the Total degree of a vertex in \( G_1 \times G_2 \) is defined as

\[ td_{G_1 \times G_2}(u_1, u_2) = (td_{\mu_{G_1 \times G_2}}(u_1, u_2), td_{v(G_1 \times G_2)}(u_1, u_2)) \]

**Theorem 3.3.** Let \( G_1 : (\mu, v) \) and \( G_2 : (\mu', v') \) be two intuitionistic fuzzy graphs.

(i) If \( \mu_1 \geq \mu_2 \) and \( \mu'_1 \geq \mu'_2 \) then \( td_{\mu_{G_1 \times G_2}}(u_1, u_2) = td_{\mu_{G_1}}(u_1) + td_{\mu_{G_2}}(u_2) \)

(ii) If \( v_1 \leq v_2 \) and \( u'_1 \leq u_2 \) then \( td_{v_{G_1 \times G_2}}(u_1, u_2) = td_{v_{G_1}}(u_1) + \neg v_1(u_1) \lor v_1'(u_2) \)

**Proof:**

(i) From (3.2.1),

\[ td_{\mu_{G_1 \times G_2}}(u_1, u_2) = \sum_{u_1 = v_1, u_2' \in E_2} \mu_1 (u_1) \land \mu_2 ' (u_2 v_2) + \sum_{u_2 = v_2, u_1' \in E_1} \mu_1 ' (u_2) \land \mu_2 (u_1 v_1) + \mu_1 (u_1) \land \mu_2 ' (u_2) \]

\[ = \sum_{u_2 v_2' \in E_2} \mu_2 ' (u_2 v_2) + \sum_{u_1' v_1 \in E_1} \mu_2 (u_1 v_1) + \mu_1 (u_1) + \mu_1 ' (u_2) - \mu_1 (u_1) \lor \mu_2 ' (u_2) \]

\[ = \sum_{u_2 v_2' \in E_2} \mu_2 ' (u_2 v_2) + \mu_2 ' (u_2) + \sum_{u_1' v_1 \in E_1} \mu_2 (u_1 v_1) + \mu_1 (u_1) - \mu_1 (u_1) \lor \mu_2 ' (u_2) \]

\[ td_{v(G_1 \times G_2)}(u_1, u_2) = td_{\mu_{G_1}}(u_1) + td_{\mu_{G_2}}(u_2) - \mu_1 (u_1) \lor \mu_2 ' (u_2). \]

(ii) From (3.2.2),

\[ td_{v(G_1 \times G_2)}(u_1, u_2) = \sum_{u_1 = v_1, u_2' \in E_2} v_1 (u_1) \lor v_2 '(u_2 v_2) + \sum_{u_2 = v_2, u_1' \in E_1} v_1 (u_2) \lor v_2 (u_1 v_1) + v_1 (u_1) \lor v_2 ' (u_2) \]
We have
\[= \sum_{u_1 \in U_1} \sum_{v_2 \in V_2} v_2'(u_2v_2) + \sum_{u_1 \in U_1} v_2(u_1v_1) + v_1'(u_1) - v_1(u_1) \land v_1'(u_2)\]
\[= \sum_{u_2, v_2 \in E_2} v_2'(u_2v_2) + \sum_{u_1 \in U_1} v_1'(u_2) + \sum_{u_1 \in U_1} v_2(u_1v_1) + v_1(u_1) - v_1(u_1) \land v_1'(u_2)\]

\[t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2) = t_{d_{\mu(G_1)}}(u_1) + t_{d_{\mu(G_2)}}(u_2) - v_1(u_1) \land v_1'(u_2).\]

**Example 3.4.** Consider the intuitionistic fuzzy graphs \(G_1: (\mu, \nu)\) and \(G_2: (\mu', \nu')\) in *Fig. 3.1.*

\[G_1 \quad G_2 \quad G_1 \times G_2\]

\[(0.3, 0.4) \quad (0.4, 0.4) \quad (u_1, u_2) \quad (u_1, v_2)\]

\[(0.2, 0.4) \quad (0.4, 0.3)(0.2, 0.4) \quad (0.2, 0.4)\]

\[(v_1, v_2) \quad (v_1, v_2) \quad (0.4, 0.4) \quad (0.3, 0.4)(0.6, 0.3)\]

**Figure 3.1:**

(i) If \(\mu_1 \geq \mu_2'\) and \(\nu_1' \geq \nu_2\) then
\[t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2) = t_{d_{\mu(G_1)}}(u_1) + t_{d_{\mu(G_2)}}(u_2) - \nu_1(u_1) \land \nu_1'(u_2)\]
\[= 0.5 + 0.7 - 0.4 = 0.8\]

(ii) If \(\nu_1 \leq \nu_2'\) and \(\nu_1' \leq \nu_2\) then
\[t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2) = t_{d_{\mu(G_1)}}(u_1) + t_{d_{\mu(G_2)}}(u_2) - \nu_1(u_1) \land \nu_1'(u_2)\]
\[= 0.8 + 0.8 - 0.4 = 1.2\]

**Theorem 3.5.** Let \(G_1: (\mu, \nu)\) and \(G_2: (\mu', \nu')\) be two intuitionistic fuzzy graphs.

(i) If \(\mu_1 \leq \mu_2'\) and \(\nu_1 \geq \nu_2'\)
\[t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2) = t_{d_{\mu(G_1)}}(u_1) + \mu_1(u_1)d_{\mu(G_2)}(u_2) + \mu_1'(u_2) - \mu_1(u_1) \land \mu_1'(u_2)\]

(ii) If \(\mu_1' \leq \mu_2\) and \(\nu_1' \geq \nu_2\)
\[t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2) = t_{d_{\mu(G_1)}}(u_1) + \nu_1(u_1)d_{\nu(G_2)}(u_2) + \nu_1'(u_2) - \nu_1(u_1) \land \nu_1'(u_2)\]

**Proof:**

(i) We have \(\mu_1 \leq \mu_2\). Hence \(\mu_1' \geq \mu_2\)

From (3.2.1) \(t_{d_{\mu(G_1 \times G_2)}}(u_1, u_2)\)
\[= \sum_{u_2 = v_2, u_2, v_2 \in E_2} \mu_1(u_1) \land \mu_2'(u_2v_2)\]
\[+ \sum_{u_2 = v_2, u_2, v_2 \in E_2} \mu_1'(u_2) \land \mu_2(u_1v_1) + \mu_2(u_1) \land \mu_1'(u_2)\]
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\[ td_{\mu G_1}(u_1) - \mu_1(u_1) \vee \mu_1'(u_2) + \mu_1(u_1) + \mu_1'(u_2) + \mu_1(u_1) \sum_{u_2 \in E_2} 1 \]

\[ td_{\mu G_2}(u_2) + \mu_2(u_1) + \mu_2'(u_2) + \mu_2(u_1) \vee \mu_2'(u_2) \]

\[ td_{\mu G_1 \times G_2}(u_1, u_2) = td_{\mu G_1}(u_1) + \mu_1(u_1) \mu_2(u_2) + \mu_1(u_1) \vee \mu_1'(u_2) - \mu_1(u_1) \vee \mu_1'(u_2) \]

(ii) We have \( v_1 \geq v_2' \). Hence \( v_1' \leq v_2 \)

From (3.2.2) \( td_{\nu G_1 \times G_2}(u_1, u_2) \)

\[ = \sum_{u_1=V_1 \cup V_2 \in E_2} v_1(u_1) \vee v_2'(u_2) \]

\[ + \sum_{u_2 = V_1 \cup V_2 \in E_1} v_1'(u_2) \vee v_2(u_1) + v_1(u_1) \vee v_1'(u_2) \]

\[ = \sum_{u_1 \in V_1 \cup V_2 \in E_2} v_1(u_1) + \sum_{u_1 \in V_1 \cup V_2 \in E_1} v_2(u_1) + v_1(u_1) + v_1'(u_2) - v_1(u_1) \wedge v_1'(u_2) \]

\[ = \sum_{u_2 \in E_2} v_2(u_1) + v_1(u_1) \mu_2(u_2) + v_1'(u_2) - v_1(u_1) \wedge v_1'(u_2) \]

\[ \vdash td_{\nu G_1 \times G_2}(u_1, u_2) = td_{\nu G_1}(u_1) + v_1(u_1) \mu_2(u_2) + v_1'(u_2) - v_1(u_1) \wedge v_1'(u_2) \]

Example 3.6. Consider the intuitionistic fuzzy graphs \( G_1 : (\mu, \nu) \) and \( G_2 : (\mu', \nu') \) in Fig. 3.2.

Figure 3.2:

(i) If \( \mu_1 \leq \mu_2' \) and \( v_1 \geq v_2' \)
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\[ td_{\mu(G_1 \times G_2)}(u_1, u_2) = td_{\mu G_1}(u_1) + \mu_1(u_1)d_{G_1}(v_1) + \mu_1(u_2) - \mu_1(v_1) \lor \mu_1'(v_1) \]
\[ = 0.5 + 0.3(2) + 0.6 - 0.6 = 1.1. \]

(ii) If \( \mu_1' \leq \mu_2 \) and \( v_1' \geq v_2 \)
\[ td_{\nu(G_1 \times G_2)}(u_1, u_2) = td_{\nu G_1}(u_1) + v_1(u_1)d_{G_1}(u_2) + v_1(u_2) - v_1(u_1) \lor v_1'(u_2) \]
\[ = 1 + 0.6(2) + (0.5) - 0.5 = 2.2. \]

4. Total degree of a vertex in Composition

Definition 4.1. The Composition of two intuitionistic fuzzy graphs \( G_1 \) and \( G_2 \) is defined as an intuitionistic fuzzy graph \( G = G_1 \circ G_2 \) \( : (\mu, \mu', \nu \circ \nu') \) on \( G' : (V, E) \) where \( V = V_1 \times V_2 \) and \( E = \{ ((u_1, u_2), (v_1, v_2)) /u_1 = v_1, u_2v_2 \in E_2 \ or \ u_2 = v_2, u_1v_1 \in E_1 or u_2 = v_2, u_1v_1 \in E_1 \} \)

\( (\mu_1 \circ \mu_1')(u_1, u_2) = \mu_1(u_1) \land \mu_1'(u_2), \) for all \( (u_1, u_2) \in V_1 \times V_2 \) and \( (v_1 \circ v_1')(u_1, u_2) = v_1(u_1) \lor v_1'(u_2), \) for all \( (u_1, u_2) \in V_1 \times V_2 \)

\( (\mu_2 \circ \mu_2)(u_1, u_2)(v_1, v_2) = \begin{cases} \mu_1(u_1) \land \mu_2'(u_2v_2), & \text{if } u_1 = v_1, u_2v_2 \in E_2 \\ \mu_2'(u_2) \lor \mu_2(u_1v_1), & \text{if } u_2 = v_2, u_1v_1 \in E_1 \\ \end{cases} \)

\( (v_2 \circ v_2)'(u_1, u_2)(v_1, v_2) = \begin{cases} v_1(u_1) \lor v_1'(u_2v_2), & \text{if } u_1 = v_1, u_2v_2 \in E_2 \\ v_2(u_1) \lor v_2'(u_1v_1), & \text{if } u_2 = v_2, u_1v_1 \in E_1 \\ \end{cases} \)

Definition 4.1. By definition for any \( (u_1, u_2) \in V_1 \times V_2 \)
\[ td_{\mu(G_1 \circ G_2)}(u_1, u_2) = \sum_{(u_1, u_2) (v_1, v_2) \in E} ((\mu_2 \circ \mu_2)(u_1, u_2)(v_1, v_2)) = \sum_{u_1 = v_1, u_2v_2 \in E_2} (\mu_1(u_1) \land \mu_2'(u_2v_2)) + \sum_{u_2 = v_2, u_1v_1 \in E_1} (\mu_2'(u_2) \lor \mu_2(u_1v_1)) \]
\[ + \sum_{u_2 = v_2, u_1v_1 \in E_1} (\mu_1(u_1) \land \mu_1'(u_2)) \]

\[ td_{\nu(G_1 \circ G_2)}(u_1, u_2) = \sum_{(u_1, u_2) (v_1, v_2) \in E} ((v_2 \circ v_2)'(u_1, u_2)(v_1, v_2)) \]
\[ = \sum_{u_1 = v_1, u_2v_2 \in E_2} (v_1(u_1) \lor v_1'(u_2v_2)) + \sum_{u_2 = v_2, u_1v_1 \in E_1} (v_2(u_1) \lor v_2'(u_1v_1)) \]
\[ + \sum_{u_2 = v_2, u_1v_1 \in E_1} (v_1(u_1) \lor v_1'(u_2)) \]

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**Theorem 4.2.** Let $G_1 : (\mu, \cdot )$ and $G_2 : (\mu', \cdot )$ be two intuitionistic fuzzy graphs.

(i) If $\mu_1 \geq \mu_2'$ and $\mu_1' \geq \mu_2$ then

$$td_{\mu(G_1 \circ G_2)}(u_1, u_2) = td_{G_2}(u_2) + p_2 td_{G_1}(u_1) - (p_2 - 1) \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

(ii) If $v_1 \leq v_2'$ and $v_1' \leq v_2$ then

$$td_{\nu(G_1 \circ G_2)}(u_1, u_2) = td_{G_2}(u_2) + p_2 td_{G_1}(u_1) - (p_2 - 1) v_1(u_1) - v_1(u_1) \land v_1'(u_2),$$

where $p_2 = |V_2|$, $V_2$ is the set of all nodes in $G_1$.

**Proof:**

(i) $td_{\mu(G_1 \circ G_2)}(u_1, u_2) = \sum_{u_1 = v_1, v_2 \in E_2} \mu_1(u_1) \land \mu_2(u_2v_2) + \sum_{u_2 = v_2, u_1 \in E_1} \mu_1'(u_2) \land \mu_2(u_1v_1) + \sum_{u_2 \neq v_2, u_1 \in E_1} \mu_1'(u_2) \land \mu_2'(u_2) \land \mu_2(u_1v_1) + \mu_1(u_1) + \mu_1'(u_2) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= \sum_{u_2v_2 \in E_2} \mu_2(u_2v_2) + \mu_1(u_2) + \sum_{u_1v_1 \in E_1} \mu_2(u_1v_1) + \mu_1(u_1) + \sum_{u_1v_1 \in E_1} \mu_2(u_1v_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= td_{\mu G_2}(u_2) + |V_2| \sum_{u_1v_1 \in E_1} \mu_2(u_1v_1) + \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= td_{\mu G_2}(u_2) + p_2 \left[ \sum_{u_1v_1 \in E_1} \mu_2(u_1v_1) + \mu_1(u_1) \right] - (p_2 - 1) \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= td_{\mu G_1 G_2}(u_1, u_2) = \sum_{u_1 \in E_1} \mu_2(u_1v_1) + \sum_{u_1 \in E_1} \mu_1(u_1) - \sum_{u_1 \in E_1} \mu_1'(u_2)$$

$$= \sum_{u_1 \in E_1} \mu_2(u_1v_1) + \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= \sum_{u_1 \in E_1} \mu_2(u_1v_1) + \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

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(ii) $td_{v(G_1[G_2])}(u_1, u_2) = \sum_{u_1 = v_1, u_2 \in E_2} v_1(u_1) \lor v_2'(u_2v_2) + \sum_{u_2 = v_3, u_1 \in E_1} v_1'(u_2) \lor v_2(u_1v_1) + \sum_{u_2 \neq v_2, u_1 \in E_1} v_1'(u_2) \lor v_1'(v_2) \lor v_2(u_1v_1) + v_1(u_1)$

$\lor v_1'(u_2) = \sum_{u_2 \in E_2} v_2'(u_2v_2) + \sum_{u_2 = v_3, u_1 \in E_1} v_2(u_1v_1) + v_1(u_1) + \sum_{u_1 \in E_1} v_2(u_1v_1)$

$\lor v_1'(u_2) = \sum_{u_1 \in E_1} v_2(u_1v_1) + v_1(u_1) \lor v_1'(u_2)$

$= td_{v(G_2)}(u_2) + |V_2| \sum_{u_1 \in E_1} v_2(u_1v_1) + v_1(u_1) - v_1(u_1) \lor v_1'(u_2)$

$= td_{v(G_2)}(u_2) + p_2 \left[ \sum_{u_1 \in E_1} v_2(u_1v_1) + v_1(u_1) \right] - (p_2 - 1)v_1(u_1)$

$\Rightarrow td_{v(G_1[G_2])}(u_1, u_2) = td_{v(G_2)}(u_2) + p_2 td_{v(G_1)}(u_1) - (p_2 - 1)v_1(u_1)$

$\Rightarrow v_1(u_1) \lor v_1'(u_2)$

**Example 4.3.** Consider the fuzzy graphs $G_1$ and $G_2$ in Fig. 4.1.

Figure 4.1:
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(i) If $\mu_1 \geq \mu_2'$ and $\mu_1' \geq \mu_2$, then

$$td_{\mu(G_1 \times G_2)}(u_1, u_2) = td_{\mu G_2}(u_2) + p_2td_{\mu G_1}(u_1) - (p_2 - 1) \mu_1(u_1) - \mu_1(u_1) \lor \mu_1'(u_2)$$

$$= 0.5 + 2(0.4) - (2 - 1) (0.2) - (0.2 \lor 0.3) = 0.8$$

(ii) If $v_1 \leq v_2'$ and $v_1' \leq v_2$, then

$$td_{v(G_1 \circ G_2)}(u_1, u_2) = td_{v G_2}(u_2) + p_2td_{v G_1}(u_1) - (p_2 - 1) v_1(u_1) - v_1(u_1) \land v_1'(u_2)$$

$$= 1.2 + 2(1.1) - (2 - 1) 0.5 - 0.5 = 2.4.$$ 

5. Conclusion
In this paper, we have found the total degree of vertices in $G_1 \times G_2$ and $G_1 \circ G_2$ in terms of the total degree of vertices in $G_1$ and $G_2$ under some conditions and illustrated them through examples. They will be useful in studying various properties of Cartesian product and Composition of two intuitionistic fuzzy graphs.

REFERENCES